

## DATASCAN 7000 Distributed Data Acquisition System

### Thermocouple Accuracy - explanatory document.

#### Introduction

This document aims to explain in greater detail how DATASCAN 7000 modules measure thermocouples and breaks down the way the accuracy figures are arrived at for the standard Datasheets. Error sources are discussed and curves produced to give a more detailed breakdown of typical accuracies when used in the field.

NB : It must not be interpreted as a definitive statement, or as a replacement to the existing specification, but as a guide and explanatory document giving greater detail to the subject of temperature measurement.

#### Overview

Using thermocouples has advantages and disadvantages for temperature measurement.

Advantages : Wide temperature range. Versatile, e.g. sensor can be in a robust industrial unit or mineral insulated cable or as ultra fine wires. Simple application, just the junction at the tip needs to take-up the required temperature.

Disadvantages : Needs temperature reference.  
Needs extension cables for long runs which can add errors.  
Needs attention to detail for high accuracy.

Main points :

- A) The output of a thermocouple is generated only in the regions where the temperature gradients exist along it.
- B) To ensure accurate and stable operation the thermo-electric characteristics of the thermocouple conductors must be, and remain, uniform throughout.
- C) Only a circuit comprising dissimilar materials in a temperature gradient will generate an output. A circuit comprising a single uniform conductor situated in a temperature gradient will produce no output. A circuit comprising dissimilar conductors under isothermal conditions will produce no output.
- D) The thermo-electric sensitivity of most materials is non-linear with temperature. Thus a given temperature difference between the measuring and reference junctions of a thermocouple will produce different outputs at different reference junction temperatures.

There are two types of errors when performing temperature measurements using the Datascan product in conjunction with standard thermocouples, these are:

1. External Errors
  - Thermocouple tolerance
2. Internal (Datascan) Errors
  - Hot Junction measurement error
  - Cold Junction measurement error
  - Isothermal Bar Error

The diagram below illustrates the different areas of error:

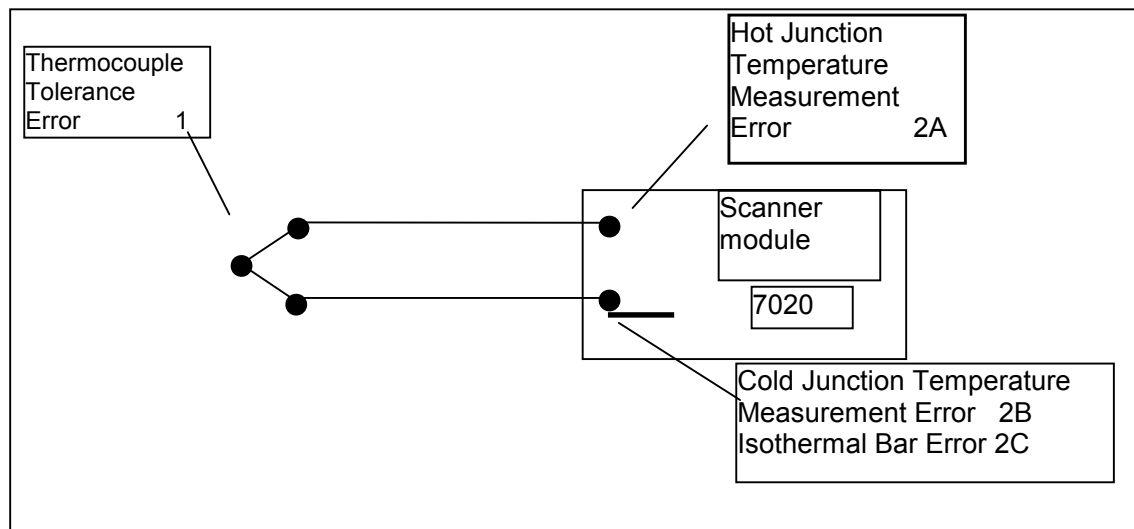


Figure 1: Error diagram.

**1. External Errors**

Thermocouple tolerances : Thermocouples are subject to manufacturing tolerances and come in 3 different classifications which give differing degrees of inaccuracy. These errors are additional to any errors produced by the measurement process and are not taken into account for the purpose of this document but produced below for information.

Type <sup>(1)</sup>	Tolerance <sup>(2)</sup>		
	Class 1	Class 2	Class 3
T	0.5° C or 0.004*t	1° C or 0.0075*t	1° C or 0.015*t
E, J, K	1.5° C or 0.004*t	2.5° C or 0.0075*t	2.5° C or 0.015*t
R, S, B	1° C (0 to 1100° C)	1. ° C or 0.0025*t	4° C or 0.005*t

- (1) : Temperature limits for validity of tolerances are given for each type and class.
- (2) : The tolerance is expressed either as a deviation in degrees Celsius or as a function of the actual temperature. The greater value applies.

Note : Compensation cables have tolerances in between +- 0.5°C and +- 5°C.

Figure 2 : Thermocouple Tolerance Table to BS4937 Part 20, 1991 ( IEC 584-2 :1982 + A1 : 1989 ).

**2. Internal Errors**

A thermocouple is formed by connecting two wires of different metals together at a single point called the **Hot junction**. Where the thermocouple connects to Datascan, another thermocouple joint is created as the metals are also dissimilar, this is called the **Cold junction**.

Voltages (EMF) are generated at the terminals of the scanner module (i.e. 7020) and are dependent on the temperature differential between the hot and cold junctions.

To calculate the temperature at the Hot junction the processor module (i.e. 7010) must correct for the voltages generated at the Cold junction, therefore to give the temperature of the Hot junction, Datascan measures both Hot junction as well as the Cold junction. These measurements involve three sources of error explained in the following paragraphs.

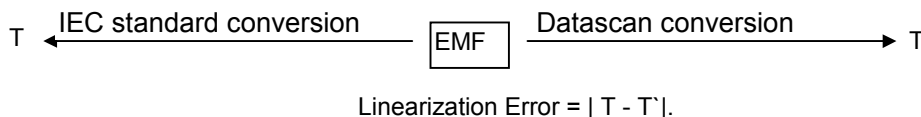
**2A. Hot Junction measurement error**

The evaluation of this error takes into account :

Linearization error

The International Electrotechnical Commission (IEC) lays down conversion laws contained in BS EN 60584-2 ( IEC 584-2 :1982 + A1 : 1989). for EMF to temperature conversion.

To improve the measurement speed Datascan uses a 4th order linearization polynomial to convert the voltages generated by the sensor. The resulting difference in between the IEC standard formulas and the Datascan polynomials is the linearization error, as defined below.



Conversion error

This error is due to the voltage measurement technique and Analog to Digital conversion, its evaluation takes into account :

- Range : Datascan has 4 voltage ranges 10V, 1.3V, 150 mV and 20 mV which are automatically selected to suit the input signal level.
- 16 bit ADC : Each voltage range gives a different resolution with a different resulting accuracy.

## 2B. Cold Junction measurement error

The evaluation of this error takes into account :

Linearization error 0.1°Celsius (See above).

Conversion error 0.2°Celsius.

This error is due to the voltage measurement technique and Analog to Digital conversion, its evaluation takes into account :

- Range (see above),
- 14 bit ADC: The thermistor technique is not accurate enough to necessitate a 16 bit ADC.
- The error in measuring the current source,
- The error due to components tolerance/stability .

Thermistor error : Thermistors are subject to manufacturing tolerances. Datascan uses a 0.2°Celsius tolerance thermistor.

## 2.C Isothermal bar error

To reduce the number of measurements, isothermal bars connect 8 Cold junctions, keeping them at the same temperature, so that one measurement gives the Cold Junction temperature of several thermocouples. Because of temperature gradients a small error is produced, typically of 0.25°C.

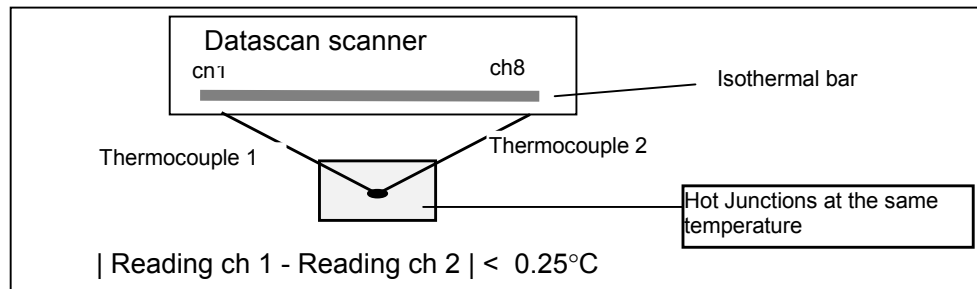


Figure 3 : Isothermal bar diagram.

## Conclusions

The total Datascan error is defined thus:

Total Error = Hot Junction Error + Cold Junction Error + Isothermal Bar Error

with

Hot Junction Error = Linearization Error + Conversion Error

Cold Junction Error = Linearization Error + Conversion Error + Thermister Error

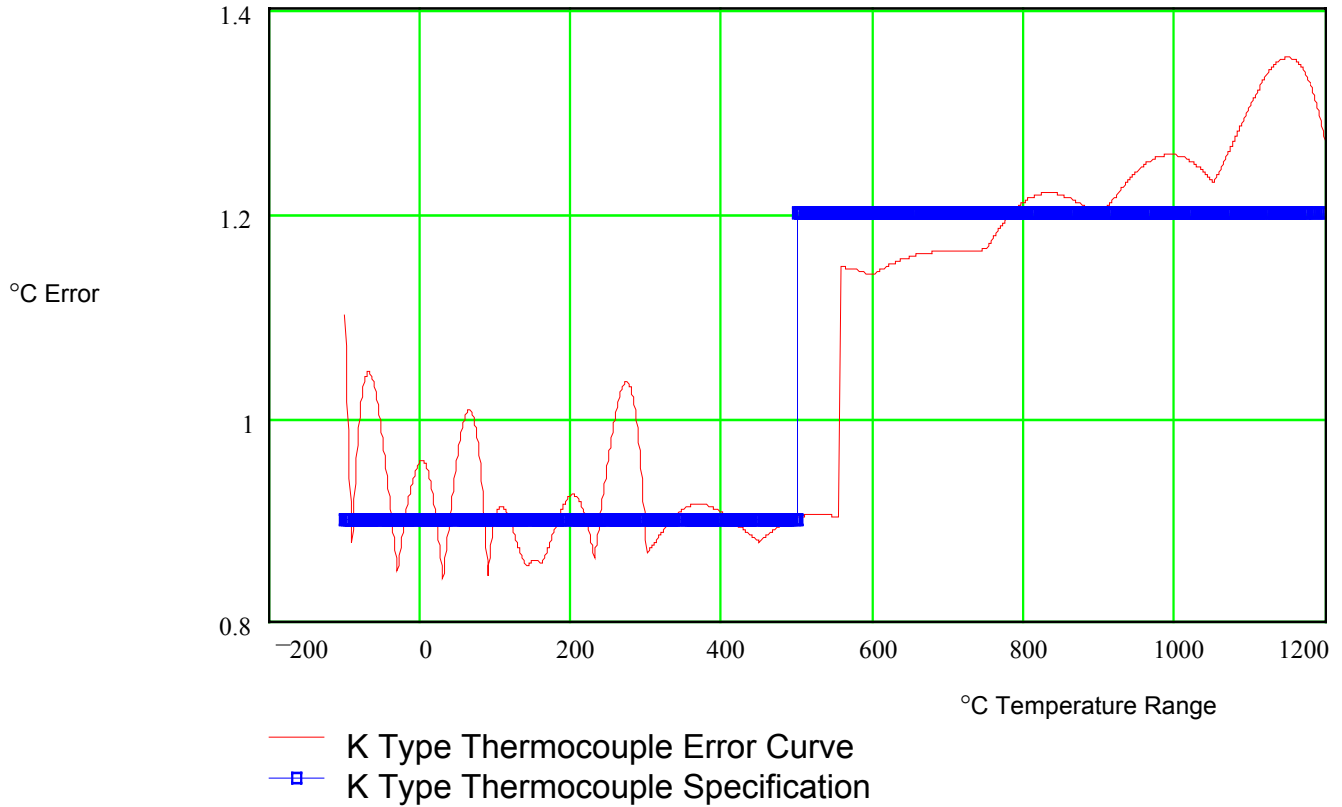
In practice it is unfair to assume that all errors sum in a linear fashion as certain errors may offset other errors to produce a better result, however this cannot be statistically proven and so only curves for the worst case scenario have been generated.

The 8 next pages give the total error curve as well as the breakdown of the error for each type of thermocouple : K, T, S, E, J, N, R, B.

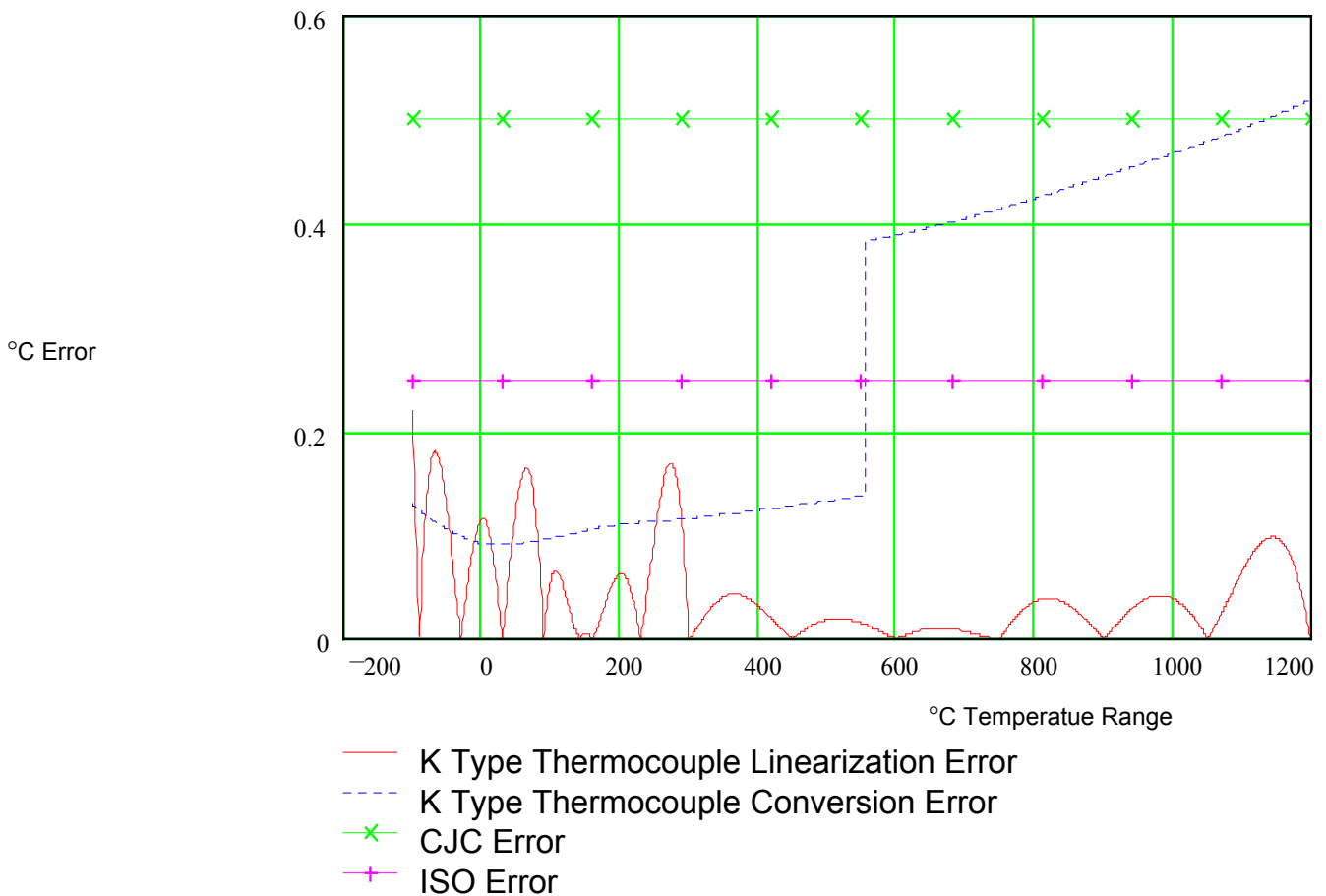
**NB : This document should not be interpreted as a revised specification.**

K Type Thermocouple

### Total Error Curve

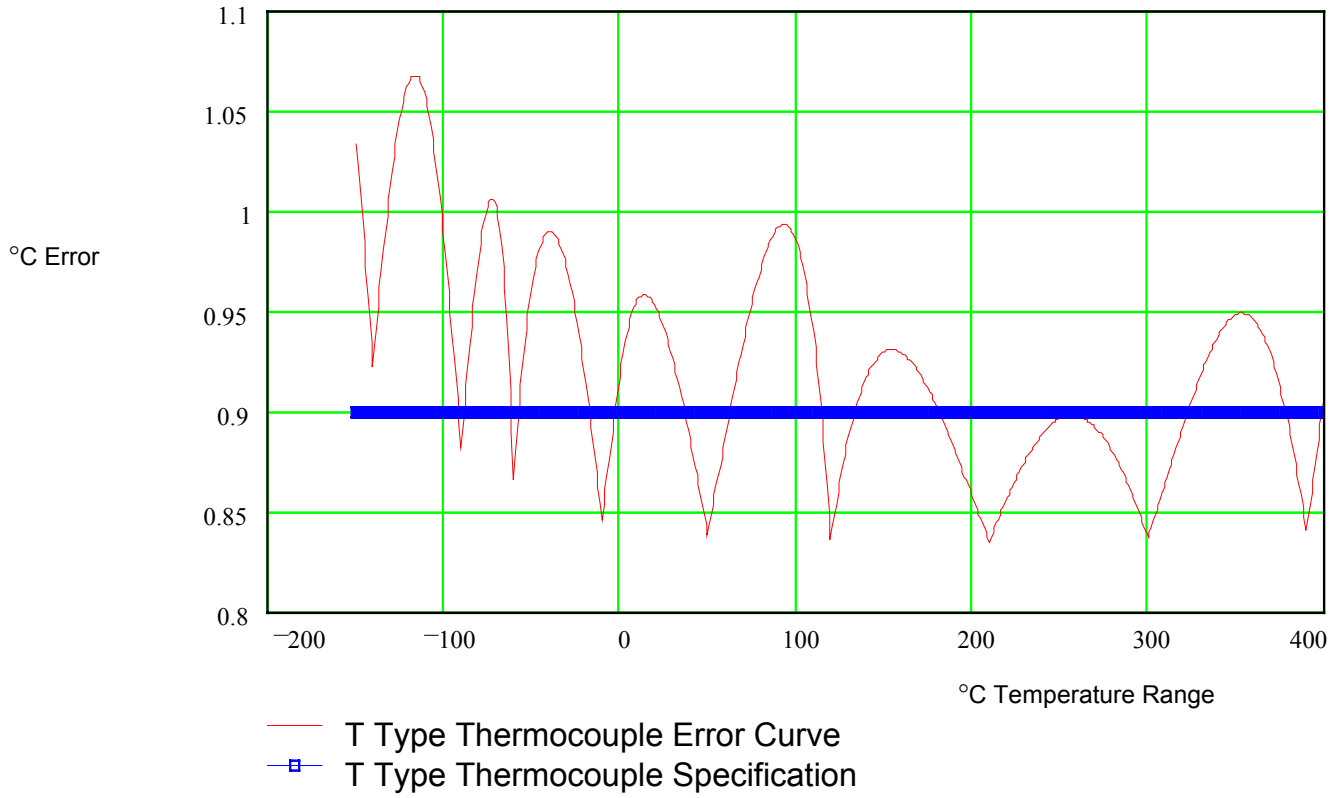


### Breakdown of the Total Error

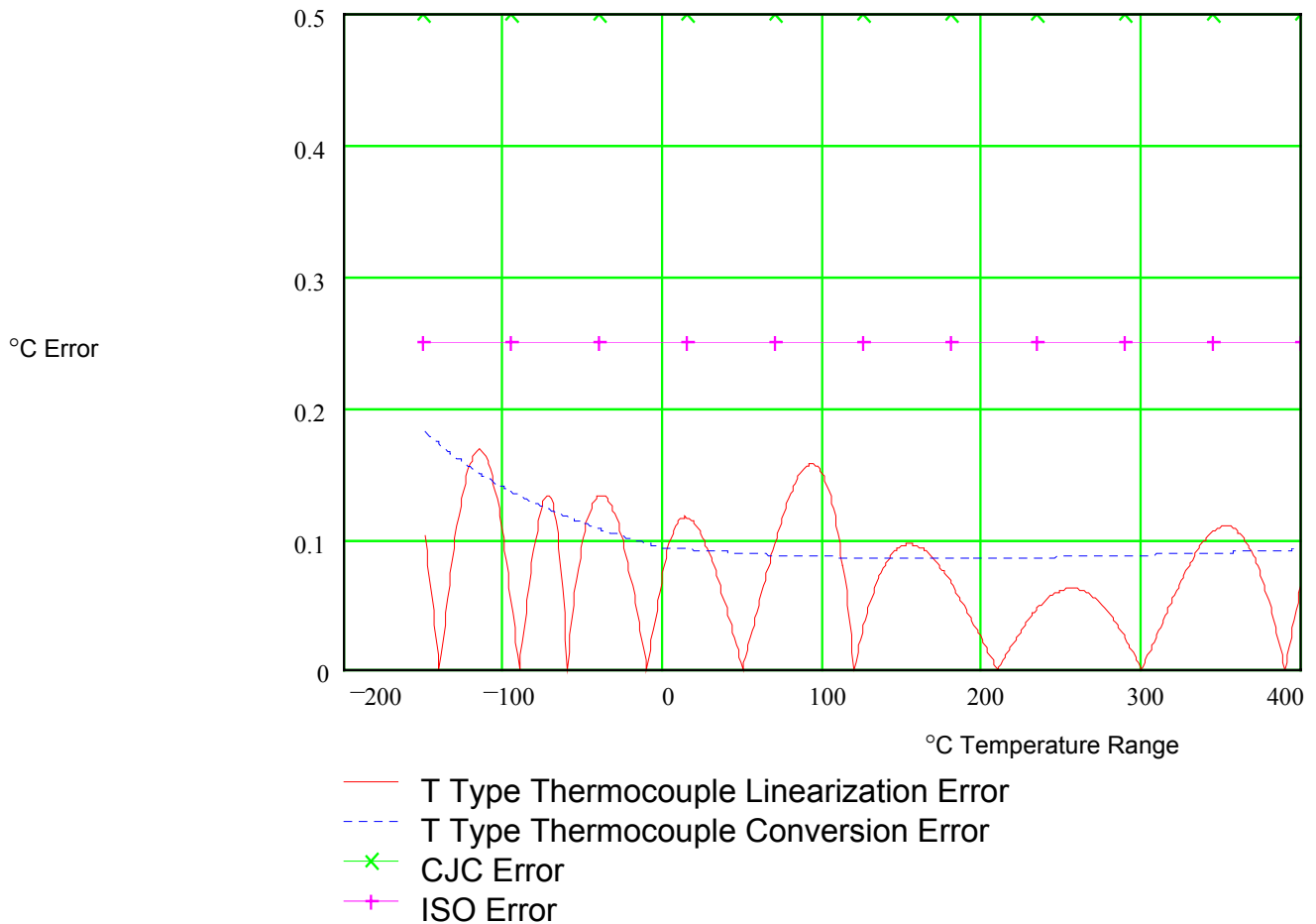


T Type thermocouple

### Total Error Curve

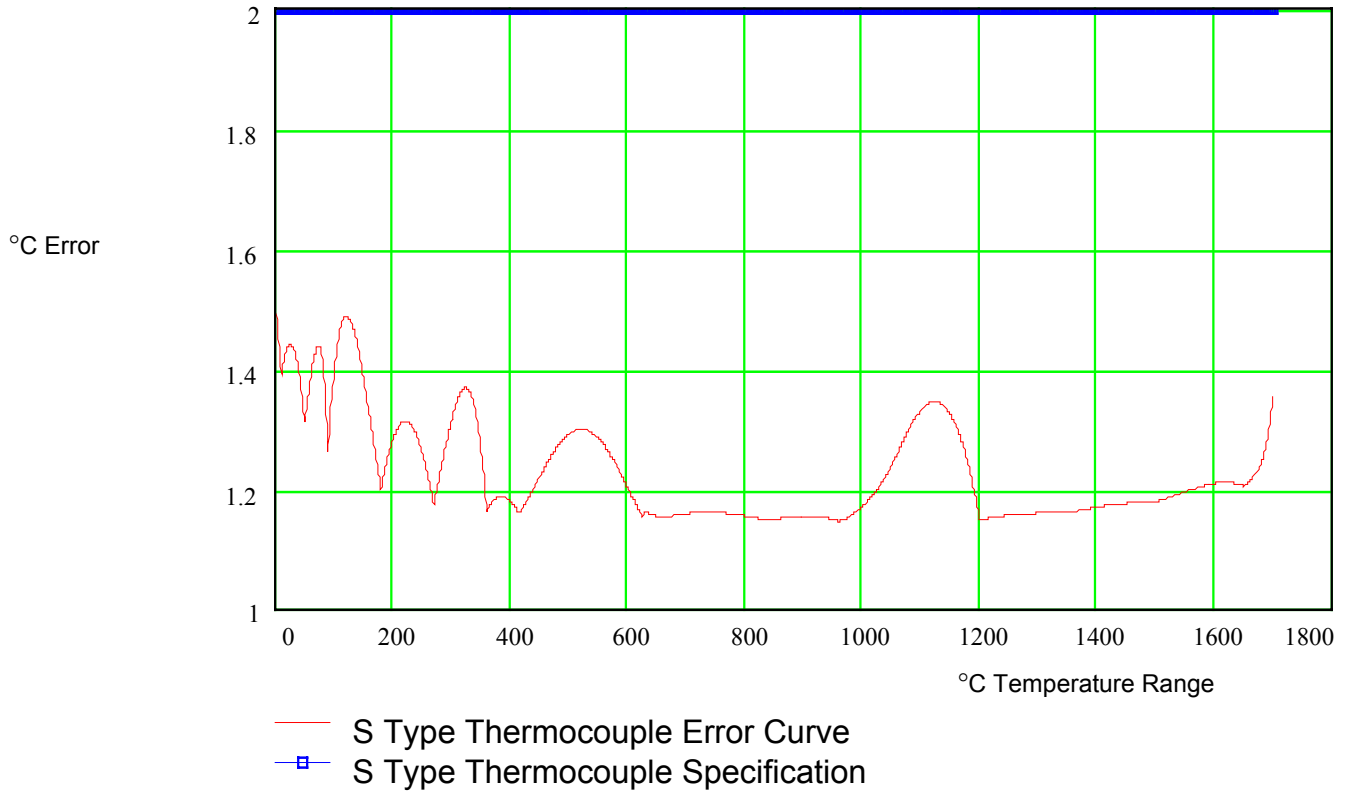


### Breakdown of the Total Error

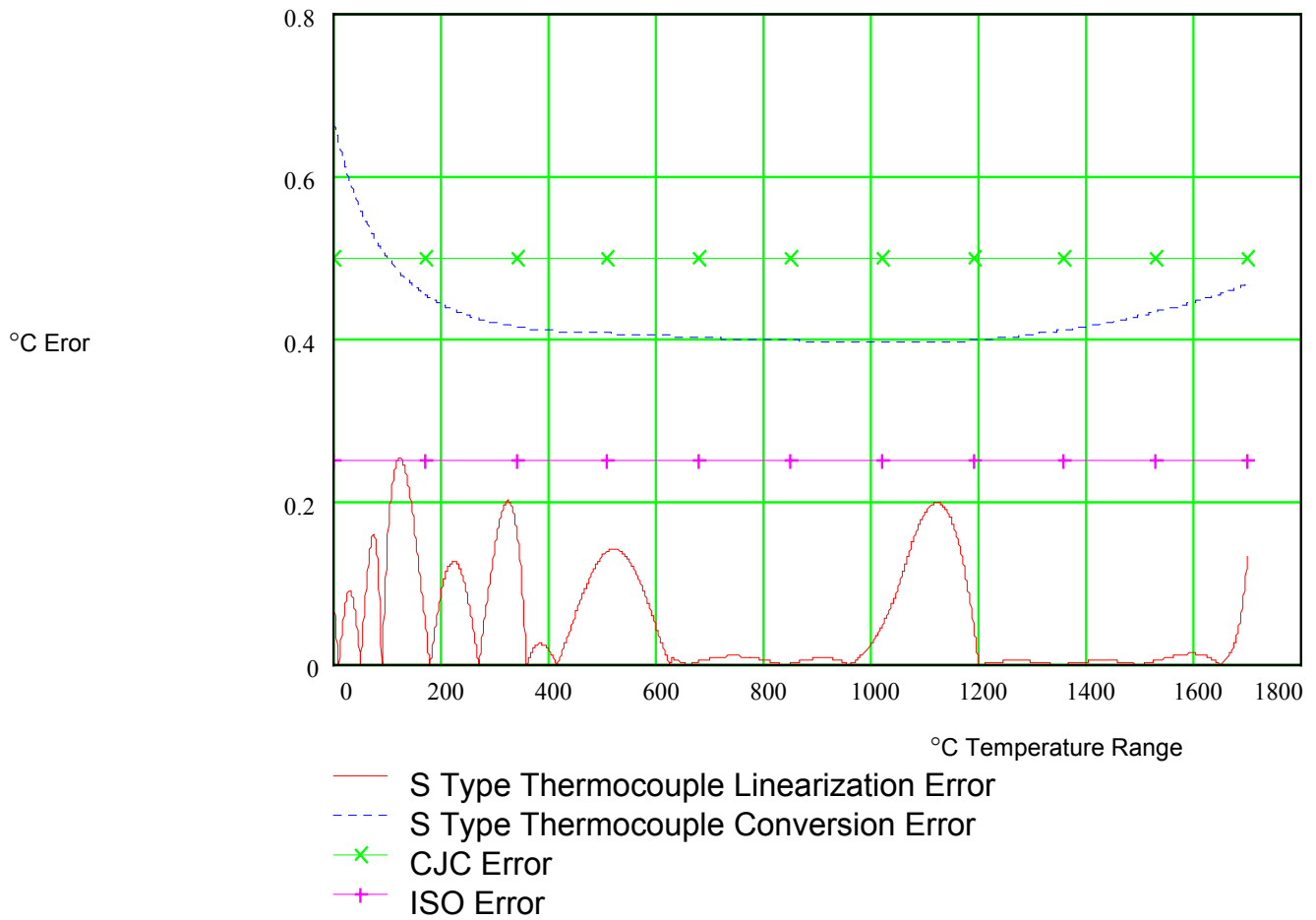


S Type Thermocouple

### Total Error Curve

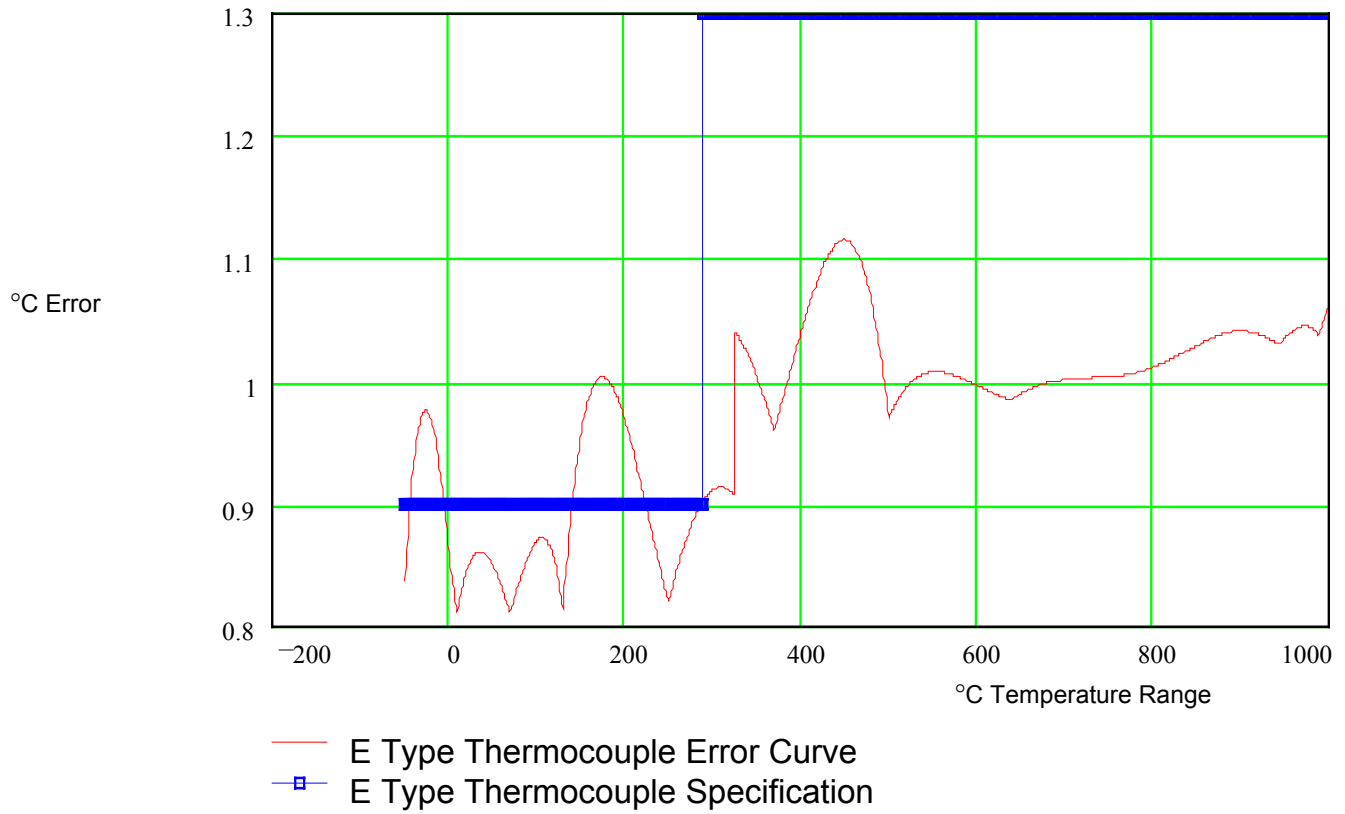


### Breakdown of the Total Error

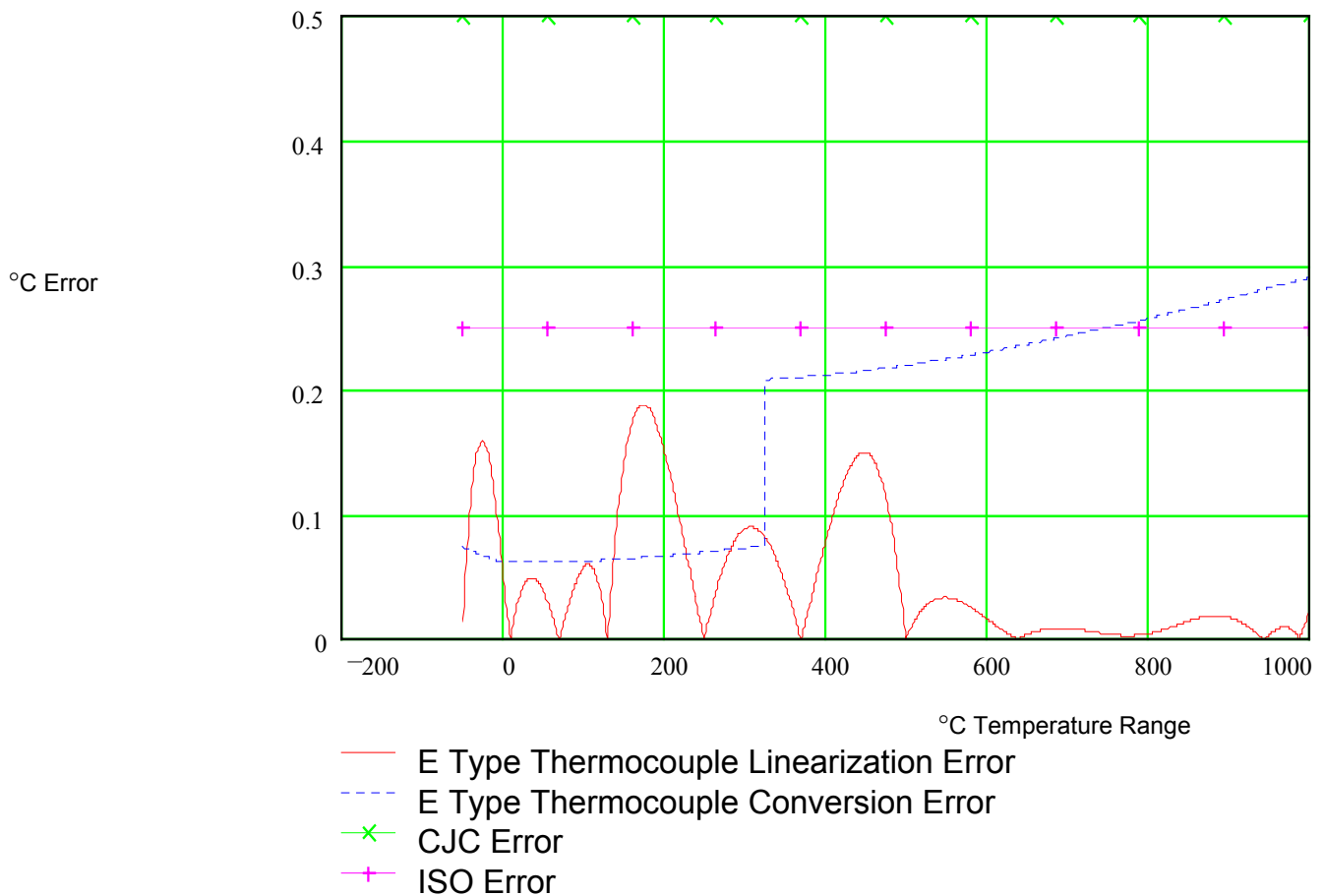


E Type Thermocouple

### Total Error Curve

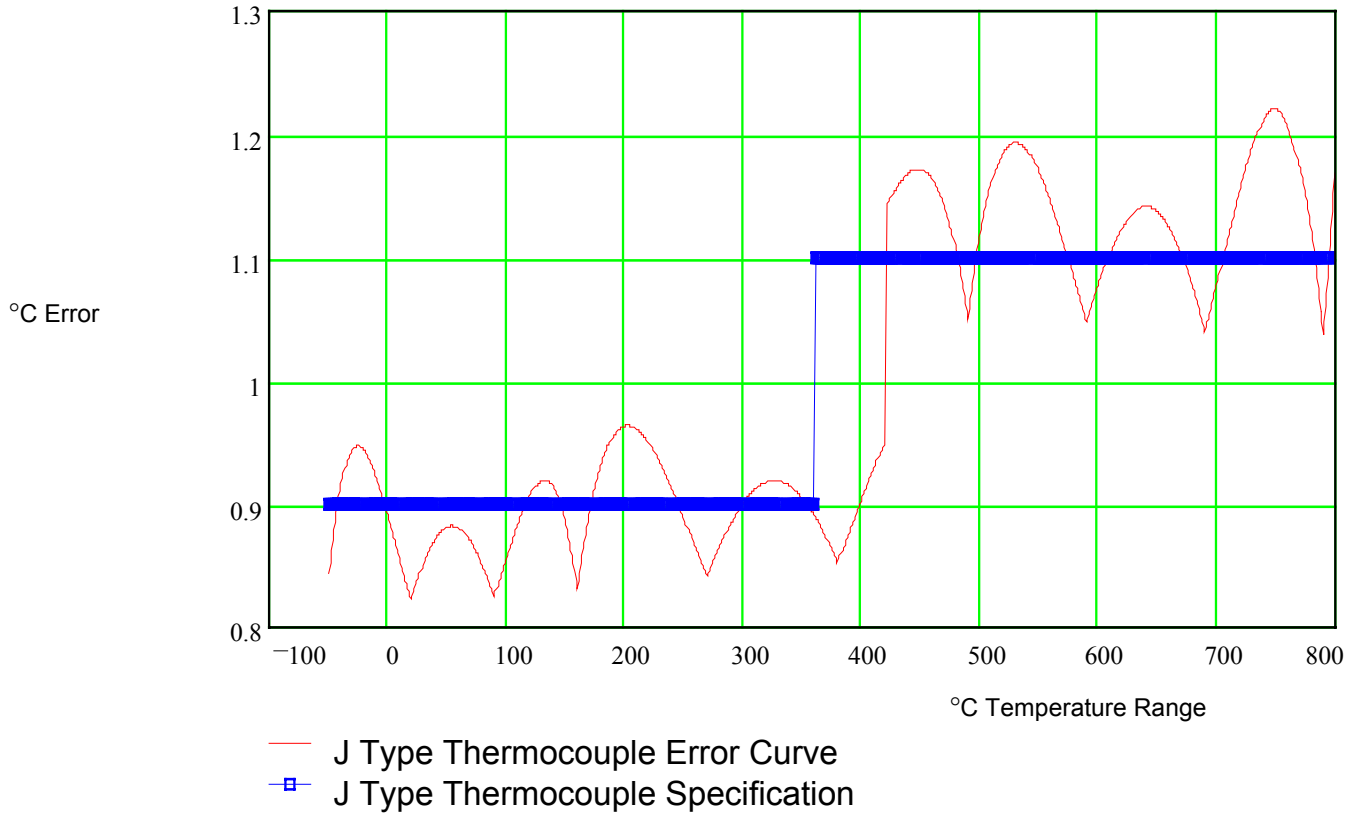


### Breakdown of the Total Error

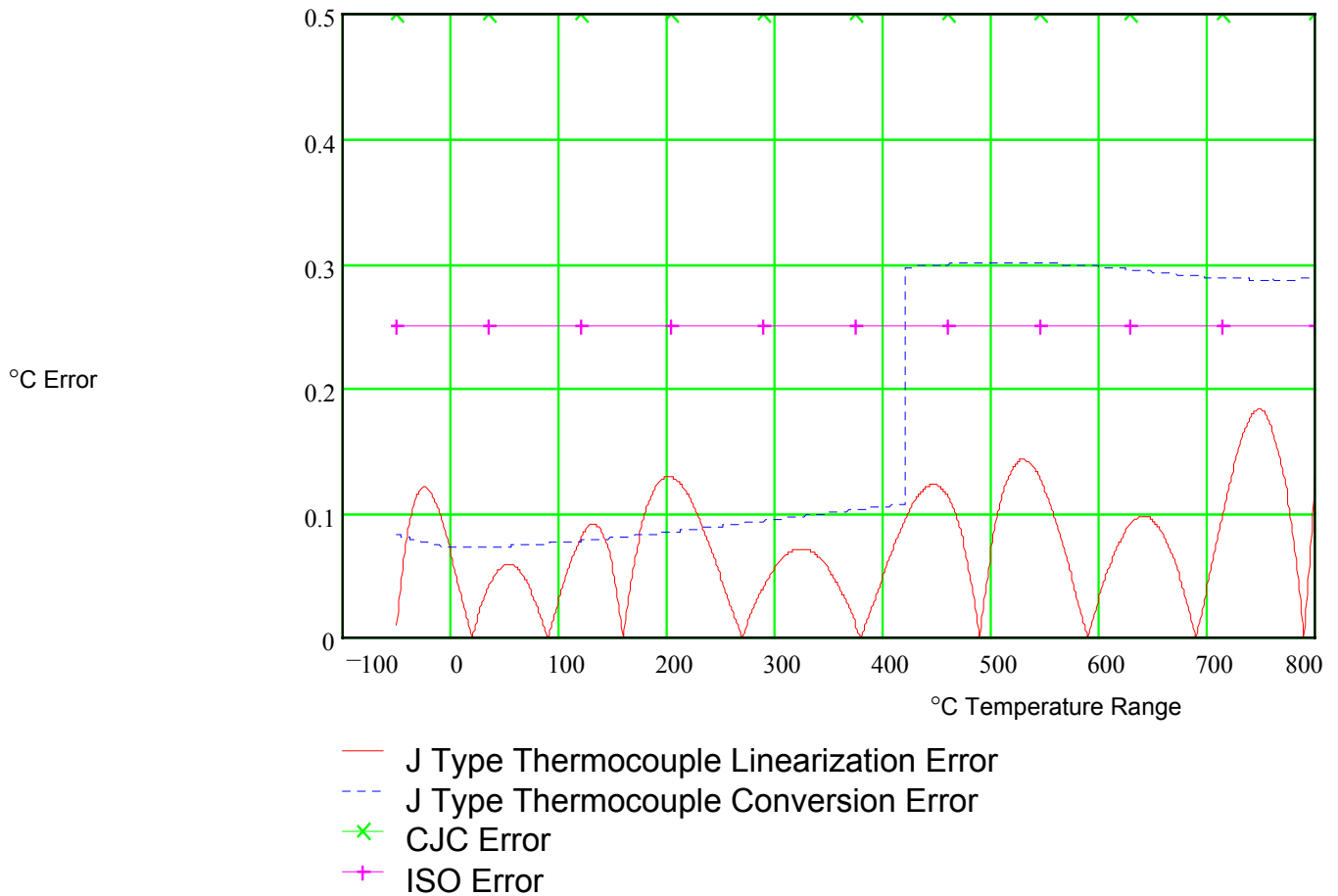


J Type Thermocouple

### Total Error Curve



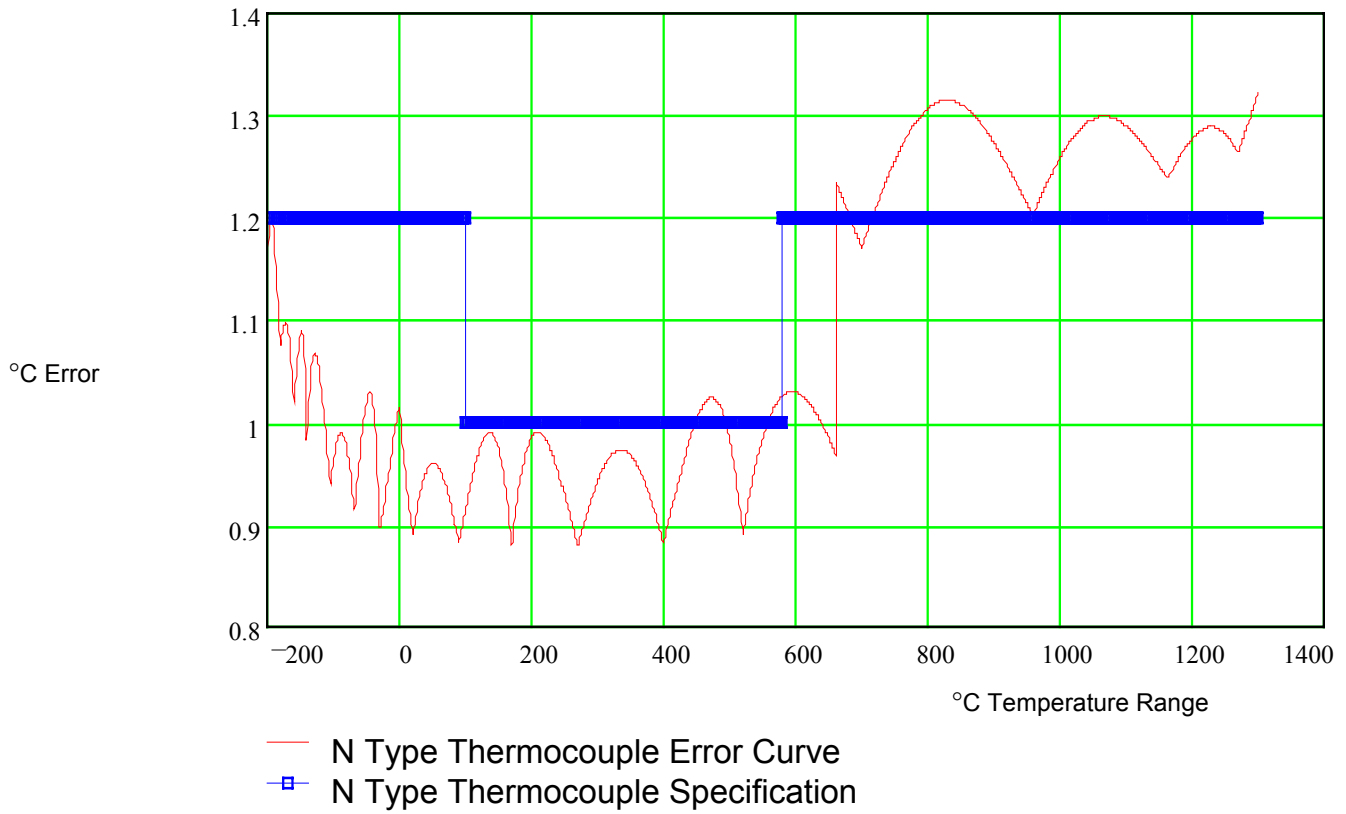
### Breakdown of the Total Error



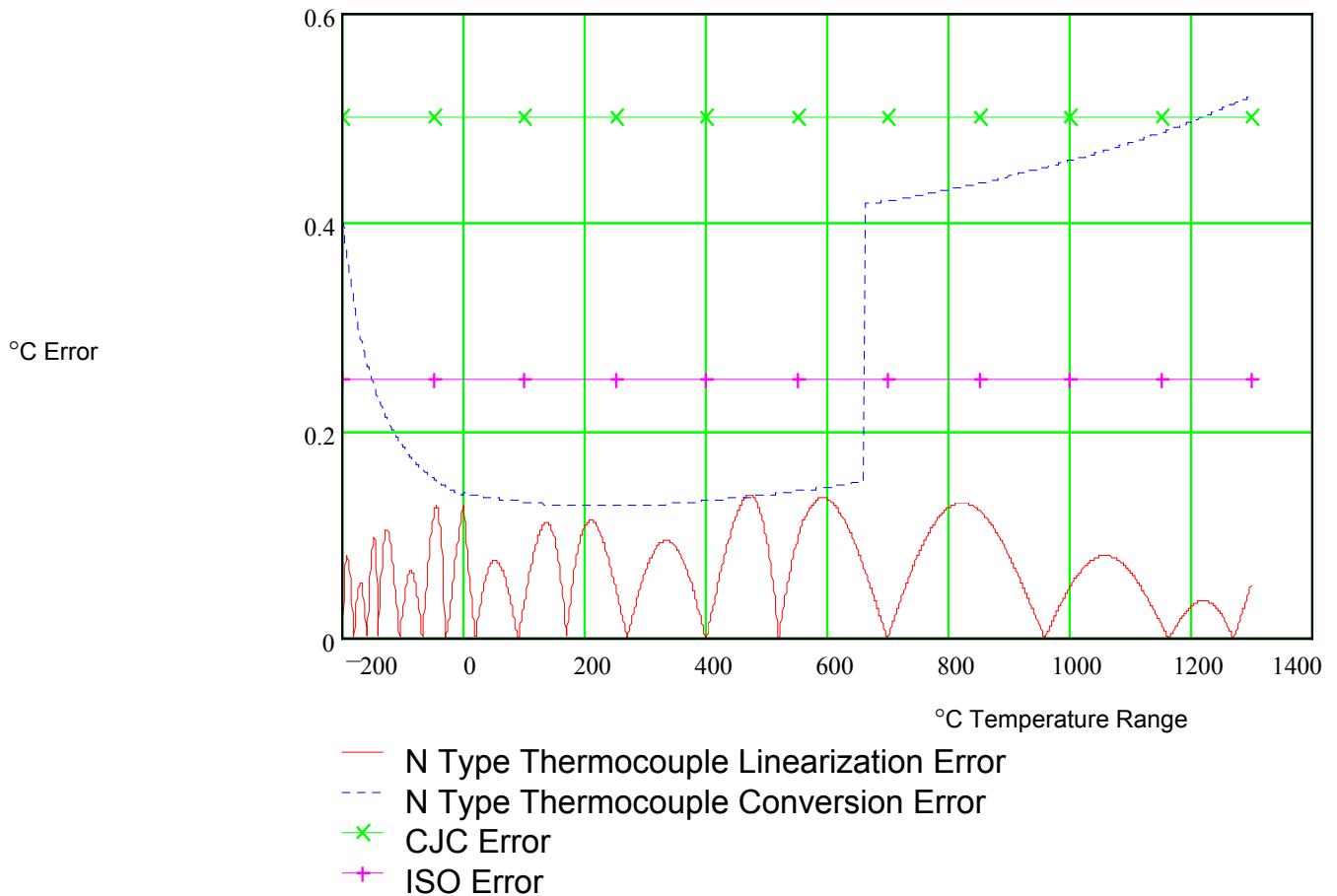


N Type Thermocouple

### Total Error Curve

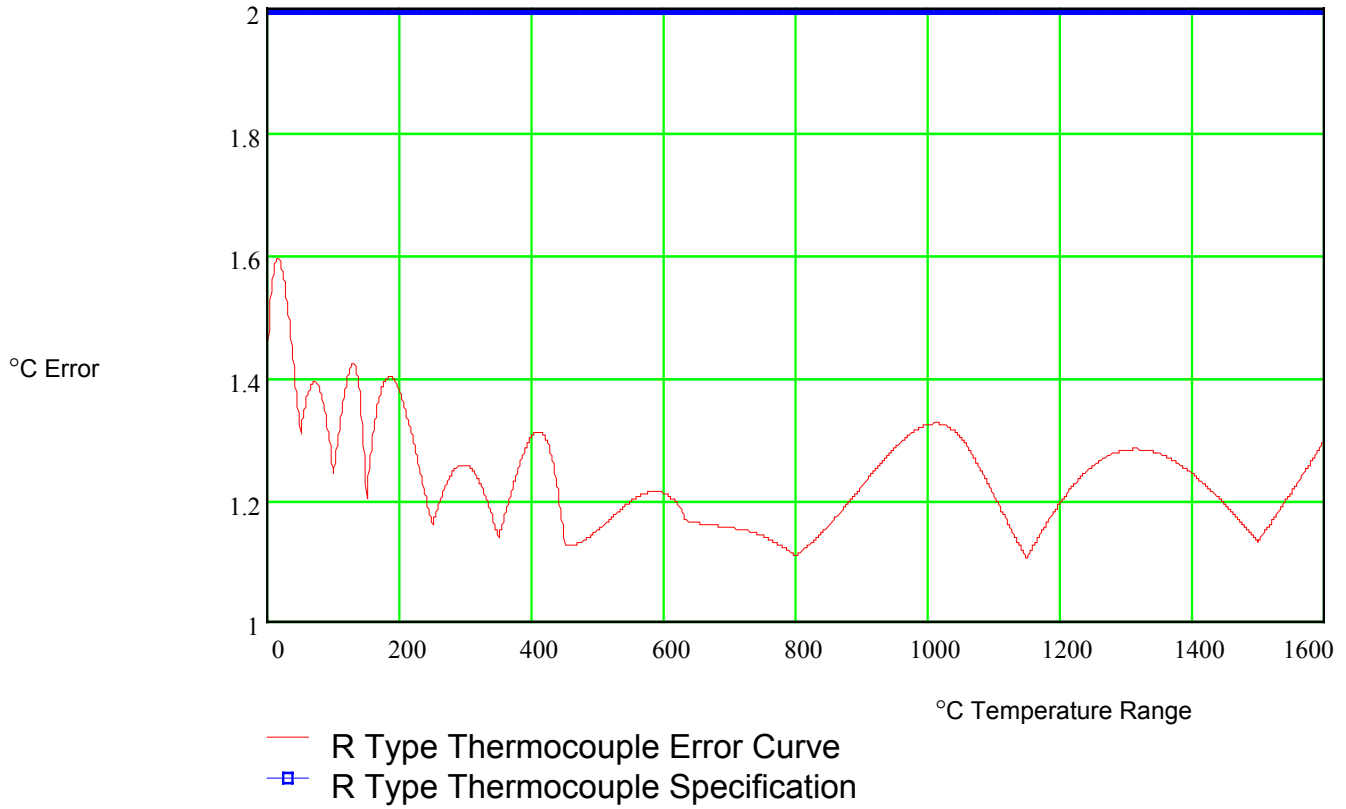


### Breakdown of the Total Error

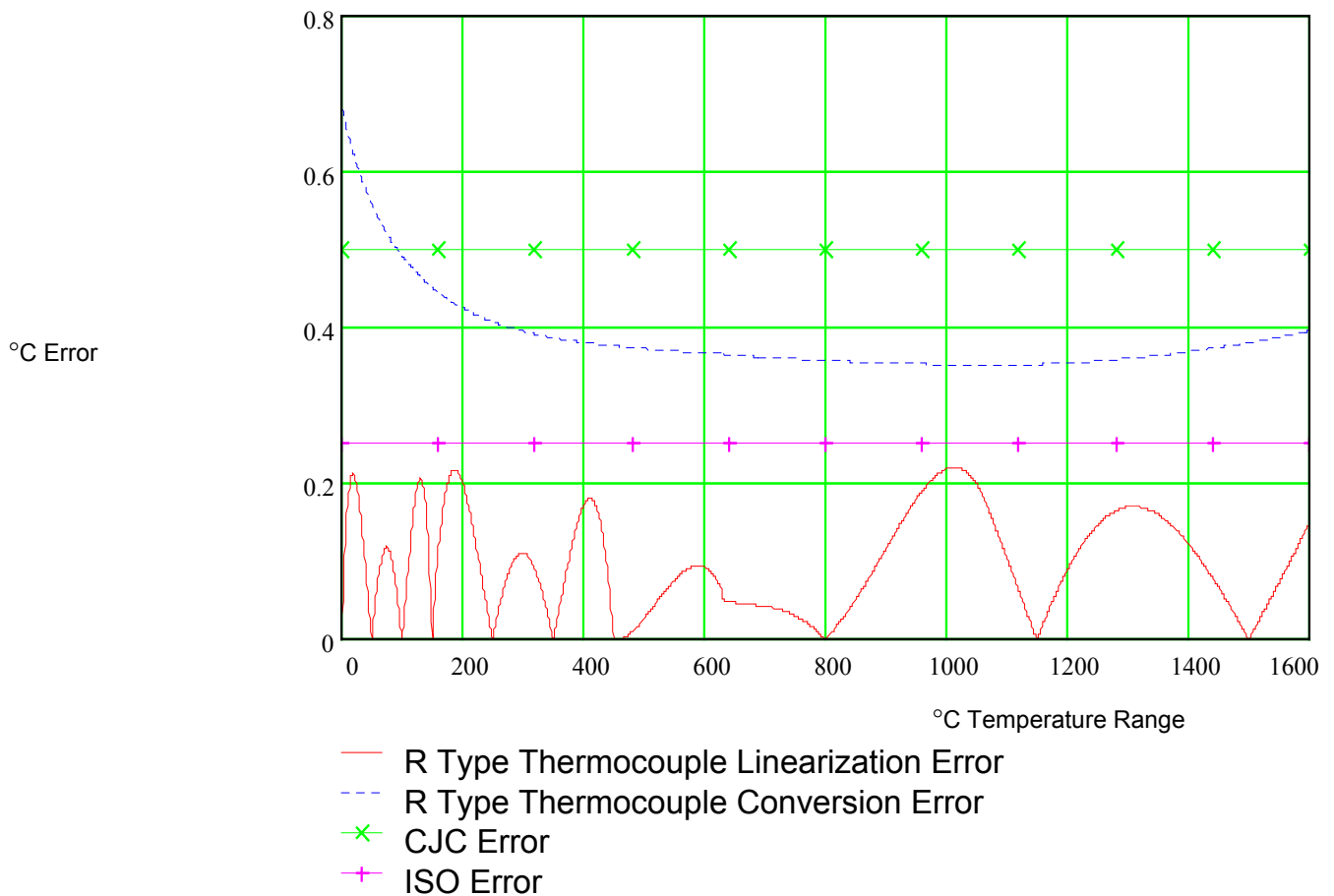


R Type Thermocouple

### Total Error Curve

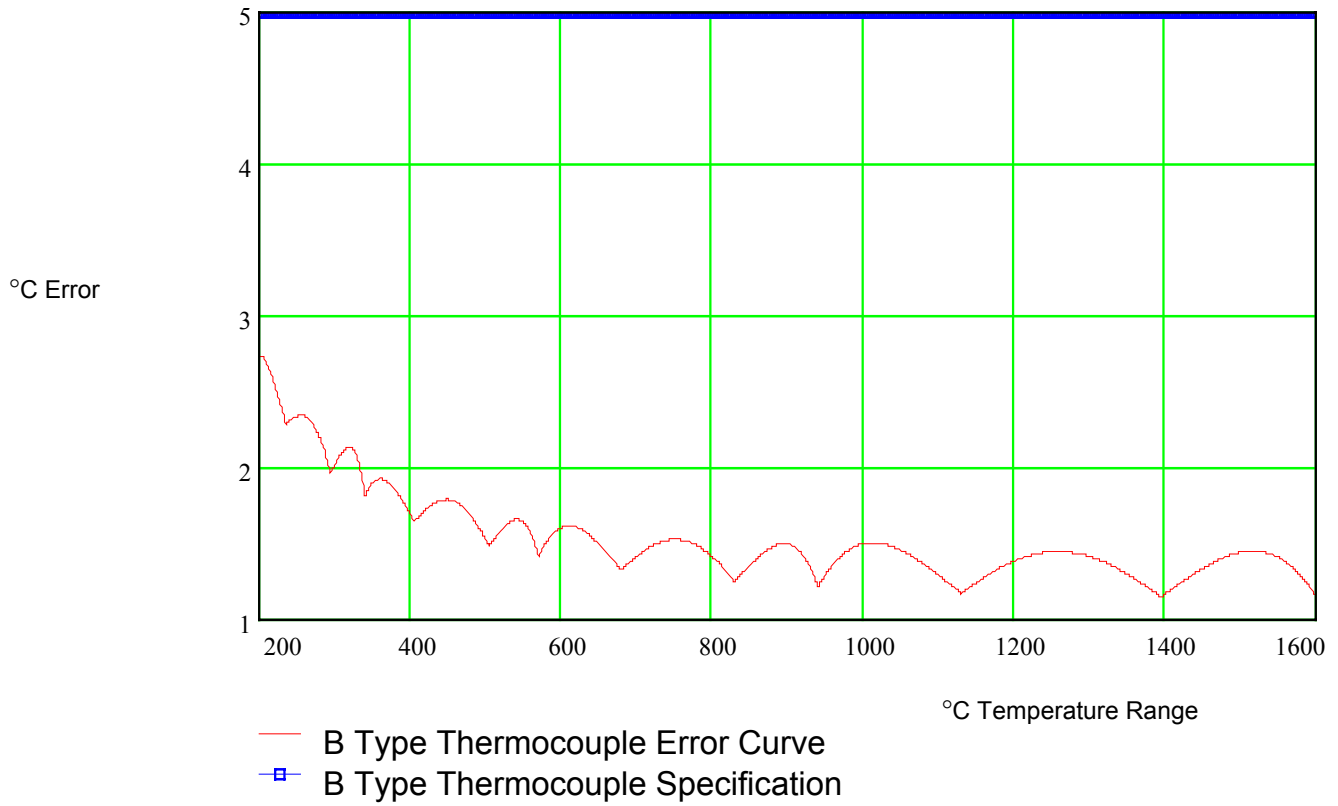


### Breakdown of the Total Error



**B Type Thermocouple**

**Total Error Curve**



**Breakdown of the Total Error**

