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Development and Characterization of a Surface Probe Calibration System at NIS.

Abstract :

This paper presents the development and characterization of a dedicated calibration system for surface temperature probes over the temperature range from 50 °C to 300 °C. The system was developed at the National Institute for Standards (NIS) to improve the traceability and reliability of surface temperature measurements. The calibration setup is based on a precision-machined aluminum plate combined with a flat spiral heater to ensure uniform heat distribution. The system performance was evaluated in terms of temperature stability, temperature in-homogeneity, and agreement with a calibrated reference thermocouple. The results demonstrate that the system achieves high stability, ranging between ± 0.1 °C and ± 0.2 °C, while temperature in-homogeneity is limited to values between 0.2 °C and 0.5 °C across the investigated range. A comprehensive uncertainty analysis was carried out considering all significant sources of uncertainty. The expanded uncertainty ($k = 2$) was found to range from ± 0.3 °C to ± 0.6 °C over the operating temperature range. The developed system provides a reliable, traceable, and practical solution for surface temperature probe calibration, representing an improvement over conventional calibration method.

Key words:-

Surface probe calibration, Temperature measurement, Homogeneity, Uncertainty

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1. Introduction

Surface temperature sensors are widely used in industrial, medical, and environmental applications, where accurate and traceable temperature measurements are essential. However, conventional calibration methods for surface temperature probes often face limitations related to temperature stability, repeatability, and restricted temperature ranges [1,2].

Several studies have addressed the calibration of surface temperature sensors using different techniques and reference systems. Contact calibration methods based on flat plates and embedded sensors have been widely used in dimensional metrology and industrial applications [1,2]. Other approaches have focused on improving thermal contact and minimizing heat losses to enhance measurement accuracy. Despite these efforts, conventional calibration systems still suffer from several limitations, including non-uniform temperature distribution, instability over time, and limited traceability. In addition, many systems operate over a restricted temperature range and do not provide a comprehensive uncertainty evaluation in accordance with international standards.

Conventional calibration systems for surface temperature probes often suffer from several limitations, including poor thermal contact, non-uniform temperature distribution, limited stability over time, and restricted operating temperature ranges. In many cases, these systems also lack a comprehensive uncertainty evaluation in accordance with international standards, which reduces the reliability and traceability of measurements.

In this work, a dedicated calibration system has been developed at the National Institute for Standards (NIS) to overcome these limitations. The proposed system provides improved temperature stability, reduced temperature inhomogeneity, and a well-defined uncertainty budget in accordance with international standards. Furthermore, the system covers a wide temperature range from 50 °C to 300 °C, making it suitable for various industrial and metrological applications. Compared to conventional calibration systems, the developed system demonstrates improved temperature stability, reduced in-homogeneity, and enhanced measurement reliability. This work therefore presents a practical and traceable calibration methodology with improved performance.

Compared to previously reported calibration systems, which often suffer from limited temperature stability (typically ± 0.5 °C or higher) and non-uniform temperature distribution, the developed system demonstrates improved performance. The proposed system achieves enhanced temperature stability (± 0.1 – 0.2 °C), reduced inhomogeneity (0.2–0.5 °C), and a wider

46 operating range (50–300 °C). These improvements provide a more reliable and traceable solution for surface temperature probe
47 calibration.

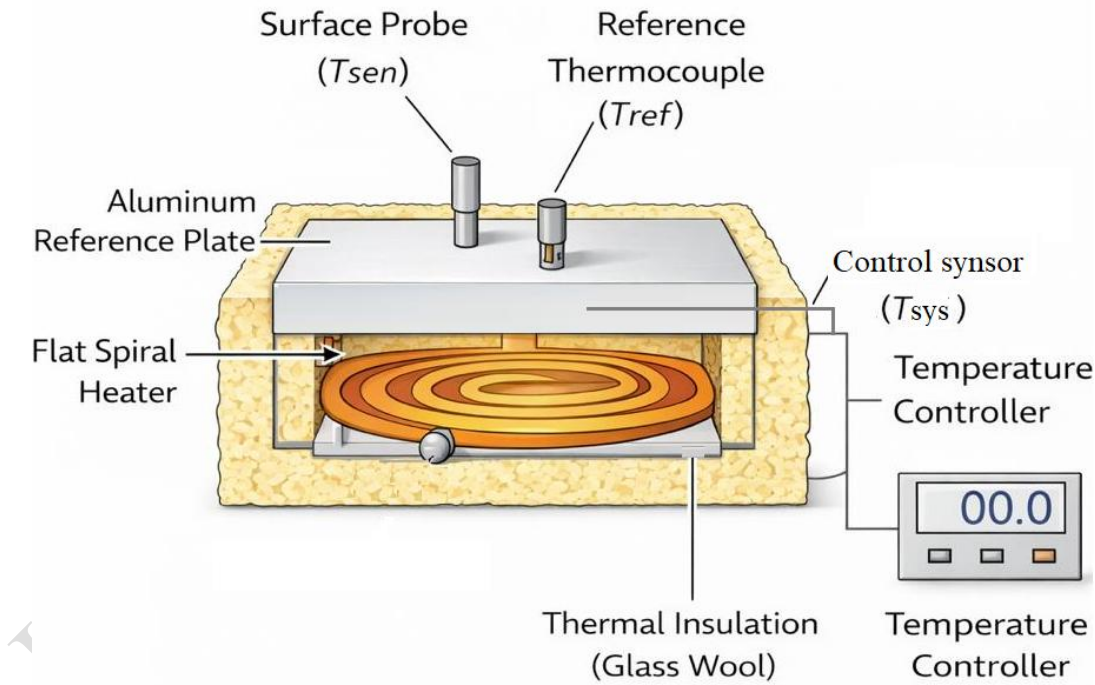
48 2. Experimental Setup

49 A schematic diagram of the NIS surface probe calibration system is shown in Fig. 1. The system is specifically designed for
50 the calibration of surface-mounted temperature probes. The aluminum reference plate used in the system has approximate
51 dimensions of 50 mm × 50 mm × 10 mm, providing a sufficiently large and uniform surface for probe placement. The heating
52 element consists of a flat spiral heater with a power rating of approximately 200 W, mounted beneath the plate to ensure uniform
53 heat distribution. The internal control sensor is positioned directly below the center of the plate to regulate the system temperature
54 accurately. The reference thermocouple used in this study is a Type K thermocouple with an accuracy of ±0.1 °C, calibrated and
55 traceable to national standards at NIS. It is mounted in direct contact with the surface, with a flattened junction positioned flush
56 with the plate surface to ensure accurate measurement of the true surface temperature.

57 To minimize heat conduction errors, the thermocouple wires are arranged horizontally along the surface for a minimum distance
58 of 10 mm before being routed away. A thin layer of thermal paste is applied to improve thermal contact. The measurement region
59 is thermally insulated using glass wool to reduce heat losses due to convection and radiation.

60 The reference thermocouple and the surface probe under calibration are positioned in close proximity and at the same radial
61 distance from the center to minimize the effect of surface temperature inhomogeneity.

62 Uniform heat distribution across the surface is achieved using the flat spiral heater clamped to an integrating block beneath the
63 surface plate. The internal control sensor ensures accurate temperature regulation. The calibration system operates over a
64 temperature range from 50 °C to 300 °C.



65
66 Fig. 1. Schematic diagram of the developed surface probe calibration system showing the aluminum reference plate with embedded
67 reference thermocouple (T_{ref}) and horizontally embedded control sensor (T_{sys}), surface probe (T_{sen}), flat spiral heater, and surrounding
68 thermal insulation (Glass wool)

69 3. Results and Discussion

70 To investigate the efficiency of the system, a series of tests were performed throughout the operating temperature
71 range. The system performance was evaluated through the following parameters [3]:

- 72 • The temperature difference between the system temperature (T_{sys}) and the temperature measured by the
73 reference thermocouple on the surface (T_{ref}).
- 74 • Comparison between the reference thermocouple and the calibrated surface probe.
- 75 • Temperature stability over time.
- 76 • Monitoring temperature variations across different positions on the reference surface using a calibrated
77 reference thermocouple.

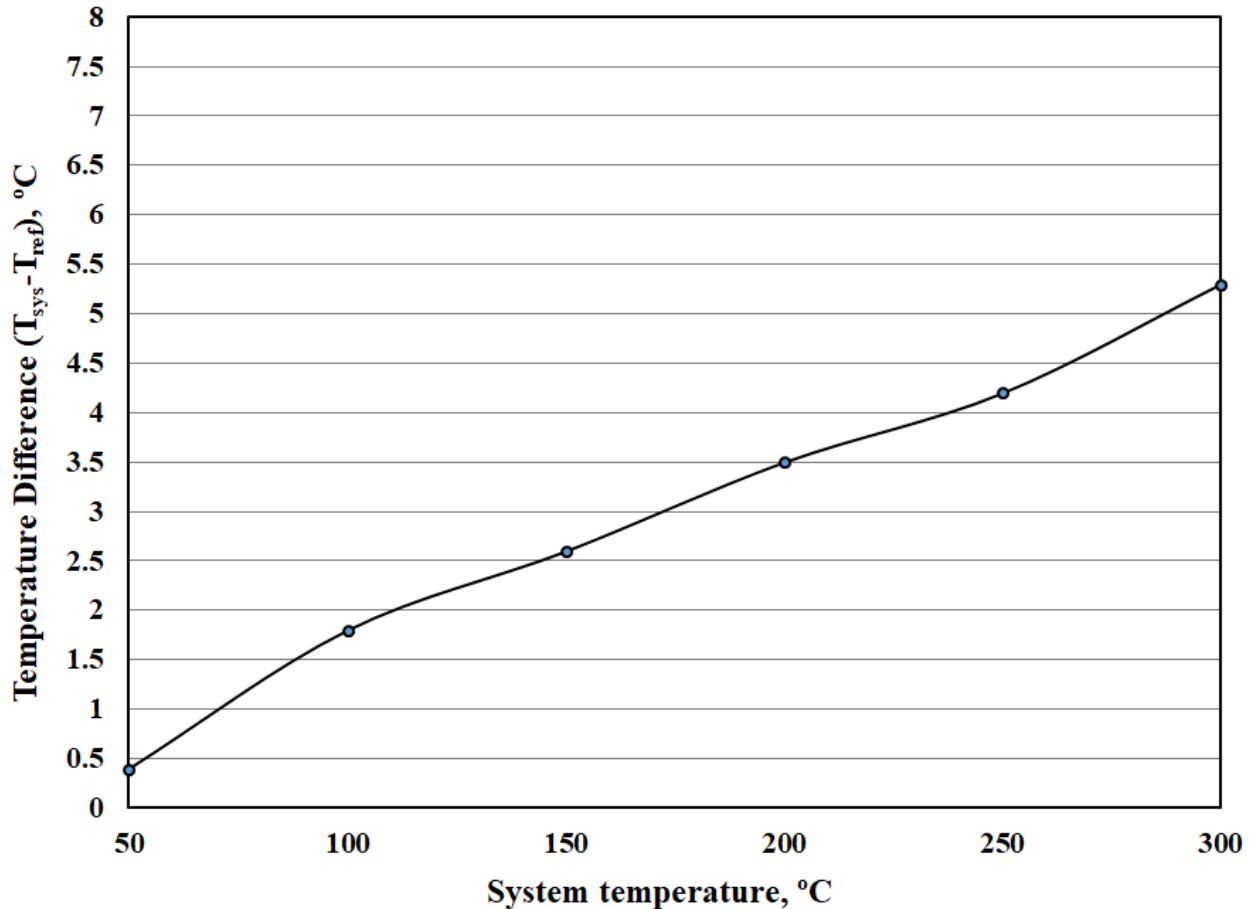
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79 3.1 Temperature Difference between System and Surface

80 The temperature difference between the system temperature (T_{sys}) and the temperature measured by the reference
81 thermocouple on the surface (T_{ref}) is shown in Fig. 2. These measurements were obtained using two sensors: the internal
82 control sensor located beneath the reference surface (T_{sys}) and a reference thermocouple placed directly on the surface
83 (T_{ref}). The results show that the temperature difference remains small across the investigated range, indicating good agreement
84 between the system control and the actual surface temperature.

85 This small temperature difference indicates good agreement between the system control temperature and the actual surface
86 temperature, confirming effective heat transfer and accurate system regulation.

87 This behavior indicates efficient heat transfer between the heating system and the surface plate, as well as accurate
88 temperature control by the internal sensor.



89

90

91 **Fig. 2. Temperature difference(°C) between system temperature (T_{sys}) and surface temperature (T_{ref}) as a function of system temperature**
92 **(°C),demonstrating system accuracy.**

93

94

95 **3.2 Temperature Stability**

96 Temperature stability was evaluated by recording temperature variations over a period of at least one hour after steady-
97 state conditions were achieved. For each temperature point, at least 30 measurements were recorded at constant time
98 intervals. Stability measurements were conducted at the center of the surface for each temperature set point [4].
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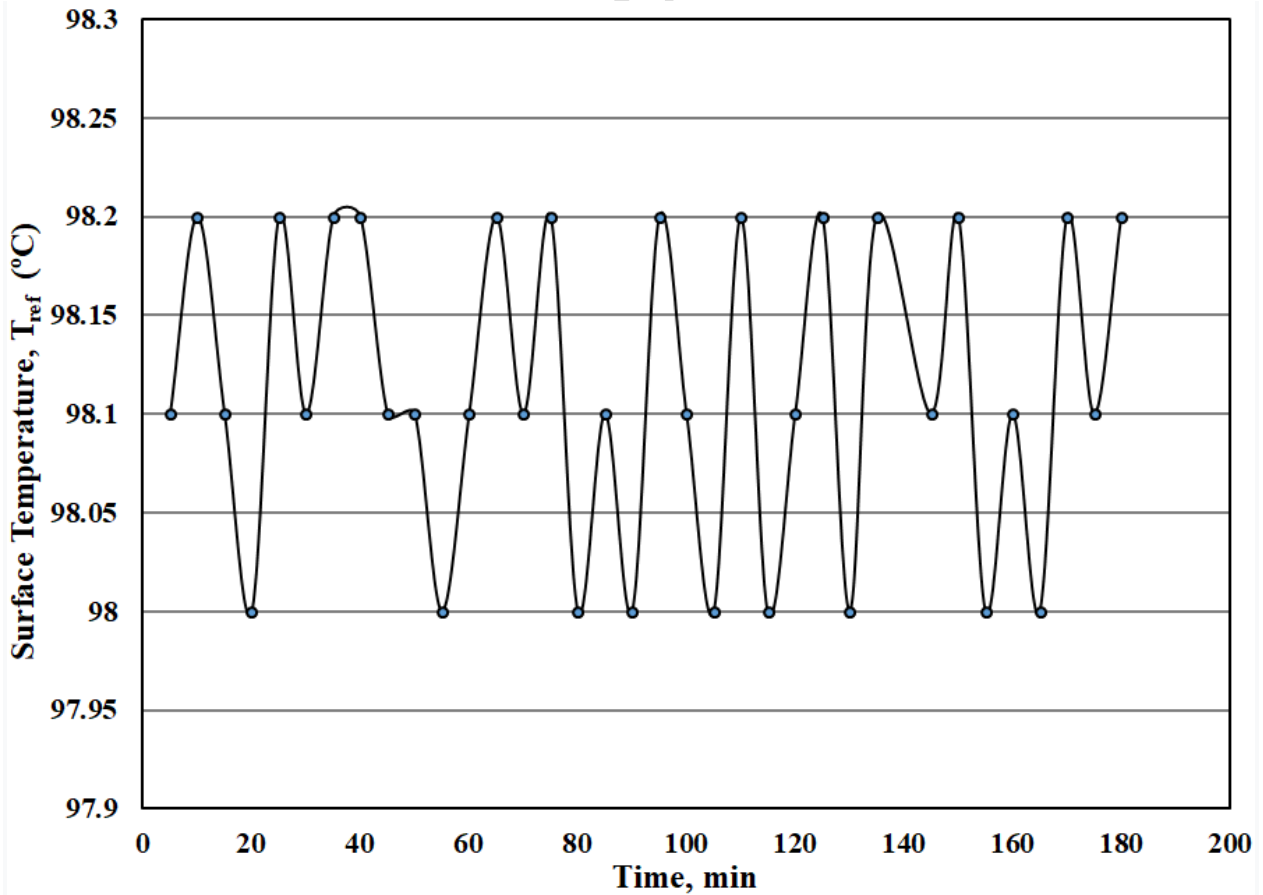
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101 An example of temperature stability measurements at 100 °C is shown in Fig. 3. The temperature stability of the
102 system, measured using the reference thermocouple, was found to be ± 0.2 °C. Over the full temperature range from 50 °C
103 to 300 °C, the stability was found to lie between ± 0.1 °C and ± 0.2 °C.

104 The system demonstrates high stability, with temperature fluctuations limited to approximately ± 0.2 °C at 100 °C. Similar
105 behavior was observed across the full temperature range, confirming the reliability of the system.

106 This high level of stability can be attributed to the uniform heat distribution provided by the flat spiral heater and the effective
107 thermal insulation, which minimize heat losses and external disturbances.

108



109

110 Fig. 3. Temperature stability at 100 °C showing temperature variation (°C) as a function of time (minutes), demonstrating system
111 stability under steady-state conditions.

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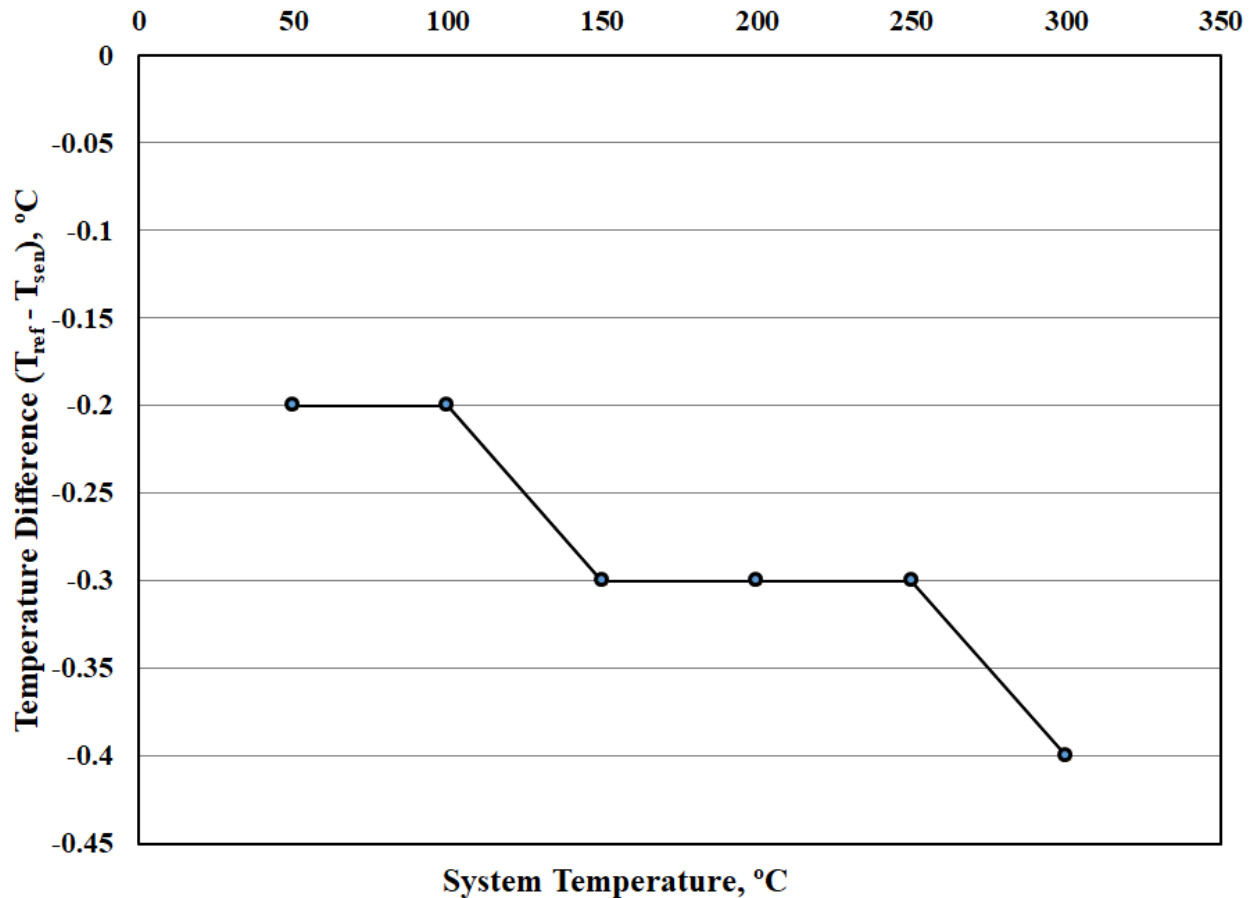
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115 3.3 Comparison between Reference Thermometer and Surface Probe

116 Measurements obtained from the reference thermometer (T_{ref}) were recorded simultaneously with those of the calibrated
117 surface probe (T_{sen}).

118 The comparison results are presented in Fig. 4, where the observed temperature difference, ranging from 0.2 °C to 0.4 °C,
119 indicates reasonable agreement between the reference thermocouple and the calibrated surface probe. This level of agreement
120 confirms the reliability of the developed calibration system. The difference remains relatively consistent over the investigated
121 temperature range, indicating stable system performance.

122 The small deviations can be attributed to differences in thermal contact between the probe and the surface, as well as the response
123 characteristics of the sensors. In addition, slight positioning differences and local temperature gradients may also contribute to the
124 observed variations.



125

126 Fig. 4. Temperature difference (°C) between the reference thermocouple (T_{ref}) and the calibrated surface probe (T_{sen}) as a function of
127 system temperature (°C), showing good agreement and small deviations between both sensors.

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129 3.4 Temperature In-homogeneity

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131 Temperature in-homogeneity was evaluated by measuring the reference thermometer output at different positions on the
132 surface plate. The measurement points on the flat surface of the calibration system are shown in Fig. 5. The distances from
133 the center were varied from 1 cm to 2 cm in both horizontal and vertical directions.
134

134

135 The temperature in-homogeneity was determined as the maximum deviation between the temperature measured at the
136 center (T_{center}) and that measured at other positions (T_{corner}), according to:

137

$$138 \text{In-homogeneity} = 0.5 \times (\max(T_{\text{center}} - T_{\text{corner}}) - \min(T_{\text{center}} - T_{\text{corner}})) \quad (1)$$

139 This approach is commonly used in surface temperature measurements to evaluate spatial temperature variation and
140 provides a practical representation of temperature uniformity across the surface.

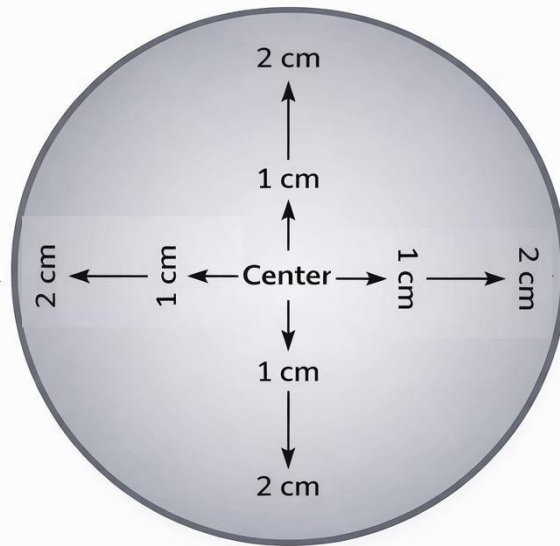
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142 The measured temperature in-homogeneity values were found to range from 0.2 °C to 0.5 °C.

143

144 The results of these tests indicate that the system efficiency is adequate for operation within the temperature range from 50
145 °C to 300 °C [5].

146 The observed in-homogeneity is mainly influenced by edge heat losses and radial temperature gradients across the plate
147 surface.



148

149 Fig. 5. Measurement positions on the aluminum reference plate for evaluating temperature in-homogeneity at radial
150 distances of 1 cm and 2 cm from the center.

151 Additional measurements were performed at representative temperature points, including 50 °C, 150 °C, 200 °C, and 300 °C. The
152 results showed consistent performance across the full temperature range.

153 Overall, the system maintains temperature stability within ± 0.1 °C to ± 0.2 °C, while temperature in-homogeneity is limited to
154 values between 0.2 °C and 0.5 °C, demonstrating high performance and reliability.

155

156 **3. Uncertainty of measurement**

157 **4. Uncertainty of Measurement**

158 The uncertainty budget of the developed calibration system was evaluated in accordance with the ISO/IEC Guide 98-
159 3 (GUM). All significant sources of uncertainty were identified and quantified.

160 The uncertainty of the reference thermocouple (U_{st}) was obtained from its calibration certificate. The resolution
161 uncertainty (U_{res}) is associated with the measurement system. The stability component (U_{stab}) was determined from
162 repeated measurements under steady-state conditions.

163 The temperature inhomogeneity (U_{hom}) was evaluated based on spatial variations across the surface, while hysteresis (U_{hys})
164 was determined from heating and cooling cycles. The repeatability component (U_{rep}) was evaluated statistically and
165 considered as Type A uncertainty.

166 Each component was divided according to its probability distribution, and the combined uncertainty was calculated using
167 the root-sum-square method. The expanded uncertainty was obtained using a coverage factor of $k = 2$, corresponding to a
168 confidence level of approximately 95%. The results indicate that the dominant contributions arise from temperature
169 inhomogeneity and system stability.

170 The expanded uncertainties were found to range from ± 0.3 °C to ± 0.6 °C over the temperature interval from 50 °C to 300
171 °C [6].

172 Table 1 presents an example of the uncertainty budget calculated at 100 °C, where the expanded uncertainty was ± 0.3 °C
173 using a coverage factor of $k = 2$.

174

175 Table 1. Uncertainty budget at 100 °C for the surface probe calibration system

Symbol	Source uncertainty	Value	Divisor	Sensitivity coefficient	Uncertainty contribution
U_{st}	Uncertainty of reference	0.1	2	1	0.015
U_{res}	Resolution	0.1	3.46	1	0.003
U_{stab}	Stability of the system	0.2	3.46	1	0.057713
U_{hom}	In-homogeneity of the system	0.2	1.73	1	0.1155
U_{hys}	Hysteresis	0.1	1.73	1	0.0577
U_{rep}	Repeatability (<i>Type A</i>)	0.05	1	1	0.05
Combined U_n .			0.149		
Expanded U_n .			± 0.3 °C		

176 **Conclusion:**

177 **5. Conclusion**

178 A dedicated calibration system for surface temperature probes has been successfully developed and characterized at the National
179 Institute for Standards (NIS). The system demonstrated reliable performance over the temperature range from 50 °C to 300 °C.
180 The results confirm high temperature stability (± 0.1 °C to ± 0.2 °C) and low temperature inhomogeneity (0.2 °C to 0.5 °C). The
181 uncertainty analysis shows expanded uncertainties ranging from ± 0.3 °C to ± 0.6 °C ($k = 2$).

182 The developed system provides a practical, reliable, and traceable solution for calibration laboratories and industrial applications,
183 with potential for further improvement and extension to higher temperature ranges. Overall, this work demonstrates the capability
184 of the proposed system as an effective calibration tool for surface temperature measurements in both industrial and metrological
185 fields.

186 **References**

- 187 1- Estiak Ahmed Turzo, Calibration of Contact Surface Thermometers, November 2018,39:15International Journal
188 of Thermophys
- 189 2- F Yebra, H Gonzalez-Jorge ' 1, L Lorenzo, M Campos, J Silva, F Troncoso and J Rodr'iguez, Procedure for the
190 calibration of surface temperature sensors used in dimensional metrology, Metrologia 44 (2007), 217–221.
- 191 3- Doaa Mohamed Abd El-Gelil* and Mohamed Gamal Ahmed, Extending dew-point temperature scale up to +50
192 °C
Int. J. Metrol. Qual. Eng. Volume 9, 2018. 193
- 194 4- L. Michalski, K. Eckersdorf, J. Kucharski, J. McGhee, Temperature Measurement (Wiley, London,2002), pp.
195 333–360
- 196 5- Doaa Mohamed Abd El-Galil, Essam Mahmoud, Testing the reliability of humidity generator through
197 measurements traceable to calibration standards, Measurement, Volume 124, August 2018, Pages 159-162
- 198 6- ISO/IEC Guide 98-3:2008, uncertainty of measurement – part 3: guide to the expression of uncertainty in
199 measurement (GUM, 1995) [Google Scholar].

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