Annals of Warsaw University of Life Sciences - SGGW
Forestry and Wood Technology № 92, 2015: 276-283
(Ann. WULS - SGGW, For. and Wood Technol. 92, 2015)

Project of a lumbar area stiffness regulator for an upholstered bed enabling the minimization of the user's discomfort

ŁUKASZ MATWIEJ, KRZYSZTOF WIADEREK, ANNA SZCZECHOWIAK
Department of Furniture Design Faculty of Wood Technology Poznan University of Life Sciences

Abstract: *Project of a lumbar area stiffness regulator for an upholstered bed enabling the minimization of the user's discomfort.*

The point of this research was creating of a solution for an upholstered bed base that would minimise discomfort during use.

The main idea was to create a design of a support layer – a semi-automated chassis with an adjustable lumbar support depending on a user's body shape.

Research was conducted that would establish the way the balance and deflection of mass in antropotechnical systems. The analysis was focused on the lumbar and the lower back of the spine during its resting on elastic bands with a manual tension adjustment. In order to establish the tension present where the user's body meets the bed base, an experimental technique was used. A special sensing matt was used. It featured Force Sensitive Applications system.

As a result of the analysis, the most optimal spacing of lumbar and lower back tension mechanism was established. The values tested were five, fifty and ninety-five percentile.

It was also established that spacing adjustment of the tension mechanism impacts the tension values, and thus, the comfort of use.

Keywords: antropotechnical systems, upholstered bed, comfort of use

INTRODUCTION

The bed's main function is lying down which allows the transition from the awake state into the resting state, subsequently leading to sleep. It has fundamental significance for the regeneration of the central nervous system, regulated by the brain, as well as the sleep and awakening centers (Encyclopedia PWN 2007). Currently, more and more attention is being put into the comfort of sleeping. For that reason, the bed should not only be aesthetic, but also functional and ergonomic, as sleep not only influences the regeneration of the central nervous system, but also the condition of the spine. A bed is an upholstered furniture in which we distinguish four basic construction layers: the supporting layer, spring layer, liner layer and cover layer. There is a distinct influence of each of the layer's stiffness on the intensity of the tensions developing at the spots where the user's body touches the surface of the bedding. A complete, maximal muscle relaxation becomes possible when the user's body accommodates itself to the upholstery layers and when the bed permits a natural alignment of the spine's vertical line (Kapica 1993). The apportionment most optimal for the human divides the bed into seven areas of stiffness, as it anatomically adjusted for the human physique in the greatest possible manner. Just as the mattresses, the frames also have various areas of stiffness, although in their case they are present in the lumbar region. In contrast, regulation of the slope may be possible in terms of the headboard and the footboard. Due to the ergonomy of crafting, the frame is a majorly important component, as it constitutes the supporting layer, allowing the constant airflow through the mattress and allows the moisture to shed outside. Another purpose of the frame is to enable the appropriate position during the sleep, guarantee a harmonious apportionment of body weight and to adjust itself to the person's physiological build.

Due to the ergonomical richness of the furniture mattress' market and the visible lack of constructional solutions with a regulated stiffness, this paper will attempt to conduct a design process for the construction of an upholstered bed with a regulation of the lumbar area that will minimize the discomfort in its usage.

MATERIALS

Because of the high availability of sufficiently ergonomic furniture mattresses this paper will solely focus on the supporting layer of the bed's construction - the frame.
The minimization of the discomfort in the usage was based on a solution that allows a half-automatic stiffness regulation of the frame's lumbar area, depending on the user's physique.

It has been established that the regulation will be possible thanks to the elements tying several battens in the lumbar part of the spine. The subject of the research was a chosen beech frame available on the market that allows the manual regulation of individual battens in the lumbar area.

The research was based on a measurement of contact stress in a anthropotechnical system. The anthropotechnical system is built around a technical source (a frame in this case) and a so-called animated component - in this case, a human body. Therefore, it was necessary to pair appropriate technical sources and animated components.

a. The choice of a technical source

After a review of frames available on the market a beech frame with dimensions of 1960 x 860 x 50 mm was chosen for the purpose of further research. It consisted of 28 battens, five of which included a stiffness regulation. One staff consisting of two elastic battens placed one on top of another had two tying elements (fig. 1). Moving them apart from each other increased the stiffness of a single staff, while moving them closer together made them more elastic (fig. 2).

Fig. 1. The frame used in the research; 1 - elements tying the elastic battens, 2 - battens with increased elasticity, 3 - rubber handles, 4 - middle strap (own elaboration)

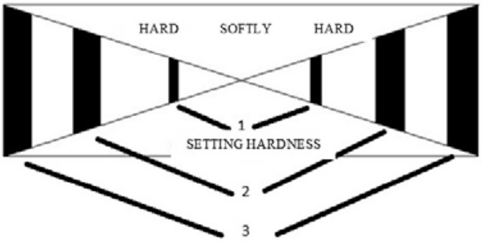

Fig. 2. Dependence resulting from the position of tying elements; 1 - central setting, 2 - middle setting, 3 - side setting (own elaboration)

b. The choice of the so-called animated component - a human body

The choice of people of sizes characteristic for the given centile was based on the data from the atlas of anthropotechnical measurements. The research included volunteers of the 5th, 50th and 95th centile (table 1).

Table 1. Juxtaposition of height and weight for the given centile (source: Gedliczka 2001)

	FEMALE			MALE		
	5C	50C	95C	5C	50C	95C
HEIGHT (cm)	152,4	161,5	170,7	164,3	174,8	185,4
WEIGHT (kg)	50	65	88	60	78	99

The optimal position of the tying elements was based on a study of the quality and the distribution of contact stress following the users contact with the bed - frame. The measurements of the quality and the distribution of stress were made with the use of a sensor mattress FSA Clinical, Vista Medical, Ltd, (sensing area 465x465 mm, size of the sensor 11,1125 mm, number of sensors 1024 (32x32), surface of sensors 211 mm^2, maximum measure value 13,0kPa). The mattress was calibrated and subsequently connected to a computer (Intel® Core™ i5 CPU, 2.53GHz, RAM 4GB, Windows 7). The mattress was placed on a beech frame (fig. 3).

Fig. 3. The test stand for the study of the quality and the distribution of contact stress (own elaboration)

Prior to every study each volunteer was measured and weighted (table 2) and afterwards subjected to a test on a sensor mattress. The measuring of the height was made using a tape measure with the accuracy of 1 mm. The weighting was made using a bathroom scale with the accuracy of 0,1 kg. The direct results of the measuring were noted in a text file and graphically presented as maps of the contact stress distribution.

Table 2. The parameters of people participating in the study.

CENTILE	WEIGHT [kg]	HEIGHT [cm]
5 C	50,0	163,0
50 C	70,0	172,0
95 C	90,0	180,0

Each test took 60 seconds. During the pressuring, the contact stress between the user's body and the bed (frame) was measured with the frequency of 10 Hz and the accuracy of 0,01 kPa. The measurements were made for three different positions of the tying elements (fig. 2) for two different arrangements of the user's body (fig. 4)

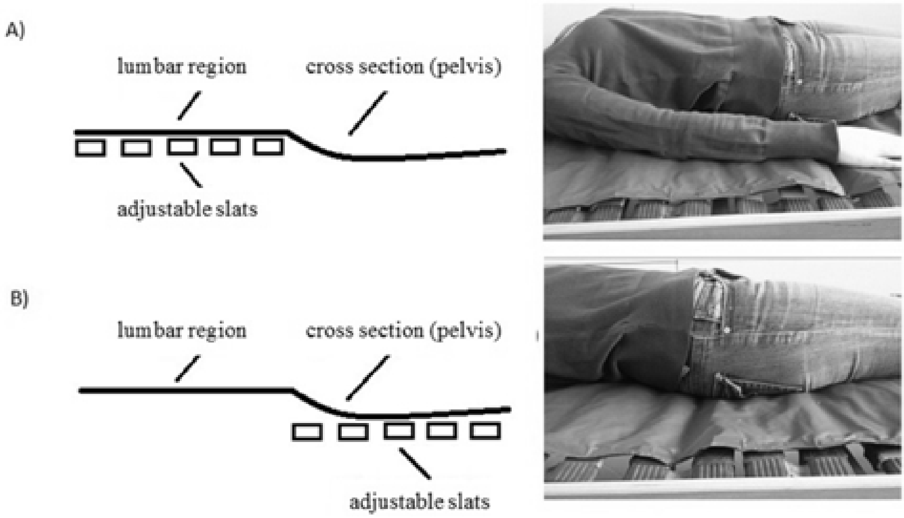

Fig.4. Type of the body's arrangement on the frame during the test; A - regulation of the stiffness in the lumbar part of the spine, B - regulation of the stiffness in the sacral part of the spine (own elaboration)

The indirect results were juxtaposed in form of tables comparing qualities: A - the area of contact, p_m - average contact stress, SPD value (Seat Pressure Distribution, Ahmadian et al. 2002):

$$SPD = \frac{\sum_{i=1}^{n}(p_i - p_m)^2}{4np_m^2} \cdot 100 \ [\%],$$

where:
n – number of sensors in which the contact stresses have a non-zero value,
p_i – contact stress in a single sensor of the mattress,
p_m – average stress for the n sensors.

As the bed's comfort directly depends on the area of contact, the rates of contact stress and the aforementioned SPD values, a decision was made to define and calculate the quality of a discomfort value (D), determined accordingly to the following equation:

$$D = \frac{SPD \cdot p_m}{A} \quad \left[\frac{daN}{m^4}\right]$$

RESULTS

The chosen exemplary maps of contact stress developed due to the pressure of the body resting on the frame are presented on figures 5-6.

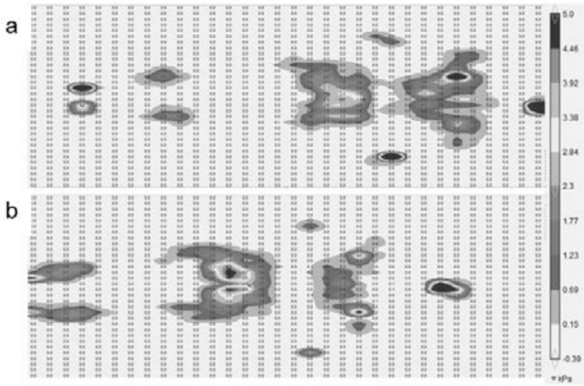

Fig. 5. The illustration of the contact stress map for 50th centile with the central placement of the tying elements a) stiffness regulation in the sacral part of the spine b) stiffness regulation in the lumbar part of the spine (own elaboration)

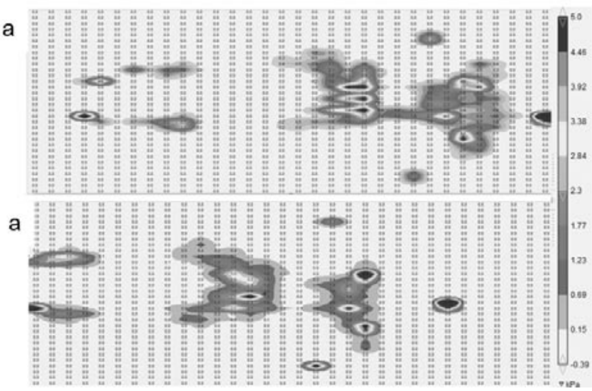

Fig. 6. The illustration of the contact stress map for 50th centile with the side placement of the tying elements a) stiffness regulation in the sacral part of the spine b) stiffness regulation in the lumbar part of the spine (own elaboration)

The initial analysis of the maps illustrating contact stress for the 5th, 50th and 90th centile have led to a conclusion that the contact stress in the lumbar area was minor, proving that there was virtually no contact between the spine and the battens.

The indirect result of the conducted studies was the SPD value (value of the stress distribution) and D (usage discomfort value). In case of the even distribution of the contact stress on the bed's surface, the p_i in a single sensor should be equal to the average stress p_m. Under such circumstances, the SPD value should be zero. Therefore, beds with a low SPD value can indicate a more even support for the user's body, in comparison to beds with a high SPD value. That does not however exclude the possibility of a situation, where the stress will be too high for the comfort of lying down.

In case of the D value it should be expected that the high user discomfort will be caused by high p_m level and low A i SPD values. In such situation, low D values will objectively signify a high comfort level of the bed's usage.

Tab.6. The juxtaposition of SPD and D values for the dla 5th centile.

THE SETTING OF TYING ELEMENTS	STIFFNESS REGULATION IN THE LUMBAR AREA		STIFFNESS REGULATION IN THE SACRAL AREA	
	SPD [%]	D [N/m^4]	SPD [%]	D [N/m^4]
UTMOST SIDE POSITION	63,55	37,90	31,24	31,72
INDIRECT POSITION	38,66	20,52	48,98	35,46
MIDDLE POSITION	53,48	25,85	38,28	28,84

Tab.7. The juxtaposition of SPD and D values for the 50th centile.

THE SETTING OF TYING ELEMENTS	STIFFNESS REGULATION IN THE LUMBAR AREA		STIFFNESS REGULATION IN THE SACRAL AREA	
	SPD [%]	D [N/m^4]	SPD [%]	D [N/m^4]
UTMOST SIDE POSITION	39,73	16,05	34,09	10,93
INDIRECT POSITION	32,04	7,82	36,18	11,04
MIDDLE POSITION	24,68	9,72	55,04	17,57

Tab.8. The juxtaposition of SPD and D values for the 95th centile.

THE SETTING OF TYING ELEMENTS	STIFFNESS REGULATION IN THE LUMBAR AREA		STIFFNESS REGULATION IN THE SACRAL AREA	
	SPD [%]	D [N/m^4]	SPD [%]	D [N/m^4]
UTMOST SIDE POSITION	48,33	14,23	35,91	14,12
INDIRECT POSITION	40,91	12,16	45,04	13,82
MIDDLE POSITION	49,78	12,80	40,18	15,15

The analysis of the results acquired from the study signifies that:

- The lowest SPD value in the regulation of the lumbar area was always in the side setting of of the tying elements, regardless of the user's body weight,
- the lowest SPD value in the regulation of the lumbar area for the 5th i 95th centile was in the middle setting of the tying elements, while for the 50th centile it was the middle position of the tying elements,
- however, the discomfort value changes if the regulation is located in the sacral area - the value varies for different positions of tying elements,
- the lowest discomfort value depending on the stiffness regulation in the sacral area for the 5th centile is located in the central position, the side setting for the 50th centile and the middle setting of the tying elements for the 95th centile,
- the smallest value of discomfort for the stiffness regulation in the lumbar area is always in the middle setting of the tying elements, regardless of the user's body weight,

- the calculated discomfort values for the given centile with the regulation of the sacral area are still greater than the discomfort value calculated for the given centile with the middle setting in the lumbar area.

An example of a technical solution for the regulation of the frame's stiffness.

As a result of the conducted studies and their analysis, the following conclusions were reached:

1. Regulation in the lumbar area has no significance for the user's comfort, as the lowest discomfort value is located in the middle setting of the tying elements, regardless of the weight.
2. As the regulation in the lumbar area bears no significance, it is worth to focus on the regulation in the sacral area, including the pelvis.
3. Comfort may be influenced by the regulation in the sacral area while keeping the stiffness of the battens in the lumbar area, matching the one during the middle setting of the tying elements.
4. Further stages of the study suggest designing a frame with a regulation in the sacral area and stiffened battens in the lumbar area while maintaining the stiffness that marches the middle setting of the tying elements.

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Streszczenie: *Projekt regulatora sztywności lędźwiowej strefy leżyska tapicerowanego umożliwiającego minimalizację dyskomfortu jego użytkowania*.

Genezą niniejszej pracy było stworzenie rozwiązania dla leżyska tapicerowanego minimalizującego dyskomfort jego użytkowania.

Celem głównym niniejszej pracy było zaprojektowanie konstrukcji warstwy podtrzymującej – stelaża – z półautomatyczną regulacją sztywności lędźwiowej strefy stelaża w zależności od budowy ciała użytkownika.

W pracy przeprowadzono badania określające rozkład oraz wartość naprężęń w układzie antropotechnicznym. Przedmiotem analizy była strefa odcinka lędźwiowego oraz krzyżowego spoczywającego na listwach elastycznych z manualną regulacją sztywności. Do określenia naprężeń występujących na styku ciała użytkownika z leżyskiem zastosowano metodę badań eksperymentalnych, wykorzystując matę sensorową z systemem Force Sensitive Applications.

W wyniku przeprowadzonych analiz dokonano wyboru najodpowiedniejszego rozstawu elementów spinających regulujących sztywność w odcinku lędźwiowym oraz krzyżowym dla 5, 50 oraz 95 centyla. Ustalono, że zmiana rozstawu elementów spinających wpływa na zmianę wartości naprężeń, a co za tym idzie – na komfort użytkowania.

Corresponding author:

Łukasz Matwiej,
Poznan University of Life Sciences
Faculty of Wood Technology
Department of Furniture Design
Wojska Polskiego 38/42
60-627 Poznan, Poland
email: matwiej@up.poznan.pl