SOME GUIDE LINES FOR OBTAINING

THE BEST PERFORMANCE FROM RTD's

AND Pt100's PARTICULARLY

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SECTION 1

ACCURACY REQUIRED

There are numerous factors to be considered in the specification of an RTD, and the accuracy required is one of the most important.

The accuracy of an RTD is usually defined with reference to the relevant International Standard for the detector, e.g. BS;EN 60751: 1996, but this can frequently be misinterpreted, especially when close tolerance is required, and there are a number of points that are often not realised;-

- The tolerances defined by the International Standards only refer to the bare detectors, and not the assembled RTD's.
- The tolerances given by such as DIN Class B do not define the "accuracy" of a detector. It defines the 'interchangeability tolerance
- Fractional tolerances e.g. 1/10th DIN are no more "accurate" than DIN Class B. it simply indicates that there is a narrower spread of values at that temperature.
- DIN 43760 only defines the interchangeability tolerance, at temperatures, for Class B, (DIN), and Class A, (1/2 DIN).
- Fractional values e.g. 1/10th DIN, are not actually defined by the Standards.
- The tolerances for other fractions of DIN are that fraction of the resistance at 0°C only, and the interchangeability tolerances at other temperatures are a function of the combined tolerances of R_0 and α, and cannot be taken to be the same fraction of the corresponding DIN value.
- Because interchangeability is a function of the combined R_0 and α, tolerances, close tolerances can only be achieved, especially at higher temperatures, by very close control of the temperature coefficient.
  (SDL works to a standard tolerance on α for it's detectors of $\pm$ 3 ppm, rather than the $\pm$ 14 ppm in the DIN standard for Class B, and $\pm$9ppm for Class A.)
- The resistance values defined by the Standards refer to the overall resistance of the detector, and not at the connection head, or the end of the leads.
- For any RTD, the actual errors (uncertainties) to be considered should be;-

  1) the detector interchangeability tolerance.
  2) the uncertainty due to the RTD's design/construction, and if relevant,
  3) the uncertainty due to the calibration procedure.

  Points 2) & 3) are difficult to predict precisely in advance, as 3) is, in part, defined by 2) for such considerations as self heating, stem conduction etc.
- For the definition of the RTD's accuracy, the important questions to be asked are

  a) What is the interpretation of the required accuracy. e.g. '1/10th DIN' at 0°C or 200°C ?
  b) What tolerance is actually achievable ?
  c) What tolerance is necessary from the application viewpoint?
  d) How will the results be used ?
  e) Would it be better to use a calibrated RTD.?

The values shown in Table 1 show values for a typical 1/10th DIN of class B RTD application, and highlights the difference between the detector tolerance, and the actual tolerance achievable over the working range for the RTD.

TABLE 1

RTD ASSEMBLY UNCERTAINTIES

SDL BAND 5

TEMP	DETECTOR	ASSEMBLY	CALIBRATION
0°C	± 0.03 °C	± 0.050 °C	± 0.010 °C
100 0°C	± 0.08 °C	± 0.12 °C	± 0.010 °C
200 0°C	± 0.13 °C	± 0.22 °C	± 0.015 °C

CALIBRATION, CLOSE TOLERANCE, OR BOTH

Frequently RTD's are specified with close tolerances when it would be more appropriate, and cost effective, to use a Class B tolerance calibrated.

This approach is only relevant where the input from the RTD is going into a PLC, or similar system where the characteristics of each thermometer can be entered individually, and so characterised perfectly with each sensor.

Close toleranced thermometers ensure that each is closely interchangeable, but does not ensure the absolute "accuracy" away from 0°C. this is because of the importance of a tolerance on the detectors performance at higher temperatures.

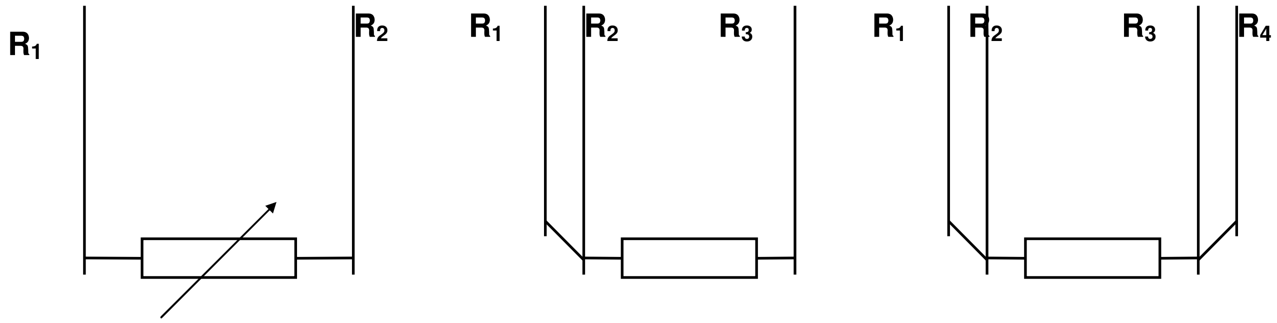
Equally, a situation that should be avoided if possible, is to specify close toleranced RTD's that are also going to be calibrated. The difficulty is that the international standards such as DIN only define the tolerances of the bare detector, and not the assembled RTD. No account is made for stem conduction errors, variations in RTD construction etc. In addition, close tolerance at elevated temperatures can only be achieved with virtually perfect α detectors, which would be prohibitively expensive.

SECTION 2

RESISTANCE/TEMPERATURE ERRORS FOR

**2,3, or 4 WIRE CONNECTED RTD's
WITH LONG LEADS**

SEE ATTACHED SKETCH



2 wire connection

For a 2 wire connection system, the error, (which will always be +ve) = $\mathbf{R_1+R_2}$

For very short leads, these errors might be insignificant, but normally, 2 wire systems should be avoided if possible. If detectors to Class A, or better are being used, 2 wire connection should not be used.

3 wire connection

Error due to 3 wire connection = $\mathbf{R_1-R_2}$

Normally, it is assumed that all 3 conductors are of equal length and conductor size, so error = 0Ω

This can be considered true generally, but if;-
Length>5 metres, and/or-
Conductor size <16/0.2,
the lead wire errors should be considered as follows;-

Lead resistance = Length x conductor resistance/metre.

The conductor resistance/metre is only quoted by the cable manufacturers as a nominal value, and there is usually a tolerance of ± 5% on this value.

The worst case would be if the conductors were at either extremes of the tolerance band, in which case

Error due to 3 wire connection =$\mathbf{R_1-R_2}$

Say R_1 = Nominal resistance+5% = 1.05R

Say R_2 = Nominal resistance-5% = 0.95R

Error due to 3 wire connection = (1.05R - 0.95R) = 0.1R ohms

(For typical values for common conductor sizes see Table 2 below)

For 100 ohm RTD, error in °C ≡ Lead wire resistance error Ω / 0.385 (°C)

TABLE 2

CONDUCTOR SIZE	CSA mm^2	RESISTANCE/ METRE	LEAD WIRE ERROR (Ω)	LEAD WIRE ERROR (°C)
7/0.2	0.22	0.092	0.21	0.55
16/0.2	0.5	0.040	0.06	0.16
24/0.2	0.75	0.025	0.038	0.10
32/0.2	1.0	0.019	0.029	0.08

4 wire connection

A 4 wire connection system will completely compensate for any lead wire errors, and is the preferred connection system for any close tolerance applications, or where long extension leads are being used.

SECTION 3

USAGE OF RESISTANCE DETECTORS AT HIGH TEMPERATURE

Platinum Resistance Temperature Detectors, (RTD's) are able to be used at elevated (i.e.>350°C) temperatures, but there are a number of precautions that should be taken to avoid running into any difficulties

The 2 problems most frequently encountered are;-

a) Poisoning of the Platinum Resistance Detector
b) Glass shift

a) POISONING

This can occur at any temperature, but is usually more likely to occur above 350°C.

Poisoning occurs when the very high purity Platinum element is exposed to some form of contamination which alters the chemical structure of the element. This is frequently exhibited by a fall in the α value accompanied by an increase in the R_0 value. (Although this is normally the case, the poisoning can affect the α & R_0 values in differing ways).

There are several common causes for element poisoning

TABLE 3

CAUSE OF POISONING	PREVENTATIVE MEASURES
i) Element used without protection in metal sheath	Sheath must be thoroughly degreased and burnt off at a temperature >200°C above maximum operating temperature to remove any free metallic ions
	Enclose detector in Quartz sheath (only practical for laboratory environments)
	Use glass or film element (not suitable for applications requiring accuracy better than Class B, or for T>450°C)
	Use 'PF' element if vibration levels are not excessive

USAGE OF RESISTANCE DETECTORS AT HIGH TEMPERATURE (continued)

ii) Element encapsulated in unsuitable media	Avoid use of Silicone Rubbers inside sheath
	All internal materials, particularly resins, should be tested for compatibility with the detector before production commences

iii)Cadmium containing braze used	Cadmium containing Silver solders must be absolutely avoided
iv)Brazing flux not completely removed	Detector/Extension lead joint must be thoroughly cleaned to remove any trace of flux

b) GLASS SHIFT

This usually occurs at temperatures above 500/550°C

The shift occurs when the glass frit used to partially support the coil, begins to soften, usually around 500/550°C When the temperature falls below the freezing point for the glass, the coil has re-aligned itself, and this set causes the R_0 value to increase with each temperature cycle.

This glass shift does not reduce the detectors reliability in any way, as SDL detectors are processed at >1000°C, and it's effect will only be observed when the element is brought back to 0°C. Even then it's effect will only be relevant if close accuracy is required at the higher temperature.

The solution, other than to use a Precision Standard Thermometer such as the SDL Q25, which is only suitable for Laboratory use, is to use a 'PF' type of element (see typical Data Sheet attached)

The 'PF' range may be used upto 700/750°C.

The limiting factors for the 'PF' detectors are that;-

a) They are only suited to applications with low levels of vibration
b) They are only available (currently) to DIN Class 'B' tolerance
c) Because of their different construction method, they are substantially more expensive than the standard types of elements

The information contained in this summary is very limited, but it is hoped that it will provide some useful guidelines for the use of RTD's at high temperatures. For more detailed assistance please contact Sensing Devices Ltd.

DETECTORS FOR USE AT HIGH TEMPERATURE UNDER CONDITIONS OF HIGH VIBRATION (continued)

Normally the detectors are constructed with their coils inserted inside the bores of a multi-bore ceramic body. Although shorter elements, such as 6D, have a higher glass filling ratio than longer detectors, there is still a slight degree of variability in this respect.

With the Pt100/4J construction, the coils are wound in grooves on the surface of the ceramic, which is then glassed over. This offers a very consistent and secure means of fixing the element, and it has been the experience of SDL that this form of construction will withstand much greater levels of shock and vibration than the standard detector type

This construction gives excellent shock / vibration resistance, with only a slightly inferior high temperature drift value than the standard Pt100/1P detector. However this performance is

achieved at the expense of significantly greater manufacturing costs, which cause the elements to be much more expensive than standard types of elements.

TECHNICAL REPORT

Object of test; To obtain quantitative data relating to standard detectors performance at high temperature, and high vibration.

Method;

a) Determination of R_o.
b) Heat treatment at; 600°C for 18 hours; 450°C for 1 hour
c) Determination of R_o.
d) Vibration at; 25g; 50 Hz; 2.48 mm displacement (peak to peak)
   Time; 3 hours
e) Determination of R_o

Detectors tested;

Pt100/1P	SDL Band 1
Pt100/6D	SDL Band 1
Pt100/4J	SDL Band 1

Results; See Table I

Conclusion; Pt100/4J represents the best detector for all round performance under high temperature and high vibration conditions

DETECTORS FOR USE AT HIGH TEMPERATURE UNDER CONDITIONS OF HIGH VIBRATION (continued)

TABLE I4

DETECTOR TYPE	Pt100/1P		Pt100/6D		Pt100/4J	
	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2

Initial R_o.	99.962	99.970	100.052	99.962	99.966	100.077
R_o after heat treatment;	99.957	99.966	100.085	99.992	100.011	100.123
$\Delta m\ \Omega_{(600°C)}$	-5	4	+33	+30	+44	+46
R_o after vibration;	99.990	100.016	100.084	99.992	100.009	100.123
$\Delta m\ \Omega_{(vibration)}$	+33	+50	-1	nil	-2	nil

SECTION 4

DETECTOR GLASSING

There are 3 basic types of Resistance Detectors,-

A) Unsupported coil
B) Partially supported coil
C) Fully supported coil

The design of any Resistance Detector is a compromise between the conflicting requirements for high accuracy (i.e. repeatability) on one hand, and resistance to shock and vibration on the other. Unfortunately these requirements are mutually exclusive, and improved performance of one characteristic may only be achieved at the expense of the other

Each type of construction has its own area of application

a) Unsupported coils have good reproducibility and show little hysteresis, but have little resistance to shock or vibration, and so their use is restricted to Standard thermometers in laboratories

b) Fully supported coils (e.g. glass detectors) have high levels of hysteresis, because of the constraint on the coil due to differential expansion between the platinum, glass, and ceramic. This severely restricts their accuracy, and they are only suitable for non-critical measurements, at low (<200°C) temperature, particularly where high vibration is likely to be present.
These detectors can not be supplied to close tolerance

c) Partially supported coils. This is the type of element made as standard by SDL.
This type offers the optimum combination of good accuracy and good resistance to shock and vibration.
The partial supporting of the coil limits the degree of movement possible during vibration, but does not constrain the coil to the same extent as with a fully supported construction, and hence limits the hysteresis.

The partially supported type of element is perfect for virtually all industrial applications, but occasionally some applications call for an element that is nearer to being fully supported , or unsupported, than the standard construction, to tailor the detectors performance more closely to the application.

With this construction we “double glass” the coil, which improves the vibration resistance considerably. The disadvantage is that we could not offer this element to better than Band 2 accuracy

SECTION 5

SELF HEATING EFFECTS, MEASUREMENT CURRENT, & STEM CONDUCTION ERRORS

SELF HEATING EFFECT

Although used as a temperature detector, any type of RTD is simply a very precise resistor, and when the measuring current is applied, the electrical energy applied (I^2R) is converted to thermal energy, and the detector actually radiates heat.

At higher temperatures, this heat does not significantly affect the thermal equilibrium of the measurement, but at lower temperatures, or where very accurate measurement is required, the heat generated by the detector/RTD must be taken into account. This is “self heating”, and the efficiency with which any given detector converts electrical to thermal energy is known as its “self heating effect”, which can be measured in m○/mWatt.

The “self heating effect” is usually a constant for any given type of detector, but can be affected by factors such as using a larger coil wire diameter inside the detector, or changing the “partial support” system of the detector.

MEASUREMENT CURRENT

The recommended measurement current for all Pt100 thermometers is 1mA, although for 100Ω Transfer Standards, it is recommended to use 0.5 mA, if very low measurement uncertainties are required for 100Ω.

The reason for limiting the measuring current is to keep the self heating of the measuring current affect to a minimum, by restricting the power applied to the detector.

Although SDL recommends using a measuring current of 1mA, it is recognised that certain applications demand the use of higher measuring currents than this.

Standard SDL detectors are frequently used at 10mA quite satisfactorily, and little reduction in service life will be experienced at this level, although this cannot be guaranteed as this is beyond the normally recommended level.

However, during controlled experiments, standard production elements have performed satisfactorily at 100/120mA, and even up to 150mA before failure, so 10mA will normally not represent any problem.

If 10mA is going to be used as a standard measuring current, SDL would recommend increasing the coil wire diameter to improve reliability. Inevitably this would involve some cost increase, and would also limit the range of detector dimensions available, but may be worth considering for ultimate reliability assurance.

MINIMUM IMMERSION LENGTH & STEM CONDUCTION ERRORS

It is always essential that the RTD is adequately immersed in the media to be measured. As a rule of thumb, the minimum immersion depth should be at least 4x the sensing length.

Anything below this will introduce errors due to stem conduction effects. This is where heat is drawn away from (or into) the source being measured, along the sheath, and so the observed temperature is different from the true temperature.

Stem conduction effect can be reduced by reducing the mass of the sheath, using smaller gauge conductors, or using thermally insulating material such as fused silica, PTFE or plastic, or a combination of all of these.

Although stem conduction, and immersion effects are usually of most significance in laboratory conditions, they can cause very large errors in normal industrial usage, and must always be taken into consideration.

LONG TERM STABILITY

Long term stability is very difficult to define because it is principally a function of the manner in which the detector is assembled into the RTD sheath, and particularly the way in which the RTD is subsequently handled, it’s maximum temperature, level of vibration etc., which is totally out of the control of the detector manufacturer.

SDL can however give an estimated value for many applications. Typically, we would anticipate a maximum annual drift value of ±0.025°C/year for a normal detector, assuming a maximum temperature of 450°C, and normal precautions being taken with the handling of the RTD.

REPEATABILITY

Any resistance detector will have a very good repeatability over it’s recommended temperature range.

The difficulty comes with;-

a) Repeating exactly the same thermal conditions again.

b) Variations in construction between apparently identical RTD’s can cause significant differences i.e element construction, partially supported or unsupported.