NUMERICAL MODELLING OF THE SPECIAL LIGHT SOURCE WITH NOVEL R-FEM METHOD

P. Fiala1), E. Kroutilová 2), T. Kříž 3)

1) 2) 3) *Department of Theoretical and Experimental Electrical Engineering, Brno University of Technology*
Kolejni 4, 612 00 Brno, Czech Republic, fax. +420541149512
1)*fialap@feec.vutbr.cz, tel. +420541149510,* 2) *kroutila@feec.vutbr.cz, tel. +420541149525,* 3) *kriz@feec.vutbr.cz*

Summary - This paper presents information about new directions in the modelling of lighting systems, and an overview of methods for the modelling of lighting systems. The novel R-FEM method is described, which is a combination of the Radiosity method and the Finite Elements Method (FEM). The paper contains modelling results and their verification by experimental measurements and by the Matlab simulation for this R-FEM method.

1. INTRODUCTION

The paper contains information about verification of the design of the special light sources by the numerical simulation of the R-FEM method and verification by experimental measurements.

2. THE R-FEM METHOD

The R-FEM method is a new direction in the modelling of lighting systems. It utilizes the similarity between physical models. This paragraph demonstrates the usage of analogy between different physical models for the modelling of light problems. The R-FEM method is able to solve tasks that fulfill the condition $\lambda_S << max\ (D) \wedge \lambda_S < 10\ .\ max\ (D)$, where λ_S is the source of light wavelength and D is one of the geometrical dimensions of the modelling task. It can be used for to model more complicated physical problems than the methods mentioned up to now. An example of a more complicated physical problem, which we can solve by the R-FEM method, is the modelling of light intensity distribution in interior or exterior spaces with non-homogeneous environment, where the light has passed through some impure air (e.g. filled with smoke, fog, mist, vapour, dust, etc.).

3. THE DESIGN BY R-FEM METHOD

In technical praxis we often encounter conjugate problems. A necessary part of the design process during the development and measurement of light sources is the modelling and experimental verification of results. The most accurate mathematical models of the sources of light include models based on the radiation principle. One possibility is to use standard one–purpose programs while another possibility offers the usage of sophisticated numerical methods, among them the finite element method, for example the ANSYS program.

The ANSYS program uses standard program tools such as modelling, discretization into a net of elements, solvers, evaluation, and interpretation of the results. The crux of the whole problem lies in the transformation of thermal field quantities into optical quantities. This can be done using the general rules described in [19]. In the following text the basics of modelling the primitive light problem are described. The verification of the model of light source is done via experiment and then it continues to the hollow light guide problems and it was also verified by experiment (for more information, see references [1] - [5]). The geometrical situations that were modeled and verified is shown in the Fig 1.

4. THE DESIGN BY R-FEM METHOD

The formulation of the basic thermal model is based on the first law of thermodynamics

$$q + \rho c v \cdot divT - div\left(k\ gradT\right) = \rho c\left(\frac{\partial T}{\partial t}\right) \qquad (1)$$

where q is the specific heat, ρ is the specific weight, c is the specific solidification heat, T is the temperature, t is the time, k is the coefficient of calorific conduction, v is the velocity of flow. This model can, with respect to the application of Snell's principles and according to the Stefan-Boltzmann principles, heat transfer by way of radiation between surfaces with relative indexes i, j is formulated as be simplified into the form

$$q_{ri} = \sigma \ \ \varepsilon_i \ \ A_{i,j} \ \ S_i\left(T_i^4 - T_j^4\right), \qquad (2)$$

where q_{ri} is the specific heat transferring from surface with index i, σ is the Stefan-Boltzmann constant, ε_i is the emissivity of surface, $A_{i,j}$ is the projection factor of surface with index i to surface with index j, S_i is the area of surface with index i, T_i, T_j are the temperature of surfaces i, j. When the projection factor is determined, it is possible to use the Gallerkin principles for converting this problem into model (1). Marginal and initial conditions must be respected.

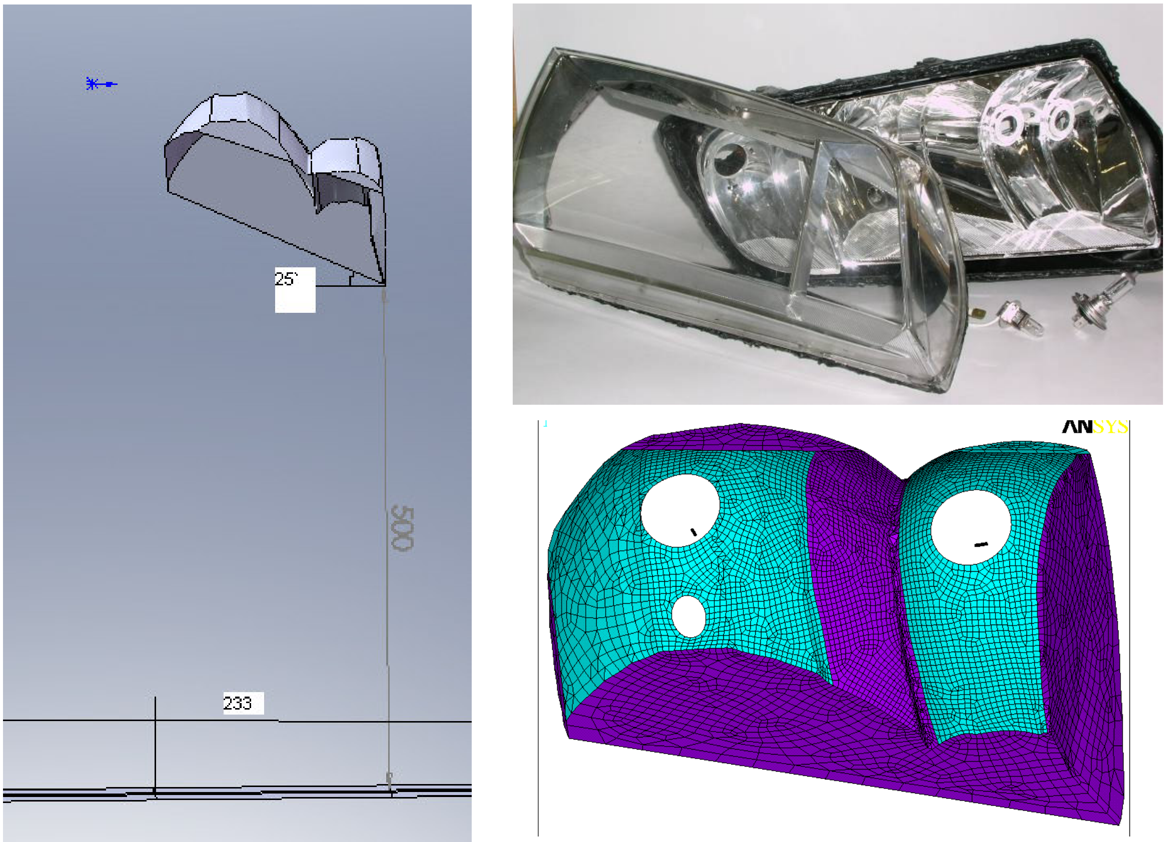


Fig. 1. Geometrical configuration of the special light source

$$[K]\{T\}=\{Q\}, \quad (3)$$

where K is the coefficients matrix, T is the columnar matrix of sought temperatures, Q is the columnar matrix of heat sources. Thermal flow T_f is determined from temperature T as

$$T_f = -(k\, gradT). \quad (4)$$

By the radiation principle, the elements of column matrix of heat sources Q and adjusting for mathematical model yields

$$Q_{i,j} = \overbrace{S_i A_{i,j} \varepsilon_i \sigma \left(T_i^2 - T_j^2\right)\left(T_i + T_j\right)}\left(T_i - T_j\right) \quad (5)$$

The heating model will be used for the modelling of light problem using the Snell principles in optics. Light source with lighting intensity E *(lx)* corresponds to equivalent heat quantity density of heat flow q'', light flow Φ*(lm)* corresponds to equivalent quantity of heat flow q'. The resulting light flow is defined by equation (6).

$$\Phi_e = \frac{T_{f,e}}{S_{n,e}}. \quad (6)$$

where Φ_e is the flow of light on the element, $T_{f,e}$ is the equivalent of the thermal flow through the element, $S_{n,e}$ is the normal surface to the element (more can be found in [19]). The result of modeling by the R-FEM method is shown in the Fig. 2.

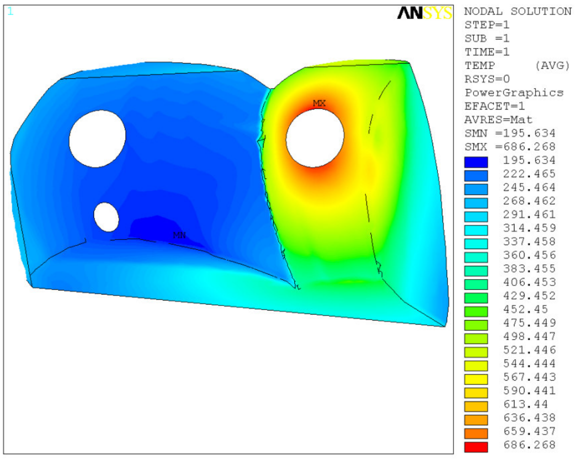


Fig 2a. The result of the R-FEM method –thermal flux, module of vector, distribution on central line

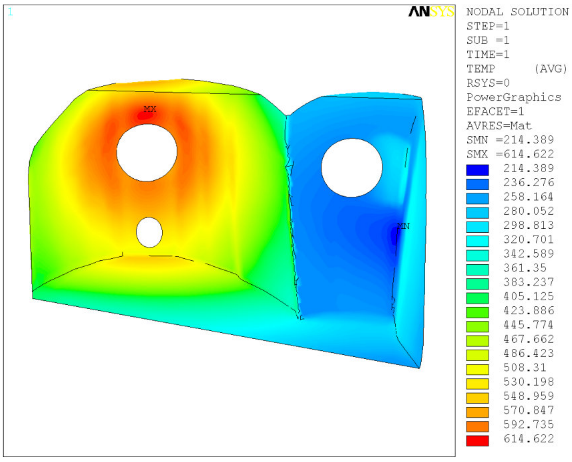


Fig 2b. The result of the R-FEM method –lighting intensity E(lx)

5. VERIFICATION OF THE R-FEM

The results of the verification of the R-FEM via experiments are given in Fig. 3. There are differences between the values obtained by modelling and experimental measurement, ranging from 5 – 15 %, depending on the distribution of the net of elements. When the elements of the net are of a lower density, the differences are also lower. This problem requires the net of elements to be optimized.

6. ADVANTAGES OF THE R-FEM

One of the biggest advantages of this method is the wide spectrum of its usage. We can design the interior and also exterior scenes with its specifications in the materials quality, climatic dissimilarities and geometrical dimension varieties. We can use all types of sources of light with their diversity of the colour distribution in the light spectrum. The designers are not limited by the geometrical dimension varieties, colour distribution in the light spectrum, material qualities or climatic dissimilarities. The other advantage is that the method is very accurate. The degree of accuracy can be chosen by choosing the method of generating nets of elements and the solution algorithm because all this is provided by the ANSYS standard program tools.

7. THE FULL FEM WAVE SOLUTION

FEM is the short form for the Finite Elements Method modelling. The light problems that fulfill the condition $\lambda_S << max\ (D) \wedge \lambda_S < 10\ .\ max\ (D)$, where λ_S is the source of light wavelength and D is one of the geometrical dimensions of the modelling assignment, will be solved by the FEM using the full wave equation, which was used to define light emissions. This method of the solution yields highly accurate results, but is demanding as regards geometrical declaration, and time-consuming (for example, for incoherent sources of light the calculation is too long). The Full FEM wave solution is suitable for a specific purpose.

8. VERIFICATION THE R-FEM SIMULATION

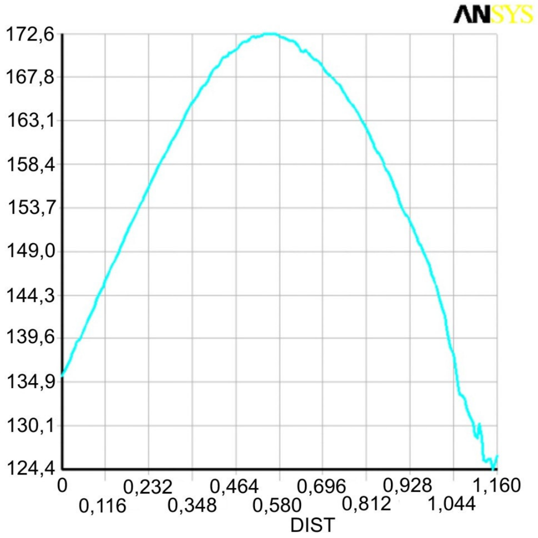


Fig 3. The results of the modeling by the Matlab – Lighting intensity E[lx]

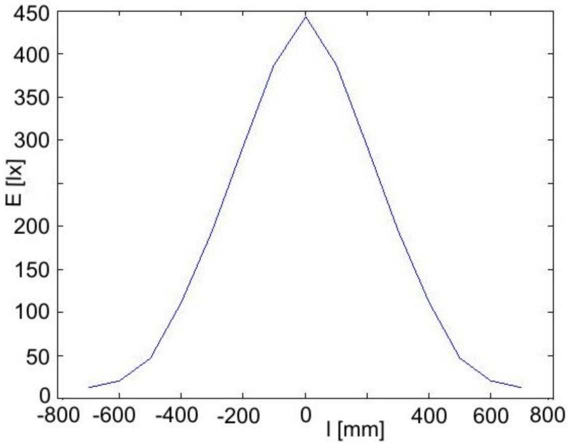
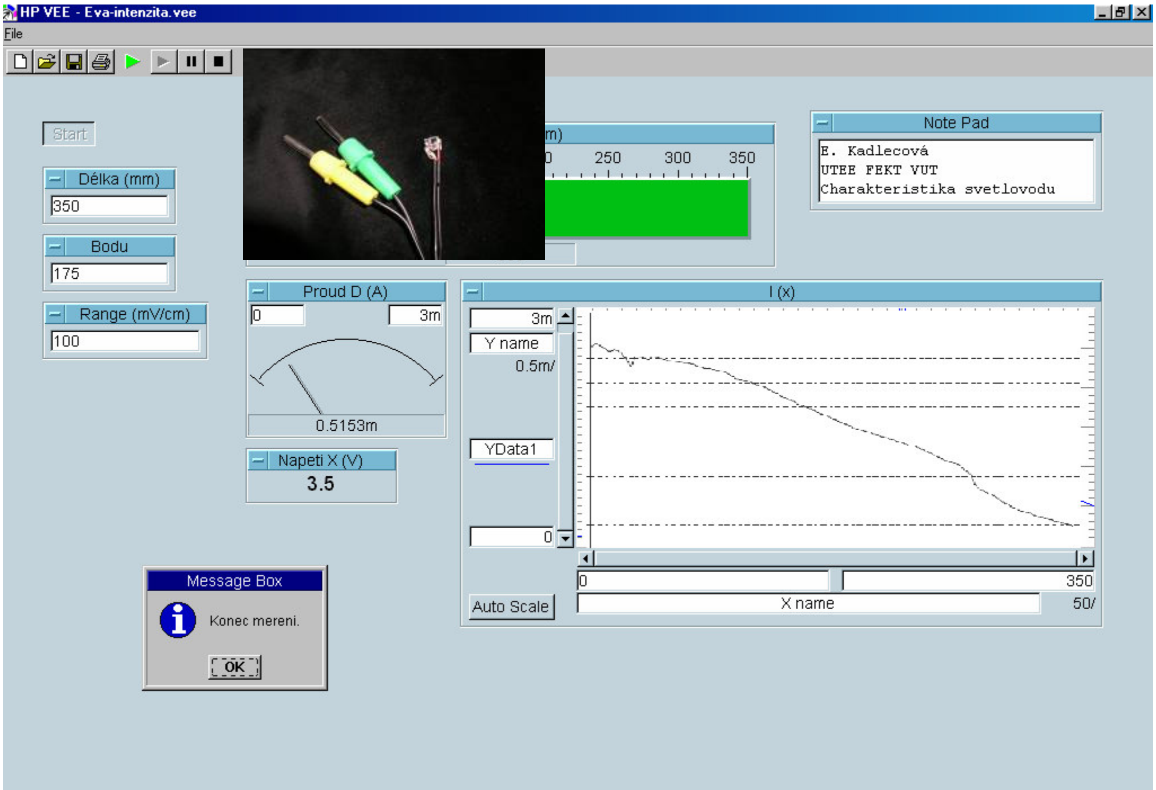


Fig 4. Results of the light intensity by the experiment with the luxmeter

The results of the verification of the R-FEM via two experiments are given in fig. 3, 4 and 5. Experimental measurements were used as first verification.



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Délka (mm): 350

Bodu: 175

Range (mV/cm): 100

Proud D (A): 0.5153m

Napeti X (V): 3.5

Note Pad:
E. Kadlecová
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Fig 5. The shape of distribution of the light intensity by experiment with the LED

9. CONCLUSION

This article describes novel numerical methods (R-FEM) of modelling lighting problems, which are used in Computer Graphics and in Lighting Engineering. Main novel described method exploits FEM ANSYS system for partial solution. Article also describes the R-FEM method, which has been verified and found to be a great asset for the modern trends in modelling lighting problems. It can solve specific light problems have been solved by using with the full geometry.

Acknowledgement

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