Modeling of Pressure Distribution of Human Body Load on an Office Chair Seat

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2013

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This thesis is submitted for completion of Master of Science in Mechanical Engineering with emphasis on Structural Mechanics at the Department of Mechanical Engineering, Blekinge Institute of Technology, Karlskrona, Sweden.
Abstract:

For a design of an office chair, the pressure distribution of human body load on the chair seat has to be known. This information is the key characteristic of an office chair.

This thesis concerns a mechanical model, its implementation and simulation of a human body sitting on an office chair’s wooden seat cushion. Firstly, Autodesk Inventor is used for modelling the human body, and the seat cushion. Secondly, we use the finite element method to mesh the models. Thirdly, fixed support and gravity load for the models are applied. Finally, the pressure distribution on the contact area is simulated in Autodesk Inventor.

The peak pressure comes out in the contact area between ischium and seat cushion, what matches results from former reports, based on the measure of the pressure distribution of the contact region between human body and seat cushion using many sensors. Furthermore one can see different sitting postures for different seating positions. Besides, the peak deformation of the seat cushion occurs at almost the same place as peak pressure does.

The simulation anatomical based model may be a good and efficient tool to design an office chair seat cushion. The anatomical based design can reduce musculoskeletal disorders caused by office work.

Keywords:
Contact area, Deformation, Finite element analysis, Human body, Mesh, Pressure distribution.
Acknowledgements

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Karlskrona, August 2012

Hao Zhu
## Contents

1. **Notation** ................................................................. 4
2. **Introduction** .......................................................... 5
3. **Survey of related work** ........................................... 6
4. **Problem statement and contribution** ......................... 17
5. **Problem Solution** .................................................... 18
   5.1 Assumption ............................................................. 18
   5.2 Problem Modelling .................................................. 20
       5.2.1 Modelling the human body ................................ 20
       5.2.2 Modelling the seat cushion ............................... 22
       5.2.3 Assembling the model ....................................... 24
   5.3 Model Materials ..................................................... 26
   5.4 Local Mesh control on the model ............................... 28
       5.4.1 Choosing the contact area in Autodesk Inventor .... 29
       5.4.2 Mesh of the non-contact area ............................. 29
       5.4.3 Mesh of the leg ................................................ 31
       5.4.4 Mesh of the trunk ............................................ 33
       5.4.5 Mesh of the seat cushion in Autodesk Inventor ....... 34
   5.5 Constraints for the seat cushion ............................... 35
   5.6 Load modelling ...................................................... 36
   5.7 Simulations and results .......................................... 38
   5.8 Analysis of the results ........................................... 45
6. **Conclusion and future work** .................................... 47
   6.1 Conclusion ............................................................ 47
   6.2 Future work .......................................................... 48
7. **References** ............................................................ 49
1 Notation

\( p \quad \text{Pressure on the seat cushion} \\
\( x \quad \text{Coordinate X} \\
\( y \quad \text{Coordinate Y} \\
\( z \quad \text{Coordinate Z} \\

\textbf{Abbreviations} \\
\text{FEM} \quad \text{Finite Element Method} \)
2 Introduction

For people who work in an office, it is common to sit on an office chair more than two hours without any break. Although an office work has a low demand in physical strength, sitting on an office chair for a long time increases the risk of getting some chronic diseases. These diseases contain low back disorder, sciatica, pressure ulcer and others.

For this reason, the design focusing on sitting comfort and anatomical aspects of office chairs have become an important issue in the prevention of musculoskeletal disorders at office workplaces. In order to design an office chair seat cushion suitable for people who sit for a long time every day, we should know what the pressure distribution on the seat cushion is.

Generally, two modelling methods can be useful for this purpose. One is an experimental method using many pressure sensors to record the pressure in each node of the contact area, between a human body and a seat cushion. This requires a real office chair, and then many people have to be involved in the measurement experiment. After transferring measurement data, a heuristic model can be defined. Another method uses a theoretical model implemented on a software platform. In this method, it is very easy to change chair’s virtual parameters, to achieve the desired properties.

The aim of this thesis is to propose a software based prototype which can be useful to simulate the pressure distribution of the contact area between the human body and the seat cushion. Such a model can be improved by adding details on the shape of human body, replacing the flat seat cushion, change the density of the seat cushion and so on. With more research, more accurate results of deformation and pressure distribution will be obtained. This can reduce the cost and time in the process of designing an office chair.

After a software model has been finished, the finite element analysis module in Autodesk Inventor is used to cope with quantitative analysis.
3 Survey of related work

A used medical model as this shown in Figure 3.1\cite{1}, do not apply a 3D representation.

\textit{Figure 3.1. A female body model} \cite{1}.
But, there are some models of human body such as the model of Josh \cite{2}, see Figure 3.2, which uses three dimensional approach. However his model does not consider soft tissues, blood, bone and other organs of human body.

![Three-dimensional human body model in Solidworks](image)

*Figure 3.2. Three-dimensional human body model in Solidworks\cite{2}.*

Todd and Thacker’s \cite{3}, propose a linear three-dimensional numerical model of a male’s and female’s buttock. They show that a finite-element model could be used as a powerful tool to analyse the pressure distribution on the cushion under the buttock. Von Mises stress distribution for a seated male is shown in Figure 3.3. The deformation in the vertical direction is shown in Figure 3.4. From this work, the minimal principal stress is 17 kPa and 15 kPa at the buttock-cushion interface for the seated male and female subject respectively.
Figure 3.3. Von Mises stress for seated male’s buttock\textsuperscript{[3]}. 

Figure 3.4. y- and z- displacements for seated male’s buttock\textsuperscript{[3]}. 

8
Wagnac et al. in [4], show that the peak pressure is 37.1 kPa at the bone-soft tissue interface when a human sits on a contoured cushion, which represents 18% reduction comparing to the flat cushion results. Additionally, peak value of von Mises stress is reduced by 12%; maximum shear stress is reduced by 9% and peak principal compressive strain underneath the ischial tuberosities is reduced by 19%. Peak pressure in the coccyx area shows a significant reduction of 30%. To obtain this result, they develop a clinical-oriented method to generate a subject-specific FE model of buttocks and also the cushion is modelled in the same way. A realistic pressure distribution is produced, thus provides it as an efficient tool for the design and a selection of suitable seat cushions. The FE model which is used in their study corresponds to lumped soft tissue, and the material exhibits viscoelastic behaviour. Their results for the internal stress and strain distributions under the ischial tuberosities when seated on the flat foam cushion can be seen in Figure 3.5 to Figure 3.9. For all parameters, peak values occur under the left ischium.

![Pressure distribution](image)

*Figure 3.5. Pressure distribution (kPa)*[4].
Figure 3.6. Von Mises stress distribution (kPa)\textsuperscript{[4]}.

Figure 3.7. Principal compressive strain distribution\textsuperscript{[4]}. 
Figure 3.8. Interface pressure distribution obtained by experiment\textsuperscript{[4]}.

Figure 3.9. Interface pressure distribution predicted by the FE model\textsuperscript{[4]}. 

\textsuperscript{[4]} Reference number or source.
In Seok-Jae-Chu’s work \cite{5}, the human body is assumed as a rigid surface and the seat cushion is assumed as a solid element. He uses both the finite element method and input stress-strain relation to find the contact stress between a seat cushion and a human body. In his study, the approximate strain calculation using the input stress-strain relation without the finite element analysis is also used to predict the contact stress; a seat cushion mounted on the zigzag spring yields 10% more displacement of the rigid human body than that mounted on the steel pan. He creates a finite element model of human body shown in Figure 3.10. From his study, in order to determine the contact stress, the input stress-strain relation can also be useful. His result can be seen in Figure 3.11 where the peak value for contact value is 18 kPa.

![Figure 3.10. Seok-Jae-Chu’s finite element model\cite{5}.](image.png)
By getting the pressure distribution between a human body and a soft seat cushion, and also between a human body and a hard seat cushion, Dongyan Chen [6] indicates that a soft seat cushion satisfies people’s requirement for a suitable seat. In her study, the Xsensor software is used to record the test data, which contains the original data of the pressure distribution, and then Rhinoceros is used to produce a curved surface on the seat, which allows avoiding excessive local pressure discomfort. Her experimental equipment is shown in Figure 3.12. In her work, the pressure distributions on the inflexible and flexible seat cushion are shown in Figure 3.13 and Figure 3.14 respectively.

Figure 3.11. Seok-Jae-Chu’s result of the contact stress [5].
Figure 3.12. An inflexible seat with body pressure distribution sensor\textsuperscript{[6]}.

Figure 3.13. Pressure distribution on an inflexible seat cushion under the load from human body\textsuperscript{[6]}.
Chen Yuxia et al. in [7], use a body pressure measurement system from Tekscan to acquire the data of pressure distribution. They found that the subsidence of the sponge seat cushion and layered structure have a great influence on the comfort of sitting posture. In the conclusion, they suggest to optimize the seat cushion by changing the layered structure as shown in Figure 3.15.

Figure 3.14. Pressure distribution on a flexible seat cushion under the load from human body [6].

Figure 3.15. Chen Yuxia, Shen et al.’s suggestion for the layered structure of seat cushion [7].
David M Brienza et al. [8], assume that the deformation is a good indicator of peak pressure and pressure gradients. They use a lot of electronic shape sensors, a computer-automated seating system and a force sensing array to find a good seating surface. Their experimental equipment is shown in Figure 3.16; the sensors are used to find the pressure of interface and soft tissue stiffness. The peak pressure for flat cushion is shown in Table 3.1.

**Figure 3.16.** Experimental equipment for measuring the pressure of interface and soft tissue stiffness [8].

**Table 3.1.** Means and standard deviations for pressure and pressure gradient for all subjects on the flat cushion [8].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Flat Cushion (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak pressure</td>
<td>23.1±4.1</td>
</tr>
<tr>
<td>Peak gradient</td>
<td>14.3±2.3</td>
</tr>
</tbody>
</table>
4 Problem statement and contribution

As it was mentioned in the previous section, there are two main methods to estimate the pressure distribution on an office chair under the load of human body. One is by using pressure sensors and the other one is by using numerical simulation. The pressure distribution on an inflexible flat seat cushion affects the deformation of buttock under the weight of human body. This deformation is unique, because the shape of human body varies for different people. The modelling process becomes even more complex when it comes to a flexible seat cushion, since two additive variables are needed: one is the deformation of buttock and legs when they are under the load from the weight of human body, the other is the deformation of the flexible seat cushion when it is under the load of the weight of human body.

In this thesis we consider the stationary human body sitting on the office chair. Our problem is to model a linear three dimensional human body and a chair with a hard flat surface, to estimate the pressure distribution of the human body loading on the chair surface. Assume that normally, a person working in an office applies three sitting postures: working, normal, relaxing. We aim to investigate how to model the pressure distribution under the load of human body in the vertical direction on the chair seat cushion.

The main contribution of this paper is a proposal of a simplified and efficient software based model, which can be used as a prototype to simulate the pressure distribution of the human body on the office chair. We use Autodesk Inventor to build the model of the human body and seat cushion. And then use finite element method to analyse the deformation and the pressure distribution of the seat cushion.
5 Problem Solution

5.1 Assumption

To model the pressure distribution on the contact area between the human body and the seat cushion, a mathematical approach is used. To create such a model a number of problems have to be considered, for instance a model of a human body consisting of several different substances such as blood, bones, soft tissue, muscle, internal organs, have to be considered. Also the complex shape of human body needs to be studied. It has to be taken under account that the deformation of human body when it is in contact with a seat cushion is irregular. To accomplish the balance between accuracy and complexity of the model of a person sitting on a seat cushion shown in Figure 5.1, some simplifications are made:

![Figure 5.1. A model for a person sitting on a seat cushion.](image)
• Only the legs, trunk and their deformation are taken into consideration.
• The upper surface of seat cushion is taken as an inflexible flat plane.
• Soft tissues, bones and other human organs are not considered.
• Only vertical deformations of seat cushion are regarded.

We apply the Finite Element Method (FEM) which is a commonly used numerical analysis tool suitable for stress analysis.

In this paper, we model the trunk, legs and seat cushion by using Autodesk Inventor.
5.2 Problem Modelling

5.2.1 Modelling the human body

The human body irregularity causes a modelling problem. After researching different solutions the model from Blair Hollshwandner has been chosen \(^9\). The original linear three dimensional model of human body in Solidworks is shown in the Figure 5.2.

![Figure 5.2. Original 3D model of human body \(^9\).](image)

For later simulation and data analysis which will be done in Autodesk Inventor 2012, this 3D model of human body in Figure 5.2 will be transferred to a document in STEP file format in Solidworks. Then we can use Autodesk Inventor 2012 to open and edit this file.

As it was assumed for the efficient approximation, we only model the trunk, legs and seat cushion. The used model of human body is shown in Figure 5.3. In order to join the human body with the seat cushion, the contact area between human body and the upper surface of seat cushion is considered as flat plane. This contact area is shown in Figure 5.4.
The model of right leg can be seen in Figure 5.5. The size of legs is determined on the basis of data from Jin Gu et al. [10], Gavriel Salvendy [11]. The length of leg in the z axis direction is 554 mm, the height in the y direction is between 200 mm and 372 mm, and width in the x direction is 106 mm. The model of trunk is shown in Figure 5.6, which is also based on the same data from Jin Gu et al. [10], Gavriel Salvendy [11]. Its thickness in the z axis direction is between 107 mm and 227 mm, the height in the y direction is 718 mm, and width in the x direction is 376 mm.
5.2.2 Modelling the seat cushion

To model a seat cushion, first we draw a 2D sketch of seat cushion in Autodesk Inventor. The 2D sketch of seat cushion is show in Figure 5.7. It is a square and its side length is 540 mm. Then we use the Extrude function in Autodesk Inventor to get the three dimensional model of seat cushion as shown in Figure 5.8. The thickness of the seat cushion is 60 mm. We use the Fillet function in Autodesk Inventor to optimize edges of seat cushion as shown in Figure 5.9.
Figure 5.7. 2D sketch of seat cushion.

Figure 5.8. Three dimensional model of seat cushion.
5.2.3 Assembling the model

Autodesk Inventor is used to assemble the model. The assembled model of a human body sitting on a seat cushion is shown in Figure 5.10. The models of a human body sitting on a seat cushion in three sitting postures: working, normal and relaxing, are shown in Figure 5.11 to Figure 5.13. When a person is working, the angle between trunk and horizontal plane is defined between 60° and 80°. When a person is just sitting on the office chair in neutral position, the angle between trunk and horizontal plane is defined between 85° and 95°. When a person is relaxing on the seat cushion, the angle between trunk and horizontal plane is defined between 105° and 120°.
Figure 5.10. Assembling the model.

Figure 5.11. Working sitting posture.
5.3 Model Materials

Normally, the seat cushion is made of sponge. Unfortunately, there is no such selection in Autodesk Inventor. We have found some references such as D.V.W.M. de Vries’ work [12] but no data about the physical parameter of sponge such as density, Young’s modulus, Yield strength are given out. However since wood has good mechanical properties with incomplete elasticity and good compressive strength, we chose oak as the material for seat cushion.

The human body consists of soft tissues, blood, bone and other organs. And for this reason a complex modelling is required. Nevertheless since the average density of human body is close to the density of water, we chose abs plastic, whose properties are similar to water, as the material of human body model in Autodesk Inventor. This material should approximate enough good the human body properties required in our model. Some parameters for the

Figure 5.12. Normal sitting posture.

Figure 5.13. Relaxing sitting posture.
materials which are chosen for the model of human body and seat cushion are shown in Table 5.1 and Table 5.2 below. Because our problem considers only pressure and deformation, thermodynamics parameters such as thermal conductivity, coefficient of linear expansion, and specific heat do not need to be regarded.

**Table 5.1. Parameters of abs plastic, the modeled material for human body.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1.060e+3</td>
<td>kg/m³</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>2.890e+9</td>
<td>Pa</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.380</td>
<td>-</td>
</tr>
<tr>
<td>Yield strength</td>
<td>4.033e+7</td>
<td>Pa</td>
</tr>
<tr>
<td>Ultimate tensile strength</td>
<td>4.000e+7</td>
<td>Pa</td>
</tr>
</tbody>
</table>

**Table 5.2. Parameters of oak, the material for seat cushion.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>560</td>
<td>kg/m³</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>9.300e+9</td>
<td>Pa</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.350</td>
<td>-</td>
</tr>
<tr>
<td>Yield strength</td>
<td>4.660e+7</td>
<td>Pa</td>
</tr>
<tr>
<td>Ultimate tensile strength</td>
<td>5.500e+6</td>
<td>Pa</td>
</tr>
</tbody>
</table>
5.4 Local Mesh control on the model

Local mesh control provides specific meshing for small or complex sure faces where the normal mesh size does not provide sufficiently detailed results. This possibility is especially useful when we want to improve stress results in a local or contact area \[13\]. The more accurate local mesh control is applied on the model, the more accurate results of deformation and pressure distribution will come out. But at the same time, the calculation burden has also been increased. So one should keep balance between accuracy and computational complexity.

In this research, the local mesh control is based on the importance of the mesh parts, i.e. the touching area will be meshed with more accurate elements comparing to the rest parts. The mesh of the whole model created in Autodesk Inventor is shown in Figure 5.14, where we can see how the mesh density varies. Such approach should be sufficient for the analysis purpose.
5.4.1 Choosing the contact area in Autodesk Inventor

For the contact area, i.e. the surface on human body marked in blue in Figure 5.15, the side length for each element is 10 mm.

![Contact area on human body](image)

**Figure 5.15. Contact area on human body.**

5.4.2 Mesh of the non-contact area

Non-contact area of the model marked in blue colour is shown in Figure 5.16. The size of mesh applied on the non-contact area is shown in Figure 5.17 with default value, which is defined and created by Autodesk Inventor itself. The meaning for default value is shown in table 5.3.
Figure 5.16. Non-contact area of the model.

Figure 5.17. Default value of the mesh size for non-contact area in Autodesk Inventor
### Table 5.3. Default value of the mesh size.

<table>
<thead>
<tr>
<th>Setting</th>
<th>Use</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Element Size</td>
<td>As a fraction of bounding box length</td>
<td>0.1</td>
</tr>
<tr>
<td>Minimum Element Size</td>
<td>As a fraction of average size</td>
<td>0.2</td>
</tr>
<tr>
<td>Grading Factor</td>
<td>Effects the uniformity of the mesh transition between fine and coarse mesh. Specifies the maximum edge length ratio between adjacent element edges.</td>
<td>1.5</td>
</tr>
<tr>
<td>Maximum Turn Angle</td>
<td>Effects the number of elements on curved surfaces. The smaller the angle, the greater the number of mesh elements on a curve.</td>
<td>60 deg</td>
</tr>
</tbody>
</table>

#### 5.4.3 Mesh of the leg

We use Autodesk Inventor to mesh the model of leg. The local mesh control for the contact area on the right leg created in Autodesk Inventor is shown in Figure 5.18 and Figure 5.19. The size of mesh differs for contact area and non-contact area on the leg. For contact area, the side length of mesh is 10
mm, while for non-contact area the size of mesh is in default value shown in Figure 5.17 which has been discussed in chapter 5.4.2.

Figure 5.18. Mesh of right leg created in Autodesk Inventor.

Figure 5.19. Mesh for the contact area on the right leg created in Autodesk Inventor.
5.4.4 Mesh of the trunk

The mesh of the trunk in Autodesk Inventor is shown in Figure 5.20. The mesh on the trunk has two kinds of accuracy. The part which is close to the buttock, i.e. the contact area, is meshed with relatively higher accuracy and the size of elements in contact area is 10 mm. For the non-contact area, the size of elements is in default value as before.

Figure 5.20. Mesh of human trunk created in Autodesk Inventor.
5.4.5 Mesh of the seat cushion in Autodesk Inventor

The mesh for the contact area of the seat cushion, i.e. the upper surface of the seat cushion is shown in Figure 5.21. Its element size is 10 mm. This way, the model assures the accuracy of the pressure distribution. The mesh for the non-contact area of the seat cushion is shown in Figure 5.22. And the size of it is also in default value as before.

*Figure 5.21. Mesh of the contact area on the seat cushion created in Autodesk Inventor.*

*Figure 5.22. Mesh for the non-contact area of the seat cushion created in Autodesk Inventor.*
5.5 Constraints for the seat cushion

Structural constraints restrict or limit the displacement of the model. For static simulations, some rigid body modes (free translational and rotational movement of the bodies) should be removed [14]. In this thesis, we assume the deformation only occur on the upper surface of the seat cushion. The boundary condition for the model is the assumed constraint on the seat cushion as shown in Figure 5.23 and Figure 5.24.

![Figure 5.23. Fixed support for the seat cushion (from upper surface).]
Figure 5.24. Fixed support for the seat cushion (from lower surface).

5.6 Load modelling

The gravity load on the model is applied as show in Figure 5.25. Normally, only the gravity of the human body, i.e. the gravity loads of the trunk and legs are the forces acting on the seat cushion. The assumed total weight of the human body model, including trunk and legs, is 76.4 kg.
Figure 5.25. The load direction in the model.
5.7 Simulations and results

*Analysis* function of Autodesk Inventor initiates the simulations. The simulation results of deformation and pressure distribution for different sitting postures are shown in from Figure 5.26 to Figure 5.31 respectively.

*Figure 5.26. Deformation of the seat cushion in the vertical direction in normal use.*
Figure 5.27. Deformation of the seat cushion in the vertical direction when a person relaxed.
Figure 5.28. Deformation of the seat cushion in the vertical direction when a person is working.
Figure 5.29. Pressure distribution on the seat cushion when an office chair is in normal use.
Figure 5.30. Pressure distribution on the seat cushion when a person is relaxed.
Figure 5.31. Pressure distribution on the seat cushion when a person is working.
The deformation of the seat cushion when a person is sitting in normal position on the chair can be seen in Figure 5.26. The figure shows small deformation in the front part of the seat cushion. The peak value of deformation is $1.543 \times 10^{-4}$ mm. The deformation in the vertical direction when a person is relaxing on a seat cushion is shown in Figure 5.27. The peak deformation, which is $9.198 \times 10^{-5}$ mm, occurs in the centre of the buttocks. In the Figure 5.28, we can see the schematic diagram of the deformation in the vertical direction when a person is working. It can be seen that the peak deformation $2.439 \times 10^{-4}$ mm, is mainly located on the interior side of buttocks.

From Figure 5.29 one can see the pressure distribution when a person is just sitting on an office chair, neither relaxed nor working. The pressure is mainly located on the central part of the seat cushion, i.e. at the contact area between buttock and seat cushion. And the peak value of pressure is 38.72 kPa. As the Figure 5.30 shows, the pressure is mainly located on the back part of the seat cushion. And in the front part, it is difficult to see the pressure distribution; because normally when a person is having a rest, his weight mainly locates on the buttoc and his back. Here the peak value of pressure is 33.21 kPa. From the Figure 5.31, the pressure mainly locates on the front part of the seat cushion. Here the peak value of pressure is 49.62 kPa.
5.8 Analysis of the results

The peak values of deformation and pressure on the chair seat cushion under the load from human body in three sitting postures are shown in Table 5.4.

*Table 5.4. The peak value of deformation and pressure*

<table>
<thead>
<tr>
<th>Sitting posture</th>
<th>Deformation (mm)</th>
<th>Pressure (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>1.543e-4</td>
<td>38.72</td>
</tr>
<tr>
<td>Relax</td>
<td>9.198e-5</td>
<td>33.21</td>
</tr>
<tr>
<td>Work</td>
<td>2.439e-4</td>
<td>49.62</td>
</tr>
</tbody>
</table>

The difference in deformation between normal sitting posture and relaxed posture is 67.8%. The difference in peak pressure between these two sitting posture is 16.6%. This is because normally the contact area will grow when a person’s sitting posture changes from relaxed to normal. When a person is sitting on an office chair and working, the contact area between human body and seat cushion is the smallest, which causes the pressure increase. While, when a person is relaxed, the situation is opposite. Therefore the peak value of pressure when a person is working is 49.4% larger than the peak value of pressure when a person is relaxed.

The result shown in Table 5.4, confirm that the largest deformation of the seat cushion in vertical direction is, when the largest pressure occurs on the seat cushion; and respectively the smallest deformation occurs for the lowest pressure.

Comparing the results from this thesis and the results of a flexible seat cushion from Dongyan Chen’s work[^6] shown in Figure 3.14, the peak value of pressure on an inflexible seat cushion is 49.62 kPa, which is about 24% larger than a flexible one.

When a person is working, compare to normal and relaxing sitting postures, the peak value of deformation and pressure are the maximum values, which are $2.439 \times 10^{-4}$ mm and 49.62 kPa respectively. Here, the peak value of pressure is 176% larger than 18 kPa, the results from Seok-Jae-Chu’s work[^5]. There are three main reasons for this. Firstly, we chose abs plastic for modeling a human body model material while he assume the human body surface is rigid and did not mention the material of human body. This
difference of material of human body reduces the deformation of the seat cushion and human body. As we discussed previously, normally the larger pressure occurs where deformation is larger. According to Seok-Jae-Chu’s analysis the pressure on the seat cushion would be much smaller comparing to the results in Table 5.4. Secondly, body shape varies from person to person. Neither a kind of shape of the human body nor a sitting posture of human body are mentioned in Seok-Jae-Chu’s research. While in presenting thesis, the body shape is based on the data from Jin Gu et al. [10] and Gavriel Salvendy [11]. Besides, three sitting postures are taken into consideration. Thirdly, the material of the seat cushion is different than by Seok-Jae-Chu [5] who used the modified Ogden model to simulate the foam material for seat cushion while we use wood. This means the surface of the seat cushion in [5] is flexible while it is inflexible in this thesis.
6 Conclusion and future work

6.1 Conclusion

For a few decades, the pressure distribution under the load from human body on the seat cushion has been a puzzling problem for researchers. An efficient tool or method to solve this problem would help to know how to design a construction or material of a seat cushion. In an experimental approach, many pressure sensors are needed which makes the solution inconvenient. In order to solve this problem, numerical modelling may be an efficient solution.

In this thesis, we use Autodesk Inventor to simulate a person sitting on an office chair applying finite element method. And then the Analysis function is used to get the deformation and pressure distribution of the seat cushion. In this way the pressure distribution under the load of human body in the vertical direction on the chair seat cushion is observed in six separated Figures from Figure 5.26 to Figures 5.31.

The simulation results of deformation and pressure distribution of the seat cushion proved that when a person is relaxing on an office chair, the deformation is $9.198 \times 10^{-5}$ mm, and the maxim pressure is 33.21 kPa. While when a person is working on an office chair, the deformation and maxim pressure is $2.439 \times 10^{-4}$ mm and 49.62 kPa respectively. The results of deformation and pressure distribution confirm the relationship observed by Seok-Jae-Chu that large deformation is correlated with large pressure. When we are working on an office chair, the pressure normally will be much larger than when we are relaxing on an office chair.
6.2 Future work

Since different people have different body types, thus the results of deformation and pressure distribution of the seat cushion may vary. The model of human body created in this thesis can be extended to present different types of human body so that different deformation and pressure distribution for different body types can be analysed.

There are numerous kinds of seat cushion with different materials and shapes. For example, the seat cushion can be of wood, sponge or plastic. The shape of seat cushion can be flat or curved. The choice of material and shape for the seat cushion will affect the results of deformation and pressure distribution under the load from human body on the seat cushion.

A dynamic simulation of how the deformation and pressure distribution on the seat cushion occur will help us to know how the load from the weight of human body generates the pressure on the seat cushion step by step. This can be done in Autodesk Inventor by using *Dynamic simulation* function.

The chair model can be completed by including a back of the chair, and then simulated as a human body sitting on an office chair and getting support from the back of the chair. In this way, more information which can be helpful to get a better design of chair will be given out.
7 References
