Error Sources That Effect Platinum Resistance Thermometer Accuracy

Part 4 - Repeatability

Introduction

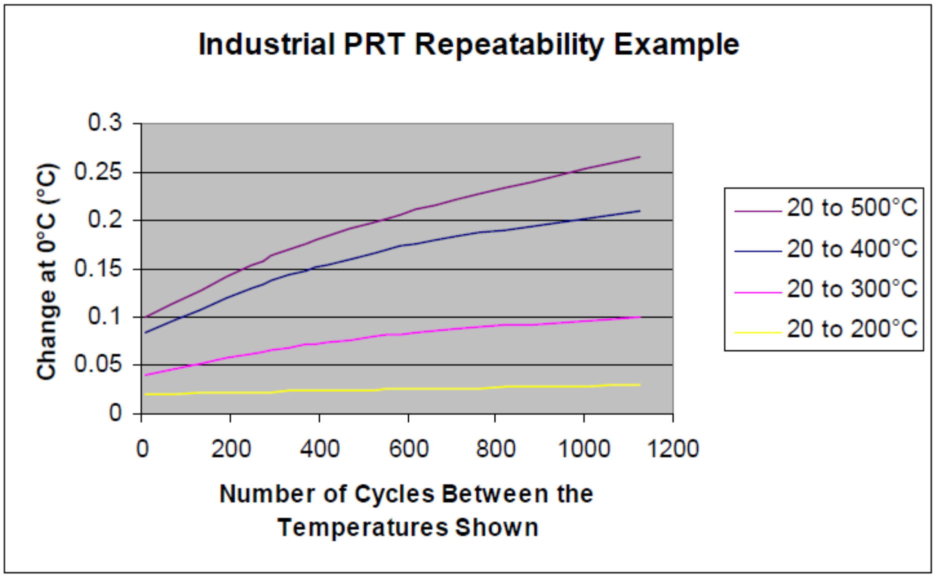
There are many sources of error that affect the performance of Platinum Resistance Thermometers (PRTs). These error sources are inherent in the design and manufacture of all PRTs, but the magnitude of the resulting error in use can vary greatly depending on the specific PRT design and environment that it is used in. It is important for users of PRTs to know and understand what these error sources are so they can make intelligent decisions related to PRT selection and use. The most common error sources fall within the following categories: Interchangeability, Insulation Resistance, Stability, Repeatability, Stem Conduction, Hysteresis, Calibration and Interpolation, Lead Wire Resistance, Self-Heating, Time Response, and Thermal EMF. This paper will discuss the topic of Repeatability.

Repeatability

Repeatability refers to the ability of a PRT to maintain its Resistance vs. Temperature (R vs. T) relationship when measured under the same conditions* after experiencing thermal cycling throughout a specified temperature range. [*Refer to the section titled "Additional Repeatability Information" on page 3 for details on what is meant by same conditions]. Industrial specification IEC 60751 refers to this as "Effect of temperature cycling" and states that the PRT can change at 0°C by the equivalent of 0.15°C for a Class A sensor and 0.30°C for a Class B sensor after 10 thermal cycles between the PRT's upper and lower temperature limits. It does not require the PRT to remain within the original resistance tolerance. The permitted change seems relatively large for such a small number of cycles, but considering the temperature range may be as large as -200°C to +850°C, it is not unreasonable. The standard does contain a note to the effect that improved performance may be achieved for certain thermometers when used over narrower temperature ranges, but no specific requirements are given. ASTM E1137 does not contain any requirement for thermal cycling performance other than to state that the PRT must be capable of continuous operation over the specified temperature range. Neither of these industry standards provides substantial information about the performance of a PRT as a result of thermal cycling.

The information that would be valuable for a good understanding of a PRTs repeatability would be a set of specifications that state the change due to a varying number of cycles over varying temperature ranges. Typically 3 or 4 temperature ranges including the maximum rated range, and cycles up to 1000 would be sufficient. The graph in Figure 4-1 below gives a realistic representation of the repeatability of a typical industrial PRT that has a temperature rating of 0°C to 500°C, over 4 different thermal cycle temperature ranges.

Figure 4-1



By examining the figure there are several generalizations that can be made about repeatability. The generalizations listed below hold true for the behavior of most industrial PRTs, however the actual values, maximum temperature ranges, etc., will all be unique based on the specific PRT design. If a better understanding is needed regarding a specific PRT, the manufacturer of that PRT should be consulted.

1. A disproportionate amount of change can occur during the first few thermal cycles. Figure 4-1 starts at 10 thermal cycles which aligns with a typical specification such as ".1°C maximum change after 10 cycles from 20 to 500°C".
2. There will be some temperature range for which there is virtually no difference in repeatability between 10 cycles and 1000 cycles. In the case of this example, that temperature range is 20 to 200°C.
3. The maximum non-repeatability will occur due to cycling over the maximum rated temperature range of the PRT. Smaller ranges will result in smaller changes.
4. The change at intermediate temperature ranges and numbers of cycles can be estimated by interpolating between known values. For example, the repeatability after 500 cycles from 20 to 350°C could be estimated as approximately .13°C.
5. The change can be estimated as linear with the number of cycles for any given temperature range. For example, the change after 2000 cycles can be estimated as 2 times the change after 1000 cycles. This method should result in a conservative estimate for most high quality PRTs.

Given the information contained in Figure 4-1, a reasonable estimate could be made for the repeatability of the PRT under various conditions. A hypothetical example would be the use of this PRT in a process that must heat from room ambient to 350°C for 1 hour and then cool back to room ambient temperature. Assuming this process runs 3 times per day for an entire year, the error due to repeatability could be estimated from Figure 4-1 as the value shown at 1095 cycles (3/day x 365 days/year) in the region between the 300°C line and the 400°C line. From the figure, an estimate of .16°C could be made. Keep in mind that this error is separate from the error that would be created due to the 1095 hours of heat soak at 350°C, that error is considered in the stability component of the overall error.

Additional Repeatability Information

There are several other important pieces of information related to determining repeatability of a PRT that can enhance the understanding of this error source.

1. Repeatability refers to measurements made under the same conditions, and after the same prior temperature exposure. This is done to make sure no other error source is inadvertently confounding the determination of the repeatability. One potentially large error source that may be experienced during thermal cycling is thermal hysteresis. Thermal hysteresis causes a change in the indication of the temperature as a result of the prior temperature exposure. For example, the difference in the indicated temperature of a PRT at 0°C between a measurement made after a -200°C exposure and a measurement made after a +500°C exposure. Because of thermal hysteresis, it is very important to know the prior thermal history of a PRT before any repeatability determination is made, and tests designed to determine repeatability should include some thermal preconditioning unless the prior thermal history is known. The topic of thermal hysteresis as an error source will be covered in detail in a future paper in this series.
2. Repeatability values determined after a large numbers of thermal cycles may actually contain a stability component that was included in the stated repeatability. As discussed in Part 2 on Stability, changes can occur from prolonged exposure to elevated temperatures. For large numbers of thermal cycles the cumulative amount of time at elevated temperature can be substantial, especially if the dwell time for each cycle has not been minimized. In general, this effect is not considered when a specification is created because there is no good method to determine the stability component. The best method to prevent stability influences from affecting repeatability is to minimize the exposure dwell time during the test.
3. The affect of thermal shock is generally not considered in repeatability information. Thermal shock, the rate of temperature change of the PRT, can have an affect on a PRT. For example, plunging a PRT directly between 500°C molten salt and liquid nitrogen at -196°C will be more severe then if the PRT was allowed to attain room ambient temperature in air between these exposures. Additionally, the use of a 500°C air furnace would be less severe than a 500°C salt bath. Most PRTs are fairly resistant to thermal shock up to the level that would be experienced during a typical calibration (ice baths, oil baths, etc), so unless there is a specific requirement or need to specify the rate of temperature change during the cycle, it should be assumed that any method may have been used to determine the specification.

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Causes of Repeatability Error

Many factors can contribute to the inability of a PRT to repeat readings after thermal cycling, but the most prominent factor is generally considered to be strain within the sensing element caused by thermal expansion and contraction. Most industrial grade PRTs are manufactured using a sensing element made from a fine diameter platinum wire, typically less than .001 inch diameter, or a thin film platinum element. The other materials used to manufacture these elements are critical because they are in direct contact with the fragile platinum and must provide mechanical support and protection while still allowing for free thermal expansion and contraction over a wide temperature range. These elements are then packaged into the final sensor configuration, the materials used here must also allow for free thermal expansion and contraction or additional strain can occur.

How to Reduce Repeatability Error

Since repeatability is controlled almost exclusively by the design and manufacture of the PRT, the best way to reduce repeatability error is to select a high quality PRT that has a low specified repeatability. When selecting a PRT, the repeatability must be considered for the maximum temperature range of use, not necessarily the maximum rated temperature range of the PRT itself since many PRTs are not used over their maximum rated ranges. Never expose PRTs to temperatures in excess of their maximum rated temperature, or less than their minimum rated temperature, without consulting with the manufacturer first to determine the effect on repeatability.

As mentioned in Part 1 on Interchangeability, using a transmitter with “matching” capabilities can nearly eliminate interchangeability error and a similar statement can be made about the repeatability error. Periodic calibration of the PRT and transmitter system can allow a transmitter to be matched to the newly characterized R vs. T relationship of the PRT. This can “calibrate out” some of the change in the PRT that occurred due to long term repeatability, however, the short term repeatability error will still be present. Recall from Figure 4-1 that the repeatability over the first few cycles can be a significant amount when the temperature range is large enough.

Summary

There are many sources of error that affect the performance of a PRT. One of these sources is Repeatability, the ability of a PRT to maintain its R vs. T relationship after experiencing thermal cycling throughout a specified temperature range. The most prominent source of non-repeatability is strain in the sensing element caused by thermal expansion and contraction. The best way to reduce repeatability error is to select a high quality PRT that has a low specified repeatability over the temperature range of use, and not to expose the PRT to temperatures outside of its’ maximum rated range. Matching a transmitter to a PRT and periodically calibrating the system to adjust for changes can reduce, but not eliminate repeatability errors.

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