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Human body modeling for engineering design

Modelowanie ciała człowieka na potrzeby projektowania inżynierskiego

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The paper presents the method of human body modeling in order to perform the FEM simulation of pressure distributions on the seat components. A CAD model was developed, taking into account internal anatomical features. As a human position, the system was based on the support of the chest, buttocks and shins.

KEYWORDS: contact pressure, FEM, human body

When designing devices directly cooperating with humans, different models of the human body are used to develop an ergonomic workplace. These models are most often developed on based on anthropometric atlases containing a number of statistical data concerning a particular population, such as the dimensions of individual parts of the human body and their mass and range of motion [1]. The figures given relate most frequently to three representative models of the human body: 5c, 50c and 95c. The symbol 5c is the five-pentyl model. Centyl (percentile) is a statistical unit that describes the position of the result relative to the whole group. In the case of anthropometric features, model 5c says that 5% of the subjects had dimensions of individual body parts smaller than the model shown. Some CAx systems contain a module with implemented anthropometric data. One example is the Ergonomics Design & Analysis module of the CATIA program. With its help, a model of a manikin or a mannequin from one of several available populations and with a specific percentile value can be imported into a device design. Thanks to this, you can specify the dimensions of the designed device, the user's working space or the scope of view.

In the case of designing some devices, such as armchairs, comfort of use is very important. Many psychophysical factors affect its level. Literature defines the relationship between comfort and usable parameters. Vibrations and pressure distribution are two mechanical parameters that are closely related to comfort [2]. In this work, the problem of pressure has been raised. Excessive and long-lasting pressure can cause skin changes, sometimes leading to pressure sores. Therefore, minimizing pressure is extremely important.

As part of the research work carried out at the Department of Machine Design at the Rzeszów University of Technology, the concept of an innovative trolley seat solution for people with disabilities [3, 4] was created, providing support for the chest, thighs and lower legs (fig. 1).

The presented solution has a number of facilities in relation to the classic chair [5], and in particular allows changing the distribution of surface pressure of the seat on the human body. Thanks to this, you can temporarily relieve the most loaded areas. The solution of the mechanism coupling the support elements with each other was submitted for patent protection - by the decision of August 2016, the patent was granted [3].

In order to determine the range of angles between the elements of the seat and the corresponding changes in the pressure distribution, it was decided to perform simulations with the use of the finite element method to select the preferred seat layout for different human models.

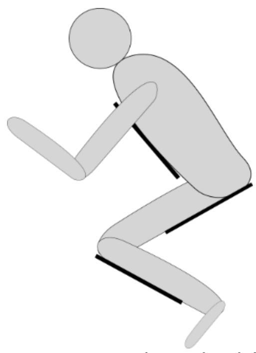

Fig. 1. Concept of a support system in a wheelchair for people with disabilities

CAD model of the human body

In order to perform FEM simulation, it is necessary to develop models of the human body. They can be made on the basis of anthropometric data or using reverse engineering methods. Due to the complexity of models, it was decided to use computed tomography (CT). Data obtained from scanning is saved in the standard DICOM format (digital imaging and communications in medicine). These data consist of a series of images. The distance between the layers (the next images) is equal to the scanning resolution.

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One of the free programs for processing DICOM files is 3D-Slicer, which allows them to be exported to universal formats, such as .stl.

The data from the scan are shown in fig. 2. After their processing, the bone system model shown in fig. 3 was made, on which one of the bones was enlarged to show the accuracy of the models.

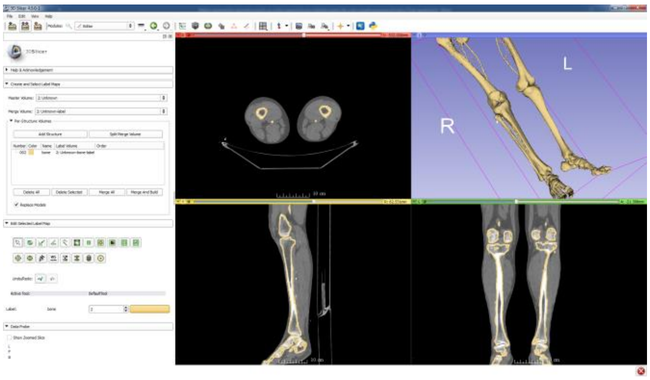

Fig. 2. Medical data obtained as a result of scanning

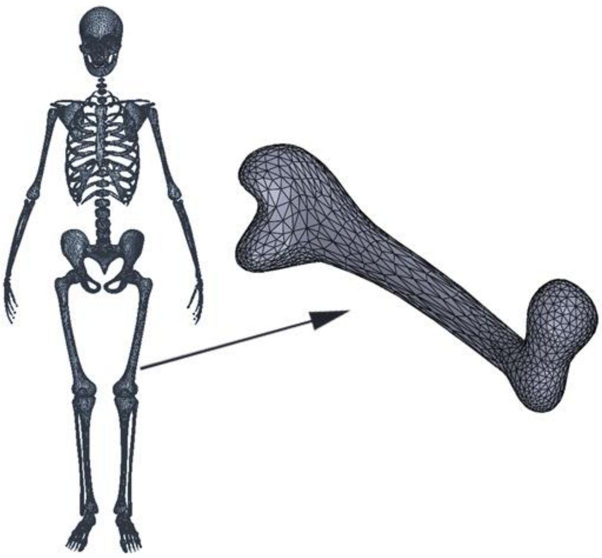

Fig. 3. Model of the skeletal system

By analogy, it was decided to approach the problem of obtaining an external surface. Due to the complexity of the model, it was simplified, especially in areas that are not significant (from the point of view of simulation), such as hands, feet and head. The model was obtained in an upright position (fig. 4a). Some simplifications have also been made in the stands so that the position of the model can be easily changed depending on the configuration of the seat. An additional object in the knee was inserted, providing a smooth transition to different variants of limb placement (fig. 4b). These operations were carried out in the SolidWorks [6] environment.

The skeletal system, including the spine, was also simplified, and in the FEM analysis only the bones that have a direct impact on the distribution of pressure of the analyzed seat on the human body were taken into account.

The bone tissue model was applied to the soft tissue model (fig. 5a), and then the solids were subtracted from each other using Boolean operations. In this way, the deformable model shown in fig. 5b was obtained.

As a simplification, the model was divided along the plane of symmetry.

a) *b)*

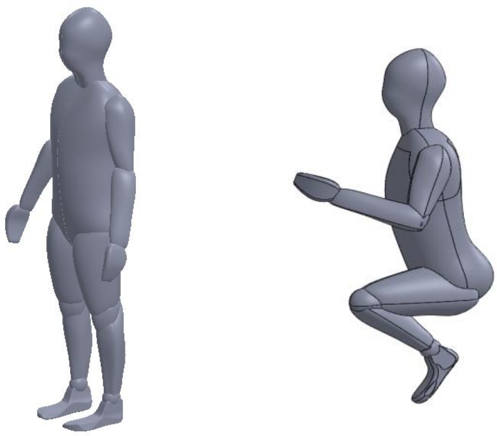

Fig. 4. Model of the human body in the position: *a*) standing, *b*) occupied in the proposed seat structure

a) *b)*

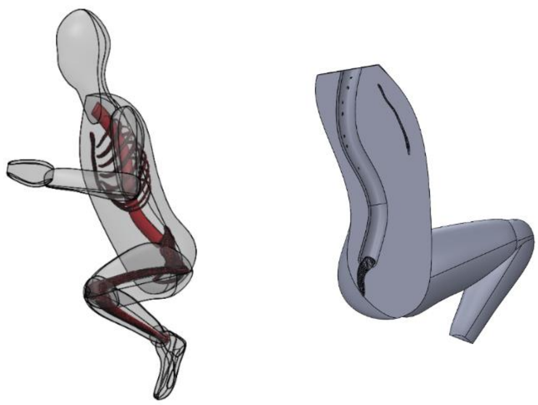

Fig. 5. Model of the human body: *a*) with a bone model applied, *b*) adopted as a deformable body after deduction of bone models

FEM model of the human body

In order to perform FEM simulation, CAD models were imported into the ABAQUS environment. The model from fig. 5b was accepted as deformable with material coefficients taken from the literature [7]. An isotropic material model, hyper-elastic, and incompressible were assumed. All other objects were treated as rigid bodies. A grid of the second-order tetrahedral elements was put on the solids (fig. 6). Between bones and elastic elements, contact was established in the form of permanent binding, while between the seat and the body of the man - friction contact. Gravity was taken as a burden. The seat elements have been fixed. In symmetrical cases, calculations were made for half of the model.

As a result of the simulation, a surface pressure distribution was obtained (fig. 7).

Presented model has a number of simplifications. In addition to the aforementioned, the distinction of soft tissues such as fat, skin, muscles and internal organs should also be indicated. All these simplifications to some extent affect the accuracy of the results obtained, but also significantly simplify the computational problem. In order to determine the consistency of such results with actual conditions, the FEM model should be validated by experimental studies confirming the validity of the adopted assumptions. This can be used for pressure mats used by car concerns for testing seats in vehicles.

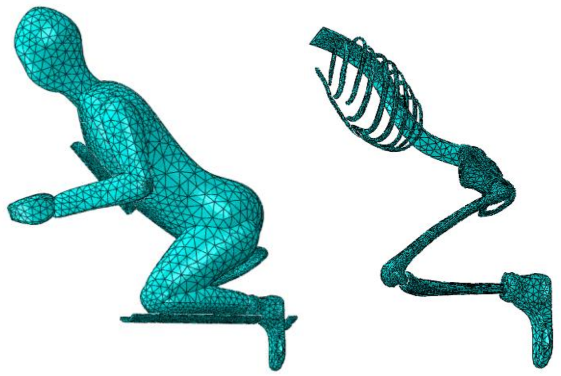

Fig. 6. Discrete model adopted for simulation

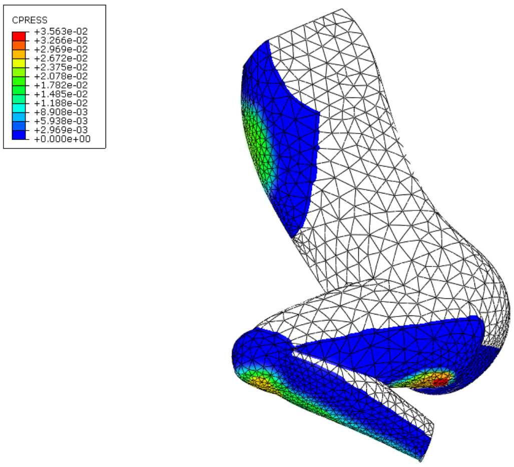

Fig. 7. Distribution of pressure (in MPa) on the human body for an exemplary configuration of the seat

Conclusions

In the case of confirmation of the validity of adopted assumptions by workplace tests, presented method of modeling the human body (and the use of such a model for numerical simulations) will allow to design devices that are beneficial from an ergonomic point of view. Knowing the distribution of pressures for different seat positions, it is possible to modify its position so as to maximize the time of human being in the wheelchair without exposing it to skin lesions. The presented approach makes it possible to optimize the structure for a specific person.

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