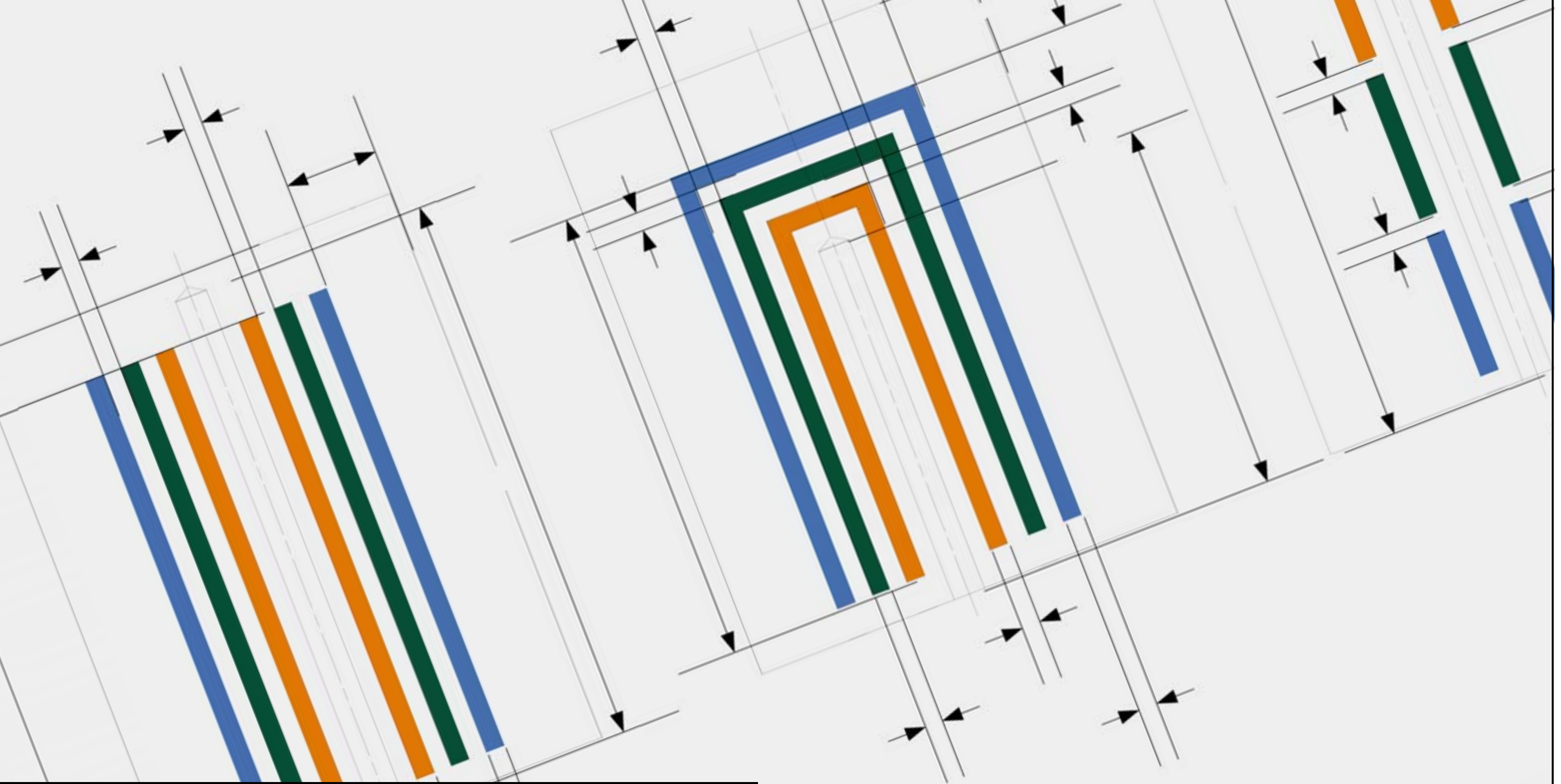

CASE STUDY // PROCESS ENGINEERING

OPTIMIZATION OF A MULTIPLE FIXED-POINT CELL AS A REFERENCE IN A DRY BLOCK CALIBRATOR

The thermal and geometrical designs of a multiple fixed-point cell could be optimized for an improved in-situ calibration by means of optiSLang and thermal simulations in ANSYS.

Introduction

Temperature sensors for industrial applications are usually calibrated by comparison with reference thermometers in thermostats or dry block calibrators. At the Institute for Process Measurement and Sensor Technology of the Technische Universität Ilmenau, a new dry block calibrator was designed with the aim of performing calibrations by comparison reaching an uncertainty less than the one currently reached with the existing dry block calibrators.

An important part of this novelty calibrator is the inclusion of a multiple fixed-point cell. Inside, it has three pure materials, indium (T_{ph}=156.5985°C), tin (T_{ph}=232.928°C) and zinc (T_{ph}=419.527°C), called fixed-point materials. They have their fixed-point temperature Tph (Melting and Freezing temperature) within the work range of the dry block calibrator from 20°C to 600°C. These temperatures are reproducible with an uncertainty of some millikelvin and they are defined in the International Temperature Scale from 1990 (ITS-90). In the case of the dry block calibrator, the fixed-point materials allow an in-situ calibration of the block calibrator internal reference sensor at their phase change temperatures. Thus, the calibration values are traceable to the ITS-90. The cell was designed by the Finite Element Method in ANSYS Workbench and optimized by parametrical variations in optiSLang.

Geometrical Design

For the design of the multiple fixed-point cell, three different geometries with coaxial arrangement of the fixed-point materials were used as models. For each model, some geometrical parameters (a to h, Fig. 1), according to the calibrator's geometry were defined. The position of each material in the cell also varied (in, ctr, out, Fig. 1). Graphite was selected as the crucible material of the cell. This material is commonly used for the fixed-point cells due its high thermal conductivity, its chemical compatibility with the fixed-point materials and its good ability for the machining.

Thermal Design

The main goal of the cell's design was to find a geometry and an arrangement of the fixed-point materials inside the cell having minimal thermal gradients in the cell and in the reference sensor during the change of a fixed-point material phase. In the ideal case, the reference sensor temperature is exactly the same as the phase change temperature of each fixed-point material. Focusing on this objective, static thermal simulations were made in three steps. In each step, it was assumed that every fixed-point material was at its fixed-point temperature, excluding the dry block calibrator , which was 2K over it. Initially, the input parameters were searched by conducting a sensitivity analysis. They have an influence on the output parameters that permit to estimate the quality of the temperature distribution, called $\Delta\vartheta T$. These output parameters were defined as the sum of the maximum temperature gradients in the cell for each phase change:

$$\Delta\vartheta_T = (\vartheta_{max} - \vartheta_{min})_T = (\vartheta_{max} - \vartheta_{min})_{In} + (\vartheta_{max} - \vartheta_{min})_{Sn} + (\vartheta_{max} - \vartheta_{min})_{Zn}$$

$\Delta\vartheta T$ = Sum of the maximal temperature difference on the cell for each fixed-point / °C | ϑ max = Maximum temperature of the cell / °C | ϑ min = Minimum temperature of the cell / °C

p	Model 1 CoP %	Model 1 iv	Model 1 op	Model 2 CoP %	Model 2 iv	Model 2 ov	Model 3 CoP %	Model 3 iv	Model 3 ov
a / mm	28	23	13	6	23	20	14	13	25.3
e / mm	68	40	48.5	51	40	40	4	1	5
f / mm	5	5	3.25	9	5	3.25	47	15	4.9
i / mm	33	10	7	-	-	-	5	10	26.6
j / mm	-	-	-	-	-	-	5	3	1
in / °C	-	-	-	-	-	-	10	157	232
ctr / °C	5	232	232	2	-	-	10	232	157
out / °C	3	420	420	3	420	420	-	-	-
CoP fm / %		90			70			83	
ANSYS / mK		1620			1695			2562	
MOP / mK		1605			1803			2501	
rd / %		1			6			2	

Table 1: Selected geometrical and thermal parameters of each model after the sensitivity analysis with $\Delta\vartheta T$ as an output parameter and optimization results with p as an input parameter, iv as an initial value, op as an optimized value, fm as a full model, rd as a relative difference

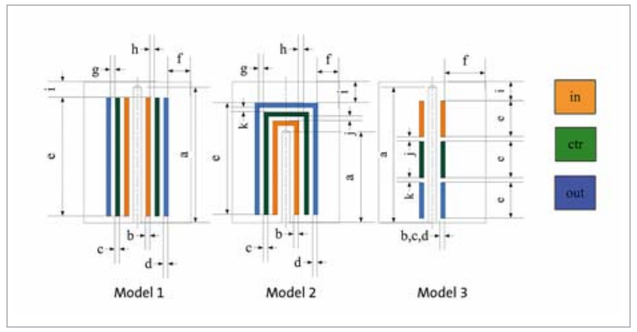

Fig. 1: Models with their fixed-point cell arrangements and parameters for the parametrical study

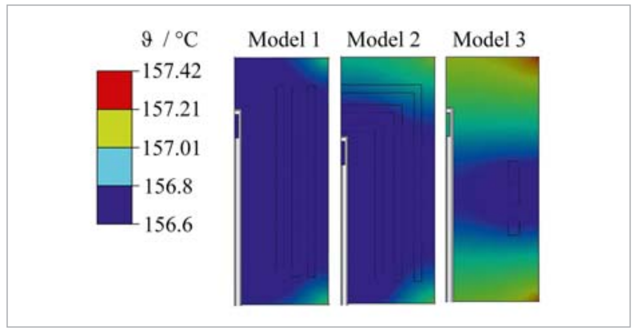

Fig. 2: Temperature field for the optimized models during indium´s phase change

Results

Table 1 shows the CoPs of the models and the input parameters which are relevant regarding the output parameter. It also shows initial and optimized values using an evolutionary algorithm. In addition, the calculated results in the MOP and in ANSYS, as well as their relative difference are shown. Here, it is possible to observe that a CoP of more than 70% was enough to obtain a reliable result. After the optimization, it was discovered that model 1 of the multiple fixed-point cell was the best for the desired application. Fig. 2 shows the temperature distribution of the three models along with the phase change of Indium. It is possible to see that the temperature distribution for the model 1 is the most homogeneous. Similar results of temperature distributions were obtained for the phase changes of tin and zinc.

Summary

A multiple fixed-point cell for an in-situ calibration of a new block calibrator's reference sensor was designed which is traceable to the ITS-90. This was possible by conducting finite element thermal simulations in ANSYS Workbench and a sensitivity analysis and optimization in optiSLang. The cell was designed with the aim to obtain the minimum thermal gradient during the phase changes of the fixed-point materials (In, Sn, Zn). An optimal cell's geometry and arrangement of the fixed-point materials inside could be found for this application.

Authors // S. Marin / Univ.-Prof. Dr.-Ing. habil. Th. Fröhlich (Institut für Prozessmess- und Sensortechnik, TU Ilmenau)

This material is based on the VIP-Project "TempKal" supported by the German Federal Ministry of Education and Research (BMBF).