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Two approaches for heat transfer simulation of current carrying multicables

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Abstract

Excessive temperatures in cable bundles integrated in cars can cause harms to connecting structures and essential components. To avoid hotspot generation already at the production of cable harnesses, reliable predictions of temperatures in cables under load are necessary. Two approaches for stationary heat transfer simulation in current carrying multicables, i.e. thick cables composed of several smaller ones, are compared in this work. An extensive model with partial differential equations, solved via the finite element method, is subject of the first approach. In the second one, formulas for temperatures at characteristic cable positions are derived and computed via a fixed point approach. The first approach provides a detailed temperature profile and thus enables the location of hotspots a priori, the second approach excels by very fast determination of average temperatures without time consuming geometry creation. Furthermore, accordance to realistic settings is demonstrated by comparison to measurement results.

Keywords: Finite element method; Fixed point approach; Electric cables; Joule heating; Mathematical modelling

1. Introduction

In modern cars, a great number of devices supplied with electrical power by current carrying cables exists. Cable harnesses often include several hundred wires, implicating weights of more than 80 kg and total lengths up to 3 km. In order to save costs and weight, manufacturers optimize the layout of cables and reduce the used materials.

In contrast, cables have to sustain higher currents for long periods. Permanent overheating of cables and hotspot generation have to be avoided as they can damage the cables and cause serious harms to important car components. Many car manufacturers still layout the cables according to obsolete design rules. Thus, calculation of the generated heat by electrical currents, denoted Joule or ohmic heating, is essential to dimension cables and cable harnesses correctly in advance. In this work, we present two approaches to simulate stationary ohmic heating of

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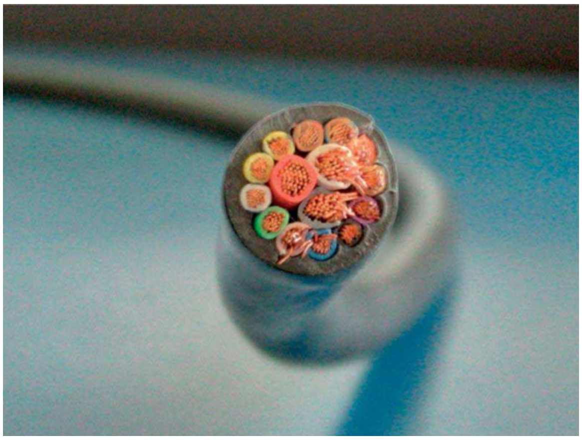

Fig. 1. Real multicable with 15 single cables.

(direct) current carrying multicables (e.g. Fig. 1). Both approaches have already been applied for cable design in cooperation with industrial partners. Especially the second forms the basis of a temperature calculation tool for cable manufacturers.

We use a stationary two dimensional cable model. Because of the great length of the cables ($l \to \infty$) and the implicated minor temperature changes in axial direction, we consider the heat generation in a single cross section area $\Omega \subseteq \mathbb{R}^2$. Interested in the long time behaviour ($t \to \infty$) and the maximally reached temperatures, we investigate the stationary case. These equilibrium temperatures give an upper bound for the time-dependent case, but allow to derive faster and more efficient algorithms. Thermal and electric effects are coupled taking into account the rise of electrical resistance $R(T)$ for increasing temperatures. Furthermore, a temperature dependent heat transfer coefficient $\alpha(T)$ is used, describing the heat exchange by convection and radiation between the cable and ambient air. The temperature dependency of R and α forces the governing equation system to be nonlinear.

In the first approach, the temperature distribution $T(x)$, $x \in \Omega$, is calculated with the finite element method (FEM) and the process of heating up is described by a nonlinear system of elliptic partial differential equations (PDEs). Via FEM, we determine an entire temperature profile with respect to the complex geometry of the cross section. Our second approach is based on the law of conservation of energy. Some simplifications concerning the geometry allow to apply a fast fixed point iteration technique.

Before going into detail, let us state some results from literature. Fundamentals of heat and mass transfer with temperature dependency of convection and radiation are explained in [3,14,15,20]. In [9], a cable model and a procedure of coupled electrical and thermal analyses for the evaluation of current and temperature via finite elements are presented. Numerical and analytical approaches for temperature calculations of electric power cables are subject of [19]. In [5], the practical problem of correct dimensioning of cable bundles, the occurring physical effects and a mathematical model for the instationary case solved via a finite volume method are described. To determine the heat conductivity in the air gaps between the single cables, an inverse problem solution method was proposed in [6]. A combination of analytical and numerical formulas was applied in [18] resulting in the possibility to reduce the great number of data necessary for the calculation of cables. These simplified formulas can describe the heat generation in cables with limitations, for example a temperature dependent heat transfer coefficient cannot be respected completely. But this is the case for our two approaches. Motivated by the above-named works and the collaboration to cable manufacturers, it is our main interest to present opportunities and limitations of our applied approaches. The paper is organized as follows: In Section 2, we define the physical problem and describe it mathematically by a corresponding PDE model. A cable squeezing algorithm to set up the layout and FEM to calculate the temperature profile is applied in Section 3. In Section 4, we derive formulas for boundary temperatures based on the law of conservation of energy, evaluated by a fixed point iteration. Section 5 contains numerical results of both approaches, compared to measurement results performed on real multicables by a collaborating laboratory. We show pros and cons of both methods and finish with concluding remarks in Section 6.