Simulation eines kompakten Heiz-Kühl-Gerätes
Simulation of a compact heating-cooling desktop device

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Kurzfassung

In diesem Artikel wird ein elektrisch-thermisches Simulationsmodell eines kompakten Heiz-Kühl-Gerätes für das energieeffiziente Temperieren kleiner Prüflinge vorgestellt. Zum Simulieren dient das Programm SimulationX 3.3. Im Detail wird dabei auf die Modellierung des nichtlinearen Verhaltens des Peltierelements und des Kühlkörpers eingegangen. Anhand des Modells kann mit geringem Zeitaufwand das Verhalten des Heiz-Kühl-Gerätes unter veränderten Leistungs- und Umgebungsbedingungen berechnet werden.

Abstract

In this paper, a thermo-electric model for the simulation of a heating-cooling desktop device, which regulates the temperature of small items energy-efficient, is presented. The program SimulationX 3.3 is used for the simulation. In particular, attention was paid to the non-linear behaviour of the Peltier element and the heatsink. With this model, it is possible to predict the behaviour of the heating-cooling desktop device, even under changing power requirements or ambient conditions.

Introduction

Thermostatic chambers are used in many enterprises and scientific institutes in order to specify the functional parameters of semiconductor devices and electronic assemblies. Typical chambers allow tempering of test items with a volume of several litres. Mostly, they have a size of a big refrigerator and require a lot of floor space. In the domain of semiconductor technology the devices under test (DUT) are much smaller. Often they only have a capacity of a few cubic centimetres. The ratio between the energy used for the process of heating or cooling the DUT and that needed by the chamber itself is unfavourable. Because of the large volume and the large thermal mass of the thermostatic chamber, tempering to the required

temperature demands much electrical power. Common measurement cycles can last for several days or weeks, and therefore require a great deal of energy. Hence, the operating expenses are a non-marginally cost factor. For this reason, a compact heating-cooling desktop device for energy efficient tempering of small items would be desirable. Because such a device was not available on the market, a small heating-cooling desktop device based on Peltier elements was developed at the Institute of Electromechanical and Electronic Design of the Technische Universität Dresden. Compared to refrigerant compressors, it is a compact, quiet and mainte-nance-free alternative for tempering small items.

Through the usage of Peltier elements (also known as thermoelectric coolers; TEC) heat can be transported actively dependent on the supply current. Like many other semiconductor devices, they have non-linear thermo-electric properties. However, it is not possible to dimension such an assembly using only linear network equations. On the contrary, utilising a simulation system like SimulationX 3.3 a complete sys-tem model of the heating-cooling desktop device can be modelled.

Thermal-electric system model

The device consists of the main components such as contact plate, Peltier element and a heatsink (Figure 1). From this, a thermo-electric analogous model can be gra-dually deduced.
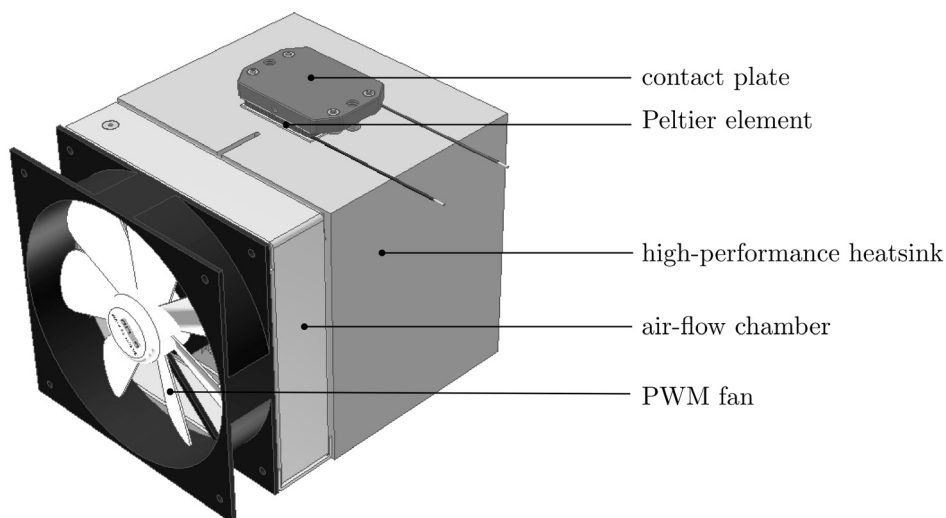

Figure 1: Mechanical assembly of heating-cooling desktop device

The DUT can be attached to the contact plate. This plate consists of copper and is the interface for the user. In the system model it is modelled as a simple thermal network consisting of a thermal resistance and a thermal capacity.

The main element of the heating-cooling desktop device is the Peltier element. Its function is the active heat transfer between contact plate and heatsink. For the complete heat transfer, three parameters are fundamentally important: the Seebeck coefficient $S_M(T)$, the electrical resistance $R_M(T)$ and the thermal conductivity $K_M(T)$ [1]. The active heat transfer from the hot to the cold side of the Peltier element

is based on the Peltier-effect. Due to the thermal conductivity $K_M(T)$ of the semi-conductor material, a certain amount of the transferred heat flows back again. Furthermore, power loss is produced due to the current flow through the electrical resistance $R_M(T)$. This Joule heat has an influence on both sides of the Peltier element. Figure 2 shows these effects schematically on the left-hand, on the right-hand the associated electric-thermical simulation model is depicted.
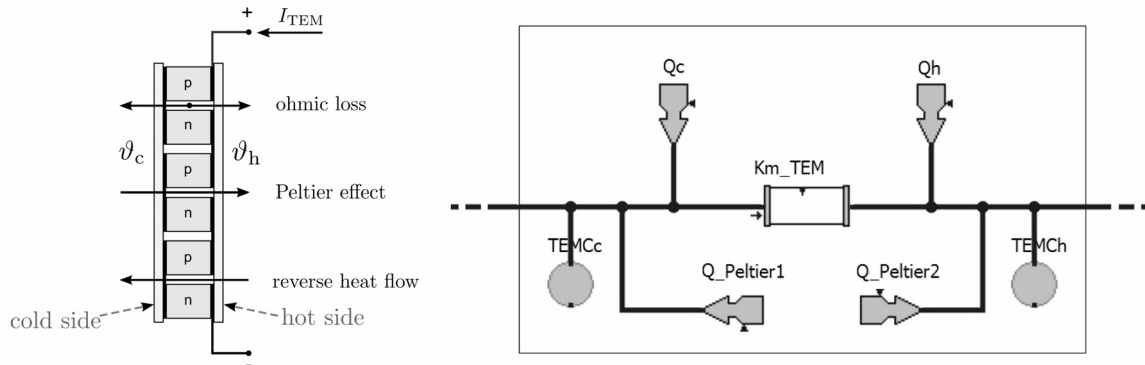

Figure 2: Scheme (l.) and model of the TEM in SimulationX (r.)

The effective overall transported heat flow from the cold side is therefore:

$$\dot{Q}_c(T) = S_M(T) \cdot T_c \cdot I_{TEM} - \frac{1}{2} \cdot R_M(T) \cdot I_{TEM}^2 - K_M(T) \cdot DT \tag{1}$$

with $DT = T_h - T_c$.

To model the complete system, the temperature-dependent parameters must be known. As manufacturer's exact material properties are not available, these parameters are approximately determined in different ways. For temperatures near ambient temperature the parameters can be determined on the basis of the given maximum operating parameters DT_{max}, I_{max}, U_{max} und Q_{max} [3]. To appropriatly model other temperatures, the manufacturer Ferrotec published empiric polynomials [2]. These polynomials can be adapted to different Peltier elements. Typical temperature profiles depending on the cold and hot side temperature T_c and T_h can be found in Figure 3.
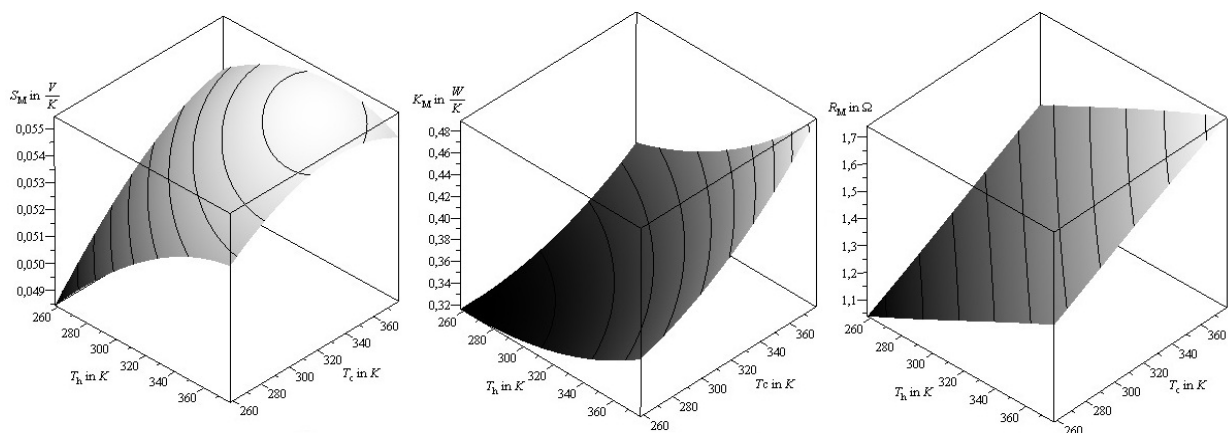

Figure 3: Temperature-dependent parameters of the used Peltier element

The active heat transfer through the Peltier element is only effective, if the transported heat flow and the power loss of the Peltier element are fast transferred to the ambient. Therefore, a high-performance heatsink with an axial fan for forced convection is used. Thus, the heat-transfer coefficient α and with it the heat-transfer from heatsink to the ambient air is maximized. Because of the complex strand casting structure, the heat distribution in the heatsink depends on the imposed thermal power, the ambient temperature and the airflow. For modelling an empirically determined model is used. To identify its structure and parameters a constant thermal power P is imposed to the heatsink and the jump response of the heatsink temperature ϑ_{KK} is measured (Figure 4).
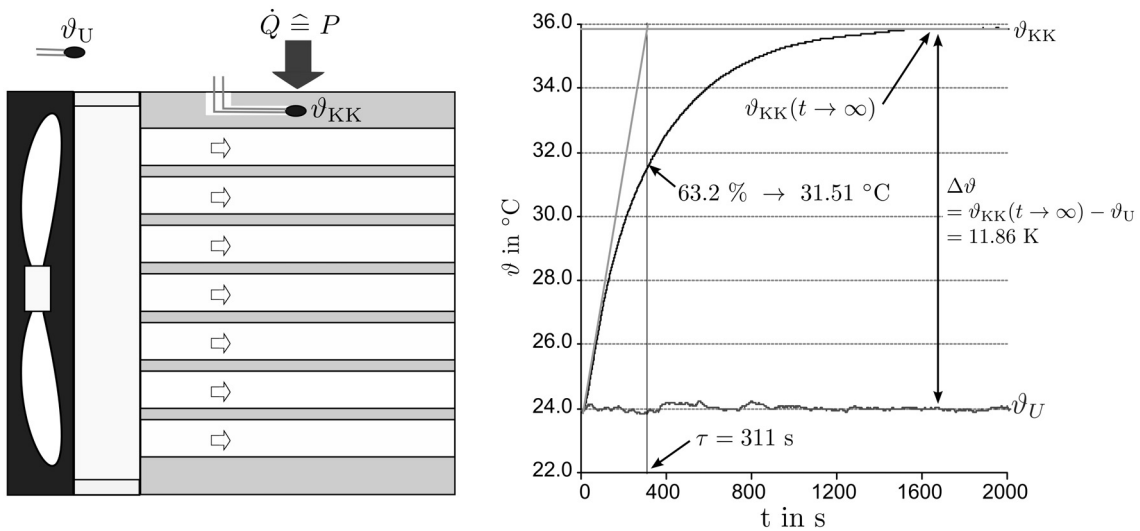

Figure 4:   Measuring setup and step response, P = 60 W, n = 855 min^{-1}, ϑ_A = 24 °C

An appropriate model for this measured behaviour is a RC-network (Figure 5). It consists of a thermal resistance (compound of thermal conductivity resistance and convection resistance) and a thermal capacity.
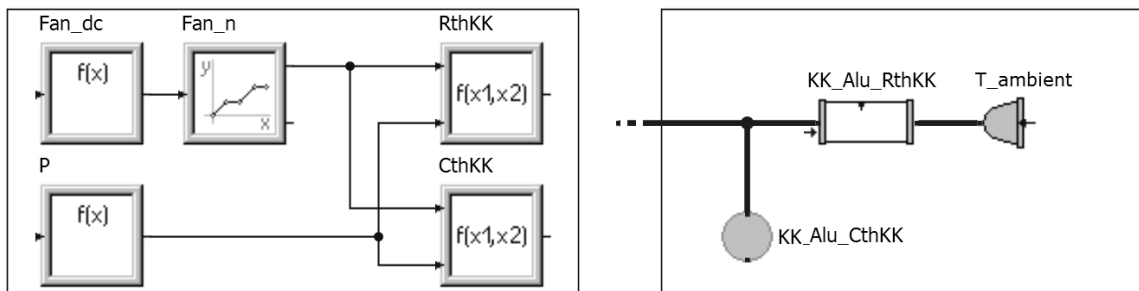

Figure 5: Functional blocks (l.) and network model (r.) of the cooling module with concentrated elements

All parameters reveal a dependency on the fan speed n as well as the imposed power P and therefore, on the current temperature difference (Figure 6).
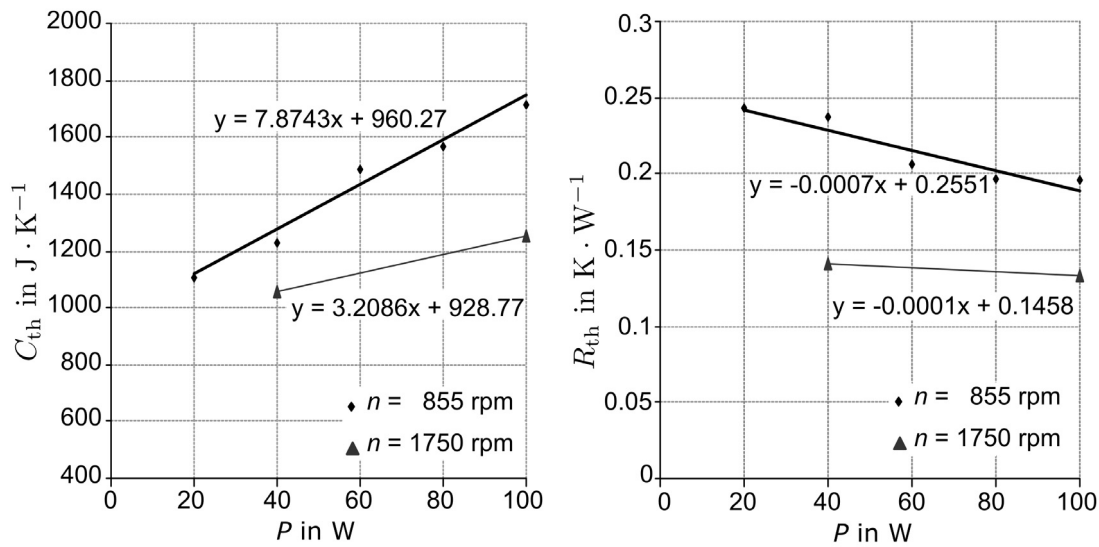
Figure 6: C_{thKK} and R_{thKK} for different values of P and n

The parameters $R_{thKK}(n, P)$ and $C_{thKK}(n, P)$ can be approximated by the use of linear interpolation:

$$R_{thKK}(n, P) = -6.916 \cdot 10^{-5} \frac{\text{K}}{\text{W} \cdot \text{min}^{-1}} \cdot n - 7.0 \cdot 10^{-4} \frac{\text{K}}{\text{W}^2} \cdot P + 0.3166 \frac{\text{K}}{\text{W}}, \qquad (2)$$

$$C_{thKK}(n, P) = -1.014 \frac{\text{J}}{\text{K} \cdot \text{min}^{-1}} \cdot n + 6.63 \frac{\text{J}}{\text{K} \cdot \text{W}} \cdot P + 1843.44 \frac{\text{J}}{\text{K}}. \qquad (3)$$

Figure 7 illustrates the complete model of the heating-cooling system in SimulationX. The used parameters in the equations (1), (2) and (3) are stored in function blocks (not shown in Figure 7). The parameter values are internally assigned to the model elements.
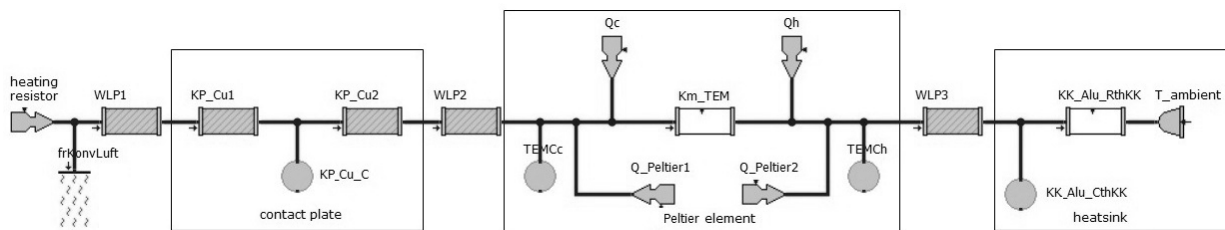

Figure 7:   Model of the heating-cooling system in SimulationX

Results and Validation

Comparing simulated temperature profiles of the contact plate with measured profiles, a very good match between the model and the real behavior can be observed (Figure 8). In a temperature range from -30 °C to +60 °C the simulated steady-state temperature has a maximum deviation of 2 K from measurement.
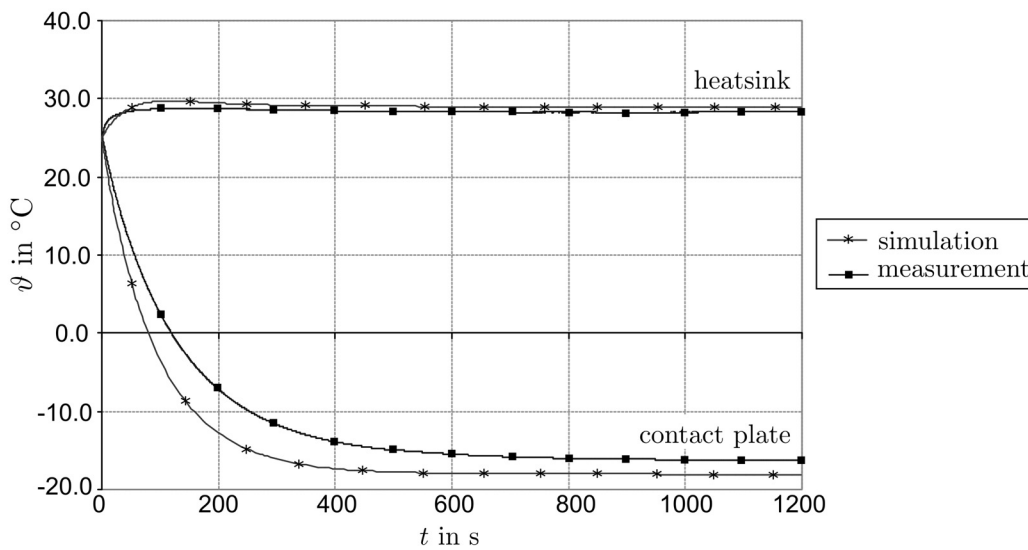
Figure 8:   Measured and simulated temperature profile of the contact plate

Conclusion

In this paper, the modelling of a compact heating-cooling desktop device with concentrated elements in SimulationX 3.3 is presented. The components Peltier element and heatsink are modelled with the aid of empirical functions.

With this model, the dimensioning of the device was simplified and design guidelines were derived. Due to the modular assembly, single components can be varied freely. The system performance can quickly and easily be analyzed through this presented model.

For future devices the dimensioning can be carried out considerably faster and with higher reliability for different power and temperature ranges. The developed heating-cooling desktop device is available as prototype and allows an exact temperature control of small items in a temperature range from -25 °C bis +80 °C with a precision of <0.1 K.

[1]   *Stapel, J.*: Weiterentwicklung einer Anordnung zum Ansteuern von Peltierelementen. Diplomarbeit, TU Dresden, 2010.

[2]   *Ferrotec*: Thermoelectric Technical Reference – Mathematical Modeling of TEC Modules. http://www.ferrotec.com/technology/ thermoelectric/thermalRef11/ (17.03.2010)

[3]   *Luo, Z.*: A Simple Method To Estimate The Physical Characteristics Of A Thermoelectric Cooler From Vendor Datasheets. Electronics Cooling, August 2008, available at www.electronics-cooling.com/html/2008_aug_a2.php (21.10.2009)