Measuring resistors and their representation in IEC and ASTM

Comparing apples and oranges?

Within the process industry, two basic types of measuring resistors are used for electrical temperature measurements: wire-wound and film. Their different behaviour is reflected in the provisions of the European IEC 60751 (DIN EN 60751) standard, while the American ASTM E1137/E1137M treats the two types of resistors equally. This leads to confusion among users.

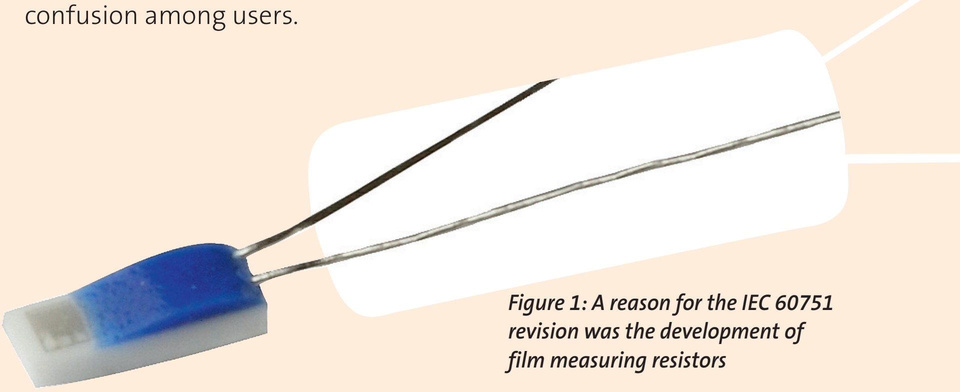

Figure 1: A reason for the IEC 60751 revision was the development of film measuring resistors

The IEC 60751 standard leaves no room for interpretation. It lists the tolerance classes with their temperature ranges separately according to the nature of the measuring resistor. The basic values indicated in the standard, the formulae for the permissible tolerance values and the test requirements apply to both types.

This detailed information has been present in the standard since 2008. The original EN 43760 standard from 1954 and its successors, from IEC 751 up to DIN EN 60751 in 1996, were developed on the basis of experience with wire-wound measuring resistors. Up to the revision of the standard, temperature ranges and class accuracies depended exclusively on the behaviour of wound platinum wires, which – embedded in ceramic or glass – change their resistance value as a function of the temperature.

The most important information, laid down as formulae and tables, was very clear. It included the basic values from -200 to +850°C, calculated using polynomials, as well as two tolerance classes (A and B) and the associated temperature ranges -200 to +650 °C (class A) and -200 to +850 °C (class B).

Over the course of time, knowledge about the physical effects that occur in the sensor platinum at higher temperatures over longer periods expanded considerably. It therefore became necessary to adapt the standard to take account of the drift behaviour of measuring resistors so that it corresponds to reality. A further reason for the revision was the development of film measuring resistors (Figure 1) – also known as thin-film or flat measuring resistors or even chips for short – and their rapid market penetration.

Focus on thin film resistors

This sensor type was not explicitly mentioned in the previous editions of IEC 60751: 2008 (DIN EN 60751: 2009). Users were therefore unsure whether the standard also applied to these new, cost-effective and exceptionally vibration-proof measuring resistors. In particular, the specification of the temperature ranges suggested that film measuring resistors could be used at the same temperature limits and with the same accuracies as wire-wound resistors. In reality, however, film measuring resistors behave differently to their wire-wound counterparts due to stretching and shrinkage effects as well as to the diffusion of foreign atoms into the thin platinum layer. The result is a characteristic curve which leaves the standard range of permissible measuring deviations at low and high temperatures earlier than it is the case with wire-wound measuring resistors (Figure 2). This behaviour physically arises as a result of the design and the materials used and must not be

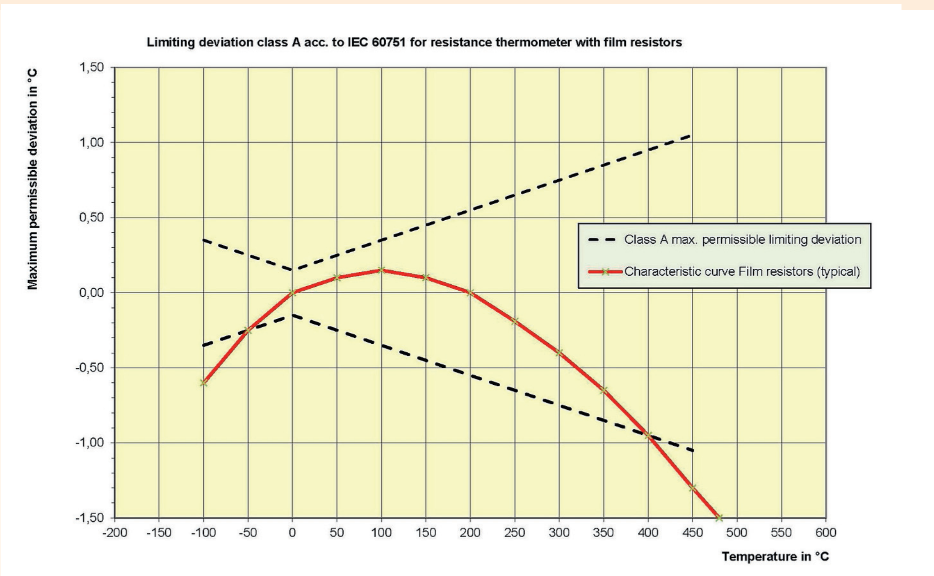

Figure 2: Characteristic curve of a standard film measuring resistor

Author

Joachim Brückner
Product Manager Electrical Temperature Measurement,
Wika Alexander Wiegand

Tolerance class	Temperature range of validity		Tolerance values *
	Wire wound resistors	Film resistors	
AA	-50...+250 °C	0...+150 °C	± (0,1 + 0,0017 |t|)
A	-100...+450 °C	-30...+300 °C	± (0,15 + 0,002 |t|)
B	-196...+600 °C	-50...+500 °C	± (0,3 + 0,005 |t|)
C	-196...+600 °C	-50...+600 °C	± (0,6 + 0,01 |t|)

* |t| = modulus of temperature in °C without regard of sign

Figure 3: Table 3 of the current IEC 60751:2008

understood as a quality deficiency. The graph shows the typical characteristic curve of a standard film measuring resistor.

In view of this finding, it was only logical to separate the temperature ranges of the various tolerance classes into wire and film measuring resistors. In addition, the tolerance classes were more clearly differentiated. The current IEC 60751:2008 (DIN EN 60751:2009-05) shows four classes in Table 3 (Figure 3).

Amended version of IEC 60751

In conjunction with the amended version, the K961 standards committee of the German Commission for Electrical, Electronic and Information Technologies (DKE) initiated a cross-company analysis. This confirmed that the above characteristics of film measuring resistors occur generally and are not manufacturer-specific. In addition, the study included new types of film measuring resistors that behave similarly to wire-wound sensors, even below -30 and above +300 °C – although not over their complete temperature range. The tests have thus underlined the direction in which the development of film measuring resistors will head. However, the new generation of film resistors is more expensive than the standard versions.

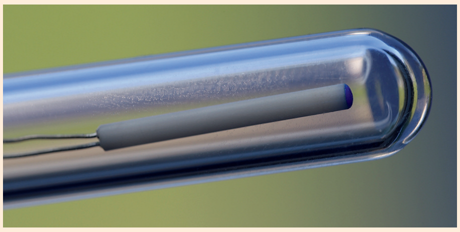

Figure 4: The component/type tests are carried out in high-purity quartz glass and with controlled air supply

The updated IEC 60751 contains yet another differentiation which has not previously been made: between the bare measuring resistor and the assembled resistance thermometer. The reasons for this are easy to see. Measuring resistors are checked by their manufacturers during production and/or under laboratory conditions. The necessary component and type tests are carried out in high-purity quartz glass with a controlled air supply (Figure 4).

For example, in a type test, the sensor must first be heated to its upper temperature limit (aged) for 1000 h. It must then, at 0 °C, not

leave the maximum permissible tolerance range for the specified tolerance class.
With thermometers, the measuring resistor is usually embedded in magnesium or aluminium oxide powder (MgO or Al_2O_3), which in turn is enclosed within a metal sleeve or a metallic sheath. Above approximately 600 °C these materials tend to poison the platinum of the sensor. This unwanted effect is temperature-dependent and increases as the temperature rises. The sensor can also be subjected to mechanical forces through thermal expansion. Against this background, the authors of IEC 60751 have defined a stability check within the framework of the prescribed type test, according to which a thermometer is considered to be thermally safe in operation. The duration of the test at the specified maximum temperature is set at 672 h (four weeks). As is also demanded for measuring resistors, the thermometer must subsequently stay within the maximum permissible tolerance range at 0 °C for the specified tolerance class.
All changes made in IEC 60751:2008 compared to the previous editions are based on findings from research and practice. The updated standard therefore aligns with requirements arising from the actual operational safety of measuring resistors and thermometers which are manufactured in accordance with it.

ASTM E1137/E1137M 2014		IEC 60751:2008					
no info		Wire wound			Film resitors		
Grade A	Grade B	Class AA	Class A	Class B	Class AA	Class A	Class B
-200 +650	-200 +650	-50 +250	-100 +450	-196 +600	0 +150	-30 +300	-50 +500

Figure 5: IEC 6075:2008 and ASTM E1137/E1137M 2014 in comparison

ASTM standard not amended

For users in countries where the ASTM (American Society for Testing and Materials) standards apply, there has been a lot of confusion since the IEC update. All the factors that led to the above-mentioned amendments to the European standard continue to be ignored by the corresponding ASTM guidelines E1137/E1137M. Even in its re-examination in 2014, the responsible subcommittee E20.03 saw no need to adapt to reality. ASTM E1137/E1137 M (reapproved 2014) fails to differentiate between wire-wound and film measuring resistors. Furthermore, it is imprecise in terms of the stability test temperatures: it prescribes the test at 0 °C but simultaneously points to ASTM E644, which requires two test temperatures. ASTM E1137/E1137 M still operates with two tolerance classes (grade A and grade B), both defined in a temperature range from -200 to +650 C°, regardless of the sensor design.
The difference between the two standards is illustrated in Figure 5. At first sight, simply comparing the figures could lead to the conclusion that all ASTM-compliant thermometers are better than IEC-qualified instruments since, according to the standard, they can be used in a wider temperature range. This has, in some cases, even led to the use of the ASTM data as a sales argument.
The desire for a higher tolerance class is also present in those countries where ASTM prevails. Here, sensor manufacturers and customers interestingly fall back on the so-called “DIN fractional classes” such as 1/2 DIN B or 1/3 DIN/IEC up to 1/10 DIN/EC, which are also used in Europe. However, this information on accuracy is not standardised. For one thing, the different spellings employed (DIN B, ... DIN A, ... DIN/IEC, ... DIN/EC) suggest that each manufacturer can consider his own interpretation of these “class accuracies” as the right one. The publication of IEC 60751:2008 has at least made the 1/3 DIN specification unnecessary, as its requirements are contained in class AA of the standard. Since then, in the day-to-day business of the “IEC world”, 1/3 DIN has actually only played a minor role. Owing to the lack of a normative basis in the ASTM regions, manufacturers and customers are reliant on close communication when “fractional classes” are used, in order to avoid misunderstandings regarding accuracy requirements. The example of the Mars Climate Orbiter shows how important this exchange can be in practice. It was lost in 1999 because NASA and Lockheed Martin used units from different measuring systems to calculate the braking pulse.
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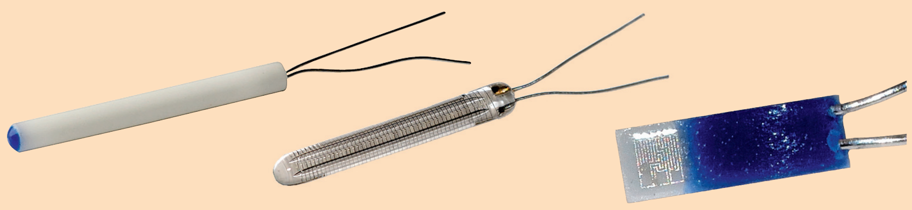
SHORT REVIEW

Measuring resistor designs

- Ceramic measuring resistors have a platinum helix inside them which is embedded in ceramic powder or compound. This only offers a small amount of mechanical resistance to the platinum wire in case of temperature changes. The sensor thus has a certain freedom of movement. This design prevents drift due to mechanical forces but at the same time restricts the vibration resistance.
- Glass measuring resistors have a platinum wire that is firmly embedded in the glass casing. This results in a mechanical limitation at high temperatures, which alters the resistance owing to the different thermal expansion coefficients of glass and platinum. The importance of this type of resistor for the process industries is decreasing.
- Film measuring resistors, also referred to as thin-film or flat measuring resistors, have a ceramic carrier plate to which a very thin platinum layer is applied. The platinum layer and connecting wire junctions are sealed against external influences by a glass layer. These measuring resistors are characterised by high vibration resistance, very small dimensions and good value for money.



Ceramic (left), glass (centre) and film (right) measuring resistors