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ON ELECTRICAL HEATING SYSTEM OF VEHICLES SEATS

BY

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Abstract. The study includes an electro-thermal analysis of the seats that are used within the automotive industry. While an electric source is always present in any car, a straightforward and common approach it is to increase the temperature of the seats is to use the available electrical power from the battery accumulator or the alternator. Whatever the case, an important parameter from electrical point of view is the power consumption. The estimation of power demand in connection to the desired seat temperature value is an objective of the study. Such information is quite useful for the designing of a vehicle interior temperature control system and the optimization of such thermal system. The analysis is performed using three dimensional computer aided design modeling and computational fluid dynamics combined with heat transfer physics. The study also includes a briefing on the required fundamentals and input data, in order to approach such an analysis.

Key words: automotive; vehicle; temperature control; computational fluid dynamics; conjugated heat transfer.

1. Introduction

The automotive manufacturers are developing various features as a response to more and more complex and stylish customers demanding regarding an improved driving mode and comfort. All the demands aim for performance requirements and manufacturing cost-effectively. One of the parts of a vehicle that must be comfortable is the seat. The reason is simply to identify because

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both the driver and passengers are sitting most of the time on those while a vehicle is operated.

The classical studies regarding the car seats refer to vehicle safety standards (Husen *et al.*, 2013), but with time the comfort has gained a lot in customer preferences. As such, various studies are dedicated to sitting comfort (Vosisin & Levrat, 2001), human tactile sensation for different top coating cloths (Nishimatsu, 2000) and the wear of fabric applied (Valera *et al.*, 2011), quality design (Elbanhawi *et al.*, 2015; Fahma *et al.*, 2015; Fan & Zhao, 2009) and customer perception (Iecbes *et al.*, 2010).

Another category of studies on car seat is the posture of the driver, that is the appropriate backward inclination of the cushion and the back-rest so that to reduce the driver's muscle fatigue (Majid *et al.*, 2011). There also an interest linked to safety, the detection of driver body orientation and warning in case of increased risk of accident by sensor matrix (Hogema *et al.*, 2009) or by infrared camera technology and body shape recognition (Makrushin *et al.*, 2009). The posture detection is also used for air-bag protection system activation as in (Xie *et al.*, 2011). The elder individuals with different motion issues are also considered when designing car seats (Wong *et al.*, 2016).

Thermal study of car seats is also another important topic. One issue is the design of temperature control system. In (Menon & Asada, 2006) it is described such a system for rapid heating and cooling of a car seat using Peltier elements as well as for massaging of the driver. Some studies target only for the cooling of a car seat, (Vinoth & Prema, 2014) where a thermoelectric cooler is drawn in. In (Mihai, 2012) it is described a temperature control system based on fuzzy control approach and implemented within a microcontroller. Nevertheless an important feature of the temperature control system is the safety of the passengers. Thus, in (Finn *et al.*, 2012) it is analyzed the heating influence over the safety of children inside the vehicle.

Based on all the subjects already shown, the objective of the analysis is to provide the temperature distribution on the car seat surface and the required amount of power. In effect, this data is useful to thermally characterize the car seat parts as thermal resistances. With such much simpler elements it is easier to design a closed-loop temperature control system. Besides, the required power is helpful to estimate the energy consumption. As a result, in the case of an electric vehicle this is significant data for forecasting the remaining running hours of the vehicle. The temperature distribution map is valuable for the optimization of the thermo-electrical heating circuit (size, shape, volume).

2. The Physical Model

The structure of a real vehicle seat type that is considered within the study is depicted in Fig. 1. The terminology for the seat back is the back rest while for the seat bottom is the cushion. Both seat bottom and back parts are similarly manufactured. The main manufacturing material is foam and above it is applied a cover. In the vicinity of the cover, an electrical heating circuit is considered. This circuit is not depicted in Fig. 1.

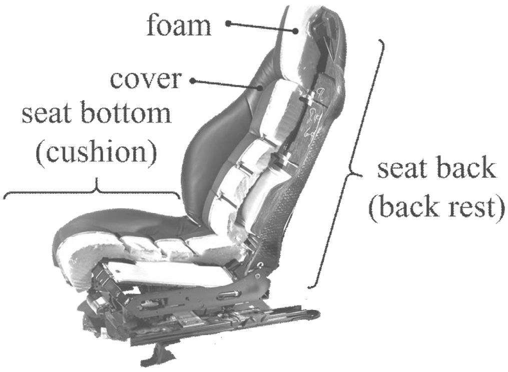

Fig. 1 − The main parts of a car seat.

The geometry implemented using computer aided design (CAD), namely ANSYS SpaceClaim 18.0 is presented in Fig. 2. The details considered are fairly complex.

The geometrical shape of the car seat registers various surfaces by means of spline curves. The elements included within the physical model are the head rest, the back rest, the seat cushion.

In order to diminish the computational effort, that is the simulation time and the hardware requirements, only half of this geometry is considered, as depicted in Fig. 3.

The electric heating system is modeled by placing inside the car seat parts two different components that are in proximity of the cushion and the back rest surfaces. These two heating parts are highlighted in Fig. 4.

Fig. 2 − The full CAD geometry of the analyzed car seat.

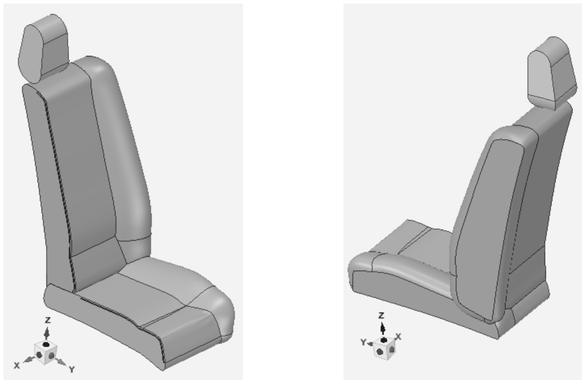

Fig. 3 − The simplified CAD geometry of the analyzed car seat (left – front view, right – rear view).

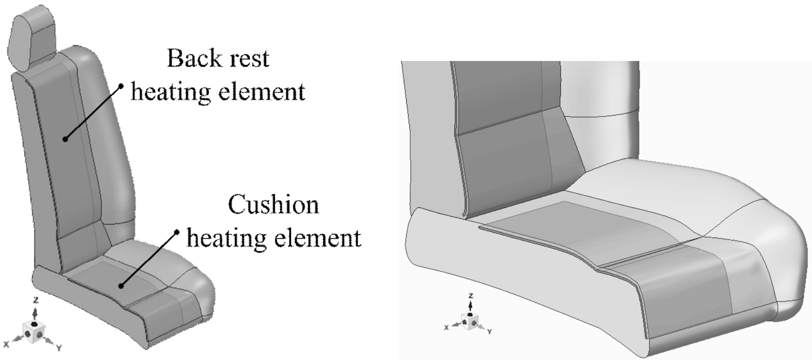

Fig. 4 − The heating elements (left – general view, right – zoom).

3. The Mathematical Model

The mathematics defines by means of analytical expressions the two coupled boundary value problems, also named combined heat transfer (*i.e.* fluid mechanics and heat transfer). Each is described by partial differential equations.

Due to the modeling of the surrounding air as an ideal fluid, the flow is considered weakly-compressible, as indicated in (ANSYS, 2017a). Thus, for the fluid mechanics problem the first set of equations is the momentum balance (Navier-Stokes) (Ferzinger & Perić, 2002):

$$\rho(\mathbf{u}\cdot\nabla)\mathbf{u} = -\nabla p + \nabla\cdot\left\{(\mu+\mu_t)\left[\nabla\mathbf{u}+(\nabla\mathbf{u})^T\right]-\left(\frac{2}{3}\mu+\mu_t\right)(\nabla\cdot\mathbf{u})\mathbf{I}-\frac{2}{3}\rho k_e\mathbf{I}\right\}+\mathbf{F} \quad (1)$$

where: ρ is the fluid's mass density [kg/m^3]; $\mathbf{u}$ is the fluid's velocity [m/s]; p – the fluid's pressure [Pa]; μ – the fluid's dynamic viscosity [Pa·s]; μ_t – the eddy turbulent viscosity, [Pa·s]; **I –** the unit matrix; k_e – the turbulence kinetic energy, [m^2/s^2]; **F –** the term for other body forces, [N/m^3]. More information on this equation is found in (Menter, 1994).

The second set of expressions for fluid mechanics problem is is given by the mass balance (continuity) equation:

$$\nabla \cdot (\rho \mathbf{u}) = 0 \tag{2}$$

where the quantities have the same significance as for the previous equation.

The heat problem is modeled using the energy balance equation which describes the heat energy and it is given by (Incropera *et al.*, 2007):

$$\rho c_p (\mathbf{u} \cdot \nabla) T + \nabla(-k \nabla T) = \dot{q} \tag{3}$$

where: c_p is specific heat at constant pressure, [J/kg/K]; k – thermal conductivity, [W/m/K]; T – temperature, [K] and $\dot{q}$ – the rate of energy generation, [W/m^3].

Depending on the computational domain this equation is tailored in consequence.

The natural convection phenomenon is included within the model by buoyancy forces. The reason is the air density variation with temperature. These body forces act in opposite direction of the gravity. The equation defining them is given by:

$$\mathbf{F} = (\rho - \rho_{ref}) \cdot \mathbf{g} \tag{4}$$

where: **g** is the gravitational acceleration, [m/s^2], and ρ_{ref} – the equilibrium mass density of air, at a given ambient temperature and pressure, [kg/m^3]. This equation is included into the momentum balance one.

The fluid density ρ is computed considering that the air surrounding the car seat behaves like an ideal gas. In consequence the expression solved by the ANSYS's CFX solver is (ANSYS, 2017b):

$$\rho = \frac{M \cdot p}{R \cdot T} \tag{5}$$

where: M is the fluid's molar mass, [g/mol]; p – the fluid's pressure, [Pa]; R – the universal gas constant, [J/mol/K]; T – temperature [K].

4. The Numerical Model

The commercial code used to solve the equations (*i.e.* ANSYS CFX code suite) is based on the finite volumes method. This method requires a meshing of all computational domains into small volumes.

In Fig. 5 is presented the final mesh. Because the flow and temperature near the car seat surface is of interest then a special attention is required. Thus, inflation layers feature is activated near these surfaces, as it is detailed in Fig. 5 (right side). In total, the resulting mesh has 5,014,539 linear elements.

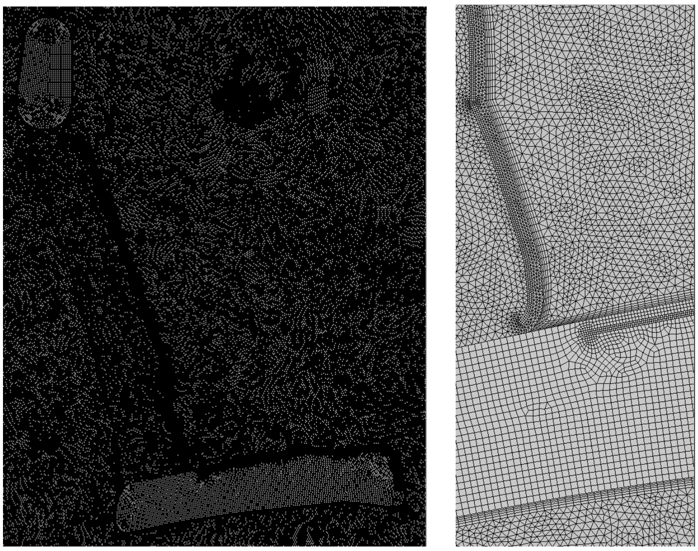

Fig. 5 – The model mesh
(left – general overview, right – close-up on inflation layers).

The heat generation within the fluid (by viscosity) is not significant. For fully mathematical definition of the boundary value problems the boundary conditions are required, that is the heat source is considered within the heating parts placed inside the car seat. The interior environment of the car is set to 20°C as this is a usual value of inside temperature when air conditioning systems is on. All the walls (car seat surface) of the model are considered as no-slip, while all the middle surfaces of all the domains are considered as symmetry.

5. Results

The studied cases refer to the following scenario. Inside the vehicle a constant temperature of 20°C is present. Then, the driver starts the heating system for the car seats without being inside the vehicle that is it is commanded a preheating of the seats before the driver gets inside the vehicle.

The temperature distribution map has been obtained for various injected powers. Then the average and maximum temperature of each car seat part have been identified. In Figs. 6,…,9 is shown the relationship between the average temperature and maximum temperature with the injected power in each heating component.

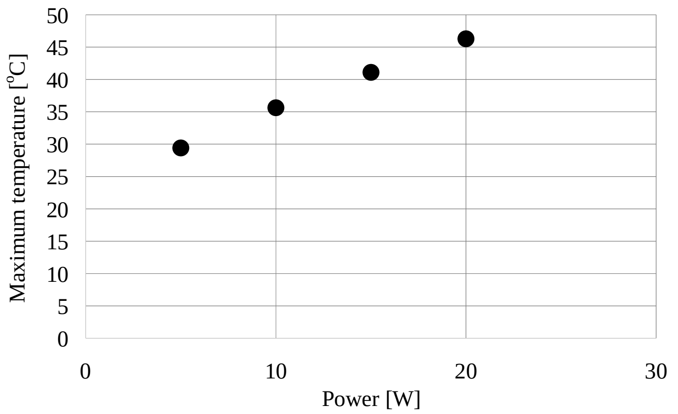

Fig. 6 – Cushion maximum temperature with injected heating power.

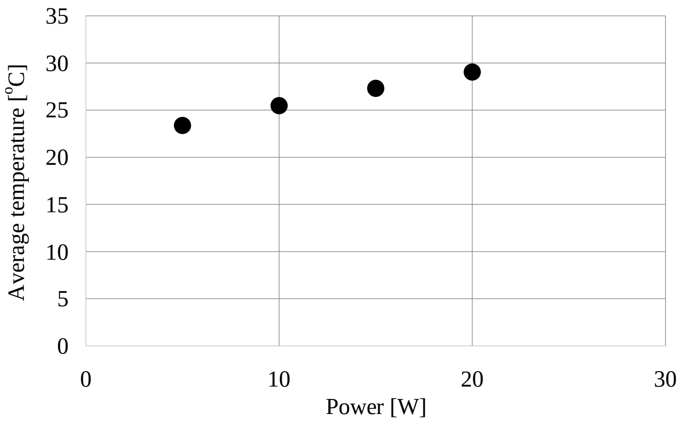

Fig. 7 – Cushion average temperature with injected heating power.

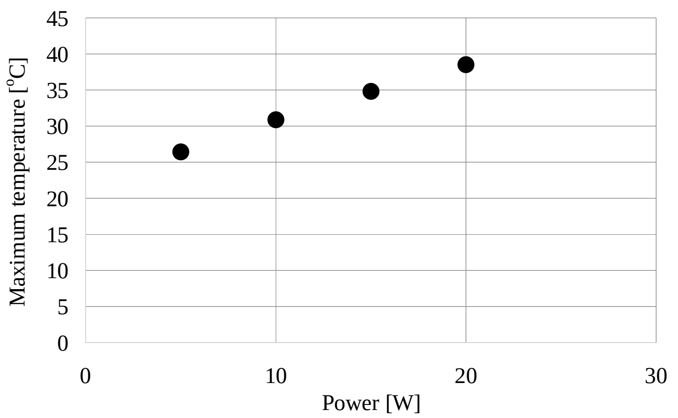

Fig. 8 – Back rest maximum temperature with injected heating power.

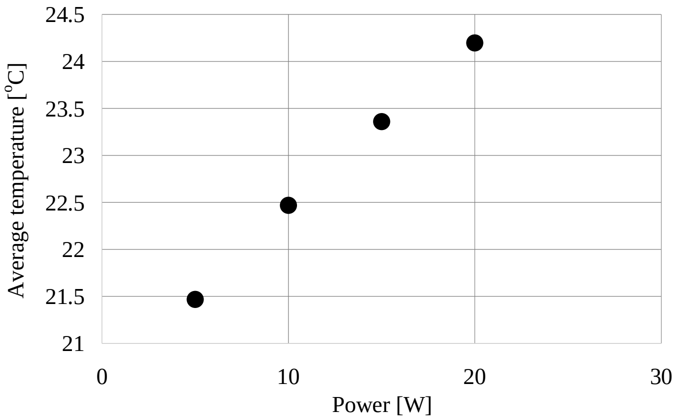

Fig. 9 − Back rest average temperature with injected heating power.

It can be observed that the relationship between the temperature and the power is almost linear which points out that the behavior of all the materials is quite linear. From thermal lumped circuit network point of view this translates to a simple thermal resistance for each component of the seat.

In the case of injecting 20 W into the bottom heater and 20 W into the back-rest heater a maximum temperature of 46.3°C for the cushion and 38.5°C for the back rest have been obtained. Such values are reasonable for a car seat.

The temperature map in this case is depicted in Figs. 10…,12.

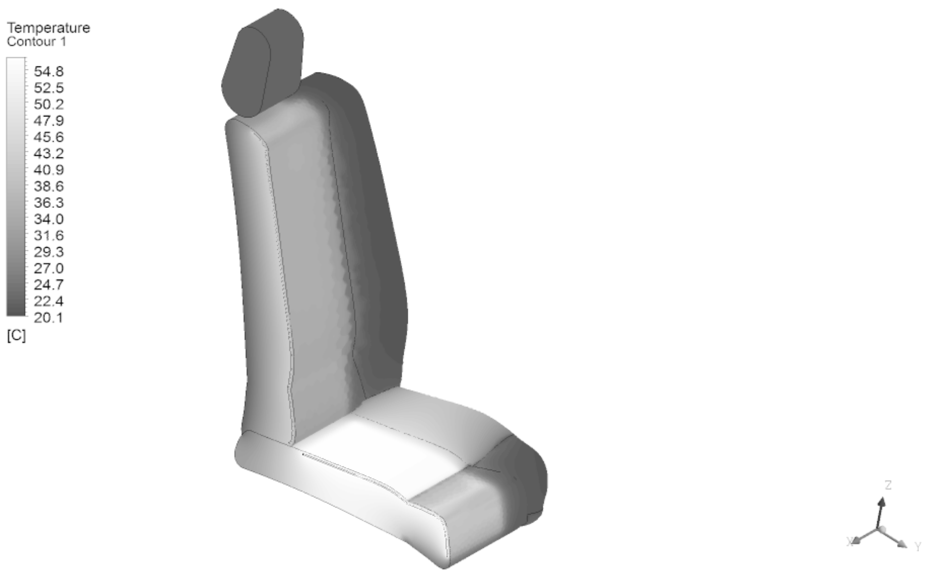

Fig. 5 − The temperature map for main parts of a car seat.

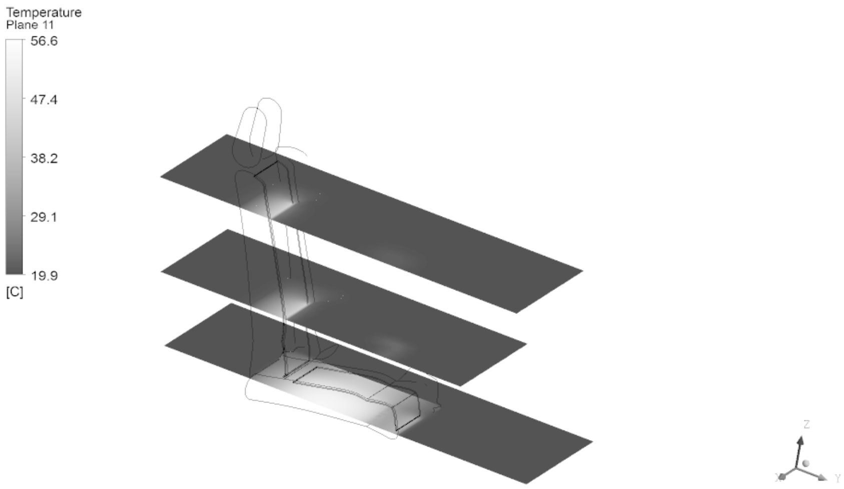

Fig. 6 − Temperature map in three horizontal planes.

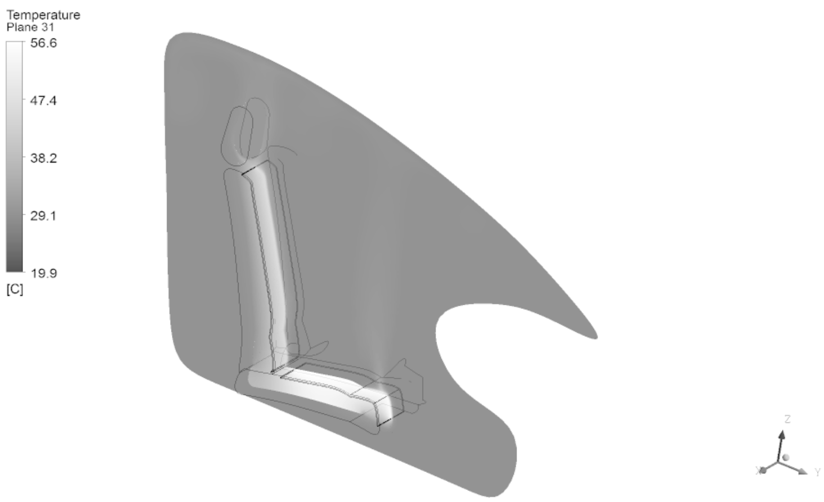

Fig. 7 − Temperature map on a vertical plane.

The maximum recorded temperature of 56.6^{o}C belongs to the cushion heater. The values illustrate that thermally the two parts of the car seat behave different.

For the same power the cushion is warmer than the back-rest with about 8^{o}C in this case, when referring to the maximum temperatures and about 5^{o}C in average temperatures.

Therefore, the power required to obtain a similar temperature is lower for the cushion and higher for the back rest.

6. Conclusions

The modeling of electric heating system is useful for the designing of car seat temperature control system. Based on the power, temperature and geometry it is possible to extract the parameters of each component in terms of thermal network elements (thermal resistances) that simplify the modeling and in effect the optimization of closed control loops.

Moreover, the power required to heat the car seats is an important parameter for the estimation of remaining running time of an electric vehicle.

The results are similar to experimental results due to the multi-physic phenomena that are modeled into detail, like heat transfer and fluid mechanics.

REFERENCES

Elbanhawi M., Simic M., Jazar R., *In the Passenger Seat: Investigating Ride Comfort Measures in Autonomous Cars*, IEEE Intelligent Transp. Syst. Magazine, **7**, *3*, 4-17 (2015).

Fahma F., Iftadi I., Putri N.A., *Customer Requirement Analysis of Driver's Seat Design Using Quality Function Deployment (QFD) Case Study: City Car*, Proc. of the Joint Internat. Conf. on Electric Vehicular Technology and Industrial, Mechanical, Electrical and Chemical Engineering (ICEVT & IMECE), 173-177, 2015.

Fan P., Zhao B., *Analysis of Dynamic Comfort of Automobile Seats*, Second International Conference on Intelligent Computation Technology and Automation, **3**, 483-486, 2009.

Ferzinger J.H., Perić M., *Computational Methods for Fluid Dynamics*, Springer-Verlag, Berlin, Germany, 2002.

Finn J. ., Wagner J.R., Walters E.J., Alexander K.E., *An Integrated Child Safety Seat Cooling System—Model and Test*, IEEE Trans. on Vehicular Technology, **61,** *5*, 1999-2007 (2012).

Hogema J.H., Vries S.C., Erp J.B.F., Kiefer R.J., *A Tactile Seat for Direction Coding in Car Driving: Field Evaluation*, IEEE Trans. on Haptics, **2**, *4*, 181-188 (2009).

Husen M.S., Sanjay D.Y., Shinde D., Deshpande G., *Strength Enhancement of 2010 Toyota Yaris Passenger Sedan Driver Seat as per Federal Motor Vehicle Safety Standards 207/210-A FEA approach*, Internat. Conf. on Energy Efficient Technologies for Sustainability, 2013, 174-177.

Iecbes, *Analysis of Car' Seat Comfort Preference for Malaysian Citizen Using Subjective Ratings*, IEEE EMBS Conf. on Biomedical Engineering and Sciences (IECBES), 2010, 320-324.

Incropera F.P., DeWitt D.P, Bergman T.L., Lavine A.S., *Fundamentals of Heat and Mass Transfer* (6^{th} ed.), John Wiley & Sons, 2007.

Majid N.A.A., Notomi M., Rasmussen J., *Musculoskeletal Computational Analysis of the Influence of Car-Seat Design/Adjustment on Fatigue-Induced Driving*, IEEE Fourth Internat. Conf. on Modeling, Simulation and Applied Optimization, 2011, 1-6.

Makrushin A., Langnickel M., Schott M., Vielhauer C., Dittmann J., Seifert K., *Car-seat Occupancy Detection Using a Monocular 360° NIR Camera and Advanced Template Matching*, IEEE 16th Internat. Conf. on Digital Signal Processing, 2009, 1-6.

Menon M., Asada H.H., *Iterative Learning Control of Shape Memory Alloy Actuators with Thermoelectric Temperature Regulation for a Multifunctional Car Seat*, American Control Conference, 2006, 1-5.

Menter F.R., *Two-Equation Eddy-Viscosity Turbulence Models for Engineering Applications*, AIAA-Journal, **32**, *8*, 269-289 (1994).

Mihai D., *Fuzzy Control for Temperature of the Driver Seat in a Car*, Internat. Conf. on App. and Theoretical Electricity (ICATE), 2012, 1-8.

Nishimatsu T., Hayakawa H., Shimizu Y., Toba E., *Influence of Top Coated Cloth for Sitting Comfort of Car Driver's Seat*, Proc. of the 17th IEEE Instrumentation and Measurement Technology Conf. [Cat. No. 00CH37066], **919/1** (**2**), 2000, 915-919.

Valera A., Benimeli F., Solaz J., De Rosario H., Robertsson A., Nilsson K., Zotovic R., Mellado M., *A Car-Seat Example of Automated Anthropomorphic Testing of Fabrics Using Force-Controlled Robot Motions*, IEEE Trans. on Automation Science and Engineering, **8**, *2*, 280-291 (2011).

Vinoth M., Prema D., *Automated Car Safety Seat Cooling System Using Thermoelectric Cooler*, Internat. Conf. on Computation of Power, Energy, Information and Communication (ICCPEIC), 2014, 488-493.

Voisin A., Levrat E., *Evaluation of a Sensory Measurement Fuzzy System for Car Seat Comfort*, 10th IEEE Internat. Conf. on Fuzzy Systems. (Cat. No.01CH37297), 2001, 805-808.

Wong S.F., Lin B., Luo Z.C., Cong Y.F., *Intelligent Car Seat Design with Ingress, Egress and Sit-to-Stand Services*, IEEE Internat. Conf. on Industrial Engineering and Engineering Management, 2016 (IEEM), 233-237.

Xiaowen Xie X, Zheng B., Xue W., *Object Identification on Car Seat Based on Rough Sets*, IEEE 3rd Internat. Conf. on Communication Software and Networks, 2011, 157-159.

* * * *CFX Modeling Guide – ANSYS CFX Release 18.0,* ANSYS, Inc. (www.ansys.com/products/fluids/ansys-cfx), 2017.

* * * *CFX-Pre User's Guide – ANSYS CFX Release 18.0*, ANSYS, Inc. (www.ansys.com/products/fluids/ansys-cfx), 2017.

ASUPRA SISTEMULUI ELECTRIC DE ÎNCĂLZIRE AL SCAUNELOR PENTRU VEHICULE

(Rezumat)

Studiul prezintă o analiză termo-electrică a scaunelor utilizate în industria automobilelor. Deoarece o sursă de energie electrică este mereu prezentă în orice automobil, o metodă uzuală şi simplă pentru a încălzi scaunele este cea pe cale electrică, energia electrică fiind disponibilă fie de la o bateria de acumulatori fie de la alternator. Oricare ar fi situația, un parametru esențial din punct de vedere electric îl reprezintă consumul de energie. Estimarea acestui necesar de putere în raport cu temperatura dorită pentru scaune reprezintă un obiectiv al studiului. Astfel de informații sunt utile

atunci când se proiectează un astfel de sistem. Analiza este efectuată folosind geometrii tridimensionale obținute prin tehnologie CAD şi calculul pe calculator a dinamicii fluidelor în tandem cu fenomene fizice de transfer termic. Studiul mai include şi o scurtă prezentare asupra noțiunilor fundamentale şi a datelor inițiale necesare pentru a efectua o acest gen de analize.