VIRTUAL TESTING AND EXPERIMENTAL VERIFICATION OF SEAT COMFORT IN DRIVER'S SEAT FOR PASSENGER AUTOMOBILE

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1. INTRODUCTION

The choice of passenger automobile depends on a lot of factors, such as, vehicle type, brand, trend, security, performance, space inside in the vehicle, design of the vehicle interior, additional equipment and other. Also, the seat comfort is very important issue where the owners of automobiles are very careful. Because the long time they spend in their car, people complain on pain caused by the discomfort of the seats. The expectations of customers regarding the seat comfort are continuously increasing.

The manufacturers of seats for passenger automobiles have to respond fast and appropriate on market requirements and offer quality and comfort seats. The manufacture of automobile seats, from the start of product development to the fabrication needs long time and lot of financial resources. The manufacturers of automobile seats make prototypes and test the comfort of their seats with aim to come to the desired results. By making few prototypes, the manufacturers lose a lot of time and financial costs. The vehicle process development is based on the virtual design of the vehicle structure and its verification, unlike from the past when the process development was based on the specific experience of the manufacturers of passenger automobiles. With help of the software for virtual modeling and representation of vehicle structure and the software which can simulate processes and system behavior, today the time needed for testing of physical prototypes is reduced. As a consequence, time and price for testing in obtaining of new or improved product is reduced. Lately, virtual testing of virtual models of automobile seats and virtual models of humans are applied in development of automobile seats.

The aim of this paper is to determine the influence on the construction parameters, such as the thickness and density of polyurethane foam, on the seating comfort for 50th and 80th percentile of man in the driver's seat for passenger automobile.

2. DEFINITION OF COMFORT SEATING ANGLES

The starting point of the process of vehicle design is the description on the people who have to be transported. In order to perform the overall dimensioning of the vehicle, sitting of the driver and other passengers, arrangement of all handling devices and controls, as well as application of all safety regulations and legislation, have to be considered. The design

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process starts with the definition of a user population and with obtaining of human body data.

The area swept out by the movement of the hand can be used to describe ‘workspace envelopes’, zones of easy or maximum reach around an operator. The size and shape of the workspace envelope depends on the position of the human body. In case of driver’s work position in the vehicle, several functional measurements determine the important parameters of the comfort: the angels in elbow joint, shoulder joint, hip joint, knee joint, ankle joint and torso orientation (Figure 1).

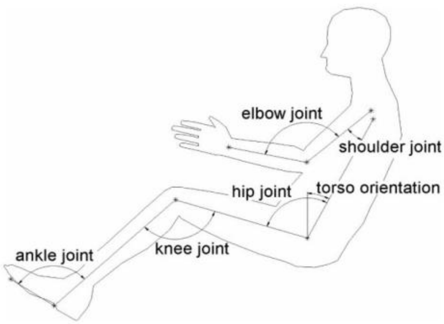

Figure 1*: *Parameters of driver’s work position [17]

In order to obtain the driving comfort, the parameters of driver’s position have to be always in the comfortable range [3]. Few researchers during the past few years have offered their recommendations about the ranges of comfortable angles [10]. There are big differences between their recommendations. Some of them recommend discrete comfort angles, and the others recommend ranges of comfort.

Using the fact that RAMSIS software [15] is specialized for the ergonomics in vehicles, we decided to adopt the recommended discrete comfort angles included in the incorporated RAMSIS data bases (Table 1). They will describe the driver’s seating posture for the following testing conditions.

Table 1: *Adopted comfortable angles for the driver’s seating posture*

Torso orientation	27^0
Angle of shoulder joint	22^0
Angle of elbow joint	127^0
Angle of hip joint	99^0
Angle of knee joint	119^0
Angle of ankle joint	103^0

In this paper, the research is performed with anthropometrc types of 50th and 80th percentile of man. Because the seats are for urban passenger automobile, the analysis with 80th percentile of man is considered in order to encounter bigger population. Experiments for the extreme case of population are not needed because their anthropometric measures are very big and the population is small. About 80% of all population will be covered with the analysis of anthropometric types of 80th percentile of man [1]. The analysis with 50th percentile of man is included for comparison of the results.

3. CREATING OF VIRTUAL MODEL OF HUMAN WITH CHARACTERISTICS OF BONES AND MUSCLES

Geometric data of virtual models of human are taken from the data base of the programming module Human Builder in Catia [5,9]. The virtual human model is composed of two parts, muscle tissue and skeleton. The human skin is not taken in the analysis because it is geometrically very complicated and has little impact on the results of the pressure distribution analysis [6]. The geometry of the skeleton is simplified with the aim to reduce the time needed for calculation of the numerical model with FEA, but the model should not be oversimplified because it will influence the validity of the received values from pressure distribution. Pelvis, femurs and simplified model of skeleton from virtual model of human are shown in the figure 2. The FEA model for numerical calculation is represented with the meshed model of the human with the characteristics of muscles tissue and bones. The mesh is created with tetrahedron elements, which are suitable for complicated geometric models.

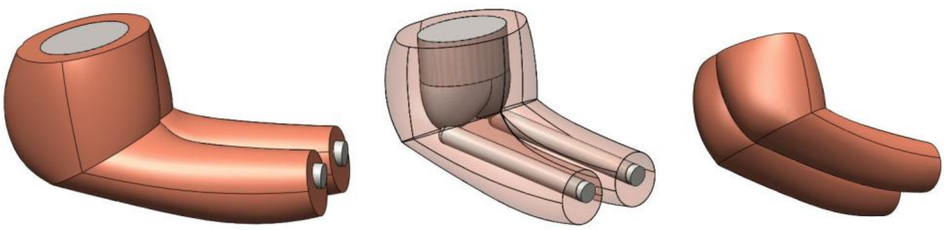

Figure 2: *Geometrical representation of part of virtual model of human – pelvis, femurs and simplified muscule tissue*

In figure 3, the mesh of human muscle tissue is composed of smaller finite elements than the mesh of simplified model of human skeleton. The human skeleton is not the goal of this analysis. The goal of the analysis is the human muscle tissue where the real contact with the seat occures, and from where the values for pressure distribution are read.

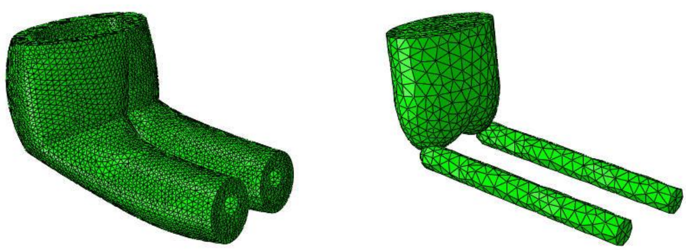

Figure 3: *The FEA mesh model of the seating human*

For human bone structures, the skeleton is assumed to be a rigid body. The human skeleton is a rigid body because the bones are not being deformed when the human body is in the seating position.

Few of the authors that worked with virtual testing of human muscle tissue are (E. Pennestri, P. P. Valentini, L. Vita [9]; A. Siefert, S. Pankoke, H. P. Wolfel [13]; and Verver, M [16]). The authors give different kinds of definition of the human muscle tissue. Verver, M [16] in her doctoral dissertation describes the parameters which define the non-linear mechanical behavior of human muscle tissue with the software package ABAQUS [2,4,7], with hyperelastic isotropic material model of Mooney – Rivlin. The strain energy function is defined by [16] as:

$$W = A_1(J_1 - 3) + A_2(J_2 - 3) + A_3(J_3^{-2} - 1) + A_4(J_3 - 1)^2 \tag{1}$$

where J_1, J_2 and J_3 are the invariants of the right Cauchy-Green strain tensor. The right Cauchy-Green strain tensor is defined by [16]:

$$\underline{C} = \underline{F}^T \cdot \underline{F} \tag{2}$$

were $\underline{F}$ is the deformation tensor. J_1, J_2 and J_3 have been defined [16] as:

$$\begin{aligned} J_1 &= trace(\underline{C}) \\ J_2 &= \frac{1}{2}\left(trace^2(\underline{C}) - trace(\underline{C})^2\right) \\ J_3 &= \det(\underline{C}) \end{aligned} \tag{3}$$

The second Piola-Kirchhoff stress tensor is obtained by differentiating the strain energy function W with respect to the right Cauchy-Green strain tensor [16]:

$$\underline{S} = 2\frac{\partial W}{\partial \underline{C}} \tag{4}$$

The material parameters A_3 and A_4 are function of the coefficients A_1 and A_2:

$$A_3 = \frac{1}{2}A_1 + A_2 \quad \text{and} \quad A_4 = \frac{A_1(5\nu - 2) + A_2(11\nu - 5)}{2(1 - 2\nu)} \tag{5}$$

The values for A_1, A_2 and ν have been set to: $A_1 = 0.00165\ MPa$, $A_2 = 0.00335\ MPa$ и $\nu = 0.49$. These values for material parameters are used by Verver, M [16].

The value for density of human muscle tissue is defined with volume and body mass. The density of human muscle tissue is 0,0026 kg/m^3.

4. CREATION OF THE VIRTUAL MODEL OF DRIVER'S SEAT CUSHION WITH CHARACTERISTICS OF THE USED MATERIALS

The driver's seat for passenger automobile consists mainly of three parts: seat cushion, seat back and head restraint [8]. In the figure 4, the seat cushion assembly is represented with the sheet metal holder and the polyurethane foam. The polyurethane foam from the seat cushion is placed on the sheet metal holder. The sheet metal is with thickness of 1 mm and is supported by the seat mechanical structure on four small perpendicular support area.

Figure 4: *Sheet metal holder, the foam from seat cushion*

The driver's seat cushion for the driver's seat, shown in figure 4, is made by Johnson Controls. The geometrical data are used for the analysis of the influence of the thickness and density of the polyurethane foam on the seating comfort.

The investigation begins with a virtual model of the seat cushion which is the same with the real seat, shown in figure 4. The virtual model of the seat cushion in figure 4 is shown in figure 5. In figure 5 we can see also two elliptical holes, which have a significant influence on the seat comfort. In the figure 6, the dimensions of the seat cushion are shown.

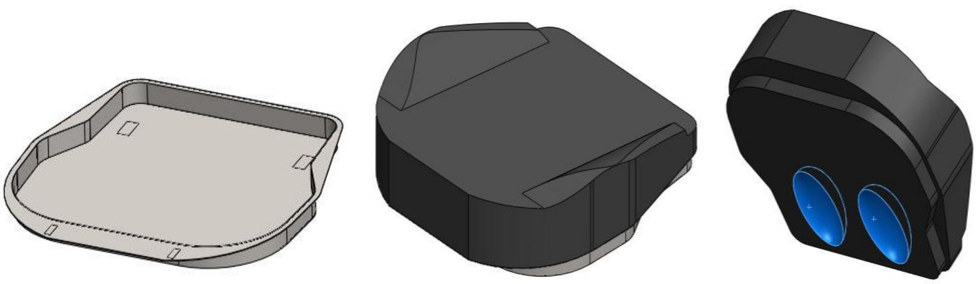

Figure 5: *Virtual model of seat cushion*

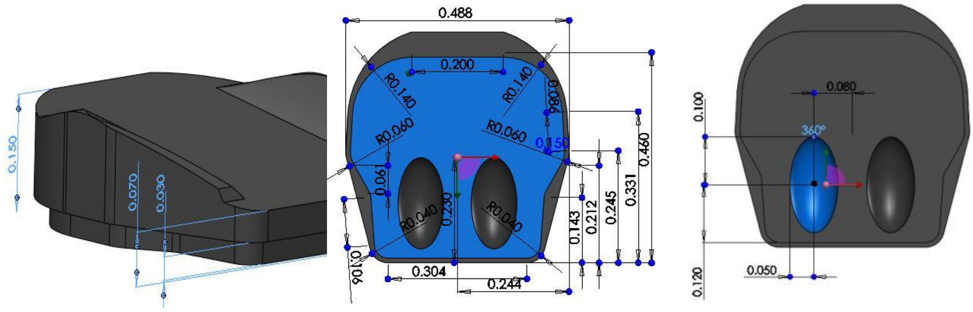

Figure 6**:** *Dimensions of the seat cushion*

The meshed model with tetrahedron elements is prepared to be used in FEA. The meshed model of the seat cushion, which corresponds to the virtual model of the seat in figure 5 is shown in figure 7.

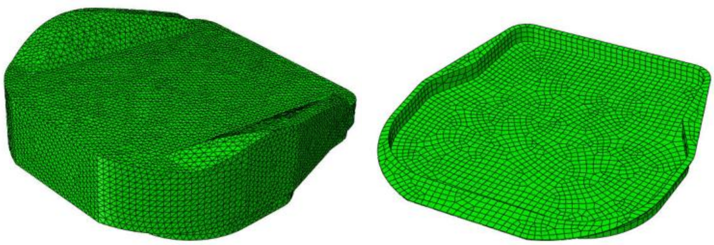

Figure 7**:** *The meshed model of seat cushion*

As means for the description of foam materials in ABAQUS [2,4,7,11], a hyper-elastic law is used. The elasticity of the material is described via the potential energy U of elastic deformation. The applied potential function for foams (Eq. (6)) consideres nearly full compressibility of polyurethane foams.

Strain energy potential of compressive foams is computed as Ogen funcion:

$$U = \sum_{i=1}^{N} \frac{2\mu_i}{\alpha_i^2} \left[\left(\lambda_1^{\alpha_i} + \lambda_2^{\alpha_i} + \lambda_3^{\alpha_i} - 3 \right) + \frac{1}{\beta_i} \left(J^{-\alpha_i \beta_i} - 1 \right) \right] \tag{6}$$

The potential energy *U* is defined by the following parameters: μ_i are the coefficients of initial shear modulus, λ_{1-3} the principal stretches, α_i the standard material parameter, β_i the coefficients for degree of compressibility and *J* the elastic volume ratio. The free material parameters μ_i, α_i and β_i are determined experimantally, with the average values out of loading and unloading.

With bold line in figure 8, are represented the nonlinear characteristic of polyurethane foam which is described with Ogden function with N =1, $\mu = 10kPa$, $\alpha = 8$ and Ogden function with N =2, $\alpha_1 = 17,4$, $\mu_1 = 18,3kPa$, $\alpha_2 = -2,0$, $\mu_2 = 0,21kPa$ and Poisson radio $\nu = 0$ [12].

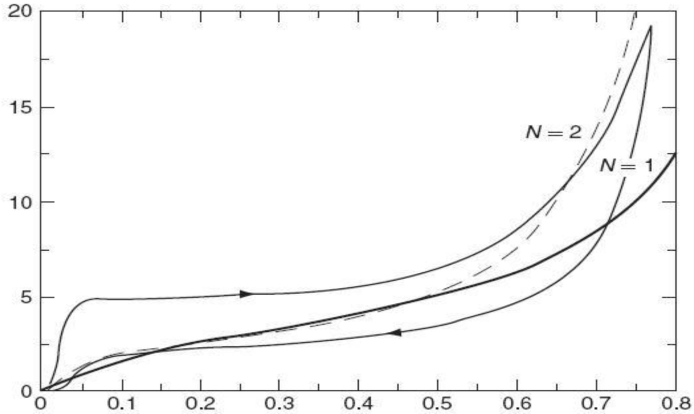

Figure 8: *Nonlinear characteristic for flexible polyurethane foam [12]*

Ogden function from second degree with N =2 is used for description of nonlinear behavior of flexible polyurethane foam [14].

The density of polyurethane foam is given from the manufacturer Johnson Controls Inc. and is 50 kg/m^3.

5. EXPERIMENTAL TESTING AND VIRTUAL TESTING OF THE MODEL

5.1. Measurement equipment

For obtaining of pressure distribution in the contact surface between the driver's seat and the driver the equipment from manufacturer XSENSOR Technology Corporation is used. The measurement equipment consist of few elements such as: sensor platform X3 PRO, sensor pad for measuring of pressure distribution, Mini – B USB cable, 12 VDC 3.75 A AC/DC power supplier, electronic for connection of sensor pad and PC, X3 node, PC and software XSENSOR - X3 MEDICAL v6.0 used for data acquisition. The sensor pad is of type PX100:36.36.02 composed of a seat sensor with resolution of 1296 sensible points, with excellent flexibility and endurance. The measurement pressure range is between 10 – 200 mmHg. The resolution of pressure measurement is 1,27 cm. The elements which are included in the measurement equipment for measuring of pressure distribution between two bodies in contact are shown in figure 9.

Figure 9*: *XSENSOR - X3 PRO system for measuring of pressure distribution

5.2. The results from the experimental measuring and virtual testing

For measuring of the pressure distribution between the driver's seat cushion from passenger automobile and the man, we use the seat described in figure 4. The measuring is performed with men from 50th and 80th percentile. The human weight of 50th percentile man before the testing was 71 *kg* and for 80th percentile man was 78,5 *kg*. The measured weights are the same with the weights of the corresponding virtual models. Before the measuring the participants were seated according to the comfort angles. The measured pressure distribution and the values for maximum contact pressure are shown in figure 10.

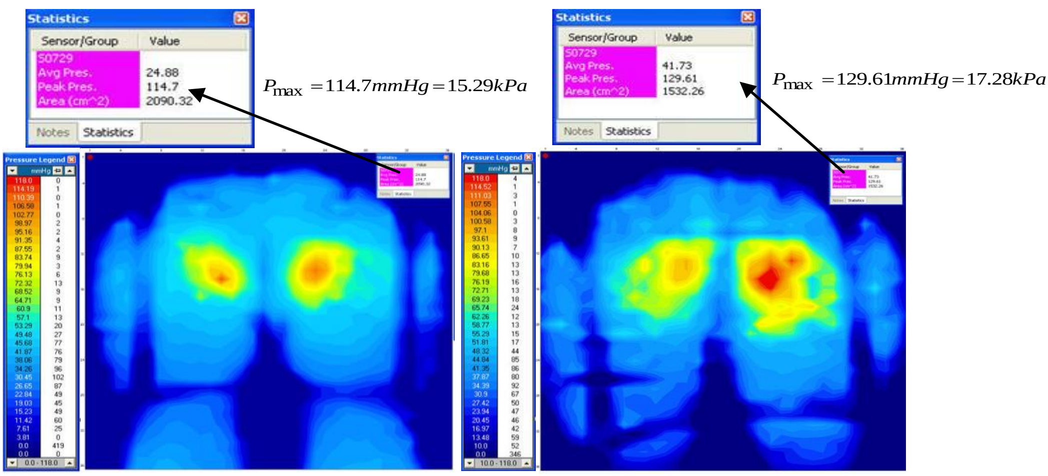

Figure 10: *Pressure distribution between seat cushion and participants from 50th and 80th percentile*

The boundary conditions in the simulation are defined on the seat geometry. In reality, the seat is fixed from below on four supports (in precisely defined areas) located on the sheet mental. The fixing is defined with translations and rotations equal to zero.

The initial conditions in the simulation is defined for the time $t = 0$ s. In the initial moment of the simulation, the virtual model of the human is placed above the seat without a contact between them, and the initial speed is set to 0.

The loading condition in the simulation is defined with gravity of 9810 mm/s^2.
The contact between the virtual model of human and the seat cushion is defined with selecting of surfaces that come in contact. In reality, there is friction between contact surfaces. The coefficient of friction between contact surfaces is 0.75. The coefficient of friction is obtained experimentally [12].

The pressure distributions on the seat contact surface resulting from the analyses for 50th (left) and 80th (right) percentile are shown in figure 11.

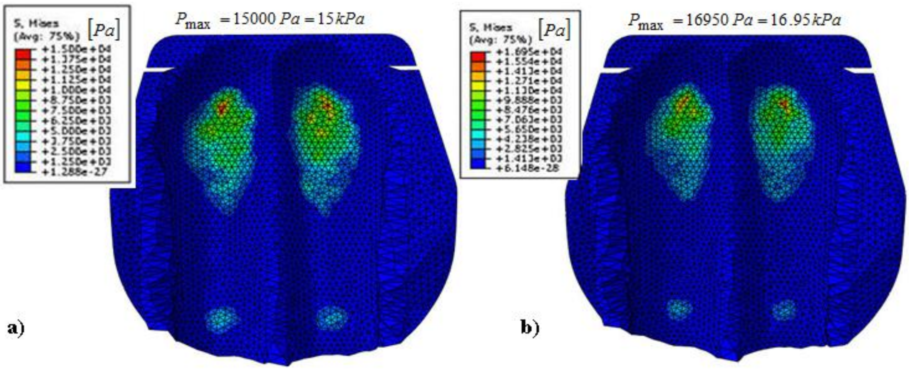

Figure 11: *Pressure distribution on the contact surface of virtual seat cushion and virtual model of human from; a) 50th and b) 80th percentile*

The experimental values of the maximum contact pressure in the contact surface between the seat cushion and the human are given in table 2. The measured values are close to the values obtained from the virtual testing.

Table 2: *Values for maximum contact pressure*

Human percentile	Maximum contact pressure from experimental measurement [kPa]	Maximum contact pressure from virtual testing [kPa]
50-tile	15,29	15,00
80 -tile	17,28	16,95

The human skin and seat cover are not considered in the virtual testing. For this reason, there is a difference in the results obtained from the experiment and the virtual testing of about 2%. This differnce is small and approves the use of the virtual model instead of the experimental testing of seat prototypes.

6. INFLUENCE OF THICKNESS AND DENSITY OF POLYURETHANE FOAM ON THE SEATING COMFORT

According to the data found in literature [12], comfortable seats are seats with maximum contact pressure less from 12 *kPa*.

For the seat geometry shown in the figure 5, the influence of the foam thickness on the maximum contact pressure is examined using the virtual models of the seat and human from 50th and 80th percentile. The initial seat has foam thickness of 70 mm. If the foam thickness is reduced to 60 *mm*, 50 *mm*, and 40 *mm*, than the contact preasure increases, first slowlly and than rapidly, such as shown in figure 12.

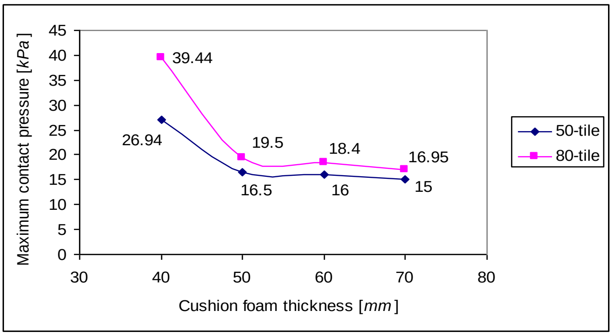

Figure 12: *Relationship of maximum contact pressure and seat cushion thickness*

To examine the influence of the dencilty of the polyurethane foam on the contact preassure, six virtual testings for design shown in the figure 5 are performed with the foam thickness of 70 mm. The results obtained from virtual testing of six virtual models of seats with density of 30 kg/m^3, 40 kg/m^3 and 50 kg/m^3 and two types of virtual models of human from 50th and 80th percentile are shown in figure 13.

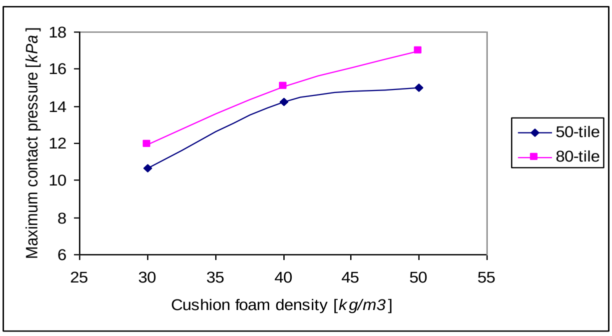

Figure 13**:** *Relationship of maximum contact pressure and density of the polyurethane foam*

7. CONCLUSIONS

The virtual testing of seating process in driver's seat for passenger automobile allows fast and simplified review of the phenomena that occurre during the seating. This virtual testbench provides a mechanism for investigation of new design ideas for new types of seats. Using this virtual testbench, the new design of seat can be validated in the product development phase, thus avoiding the financial costs and saving time for making physical prototypes.

The influence thickness of the seat cushion foam on the maximum contact pressure is examined. From the diagram shown in the figure 12, it is obvious that with reducing of the foam thickness below certail limit value, the seating comfort is deteriorating gradually.

The foam density has an important influence of the value of the maximum contact pressure. As shown in figure 13, with reducing of the foam density the value of the maximum contact pressure is decreasing slowely, and with that the seating comfort is improving.

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