METHOD OF TRANSFORMING STANDARD 3D MODEL INTO THE MODEL OF REALLY GEOMETRIC SHAPE

Category B: Digitally Simulated Textile

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ABSTRACT

The article presents the method of calculation and design of medical compressive knitted products by applying the algorithm of 3D modeling, and taking into account the results of the analysis of strained deformed state both in the material of the product itself, and on the surface of the product's contact as a result of interaction hereof with a human body in virtual 3D form. Computer designing of compressive products at the stage of designing hereof provides for the use of the finite-element program ANSYS, which is adaptable to any human body models. The results of the calculation have demonstrated that the pressure of a compressive knitted article on the human body is determined not only by the efforts arising in the material of the product's membrane and the configuration of a model leg as well as mechanical and rigidity characteristics of the material of the product's membrane and biological material of the leg model, subject to the change of these characteristics in the course of time. The offered method enables to increase the medical efficiency of application of compressive knitted articles thanks to a reasonable choice of technological characteristics for the manufacture hereof (type of elastomeric threads, kind of interlacing and shape of location of an elastomeric thread in the structure of fabric) as early as at the stage of the designing of a product.

1. INTRODUCTION

Investigations of computerized 3D garment modeling have been for the past ten years going into three directions mostly, i.e. in the search of the methods (CAD systems) [1, 2, 3] and the development of the 3D system [4, 5] for garment modeling. The third direction includes: 3D system modeled products and calculation of the state of tension and deformation along the surface of the contact of the product during its interaction with the human body in virtual shape [6, 7]. This field is of special significance to the modeling of medical compressive articles. One of the main requirements set for such products is strictly dosed pressure along the sections of the contact of the product and the surface of the human body, provided that this pressure is constant in time.

It is known that the compressive article of the same size is able to produce various pressures on the surfaces of the contact with the human body (e.g. on the section of the distal third of the ankle) of the same standard anthropometrical characteristics of the group of people (with all other equal conditions). This is accounted for by the fact that the existing ISO 8559 1989-C7 (Garment construction and anthropometrics surveys; body dimensions); State Standard 26456.1-89 on the measurement of typical figures for the designing of textile articles cannot take into account all possible dimension-types of the human body.

Computer-aided design of compressive articles at the stage of design hereof, by using the adapted finite-element estimation program (e.g. ANSYS) to any models of the human body will enable to develop the geometric shapes of these articles, which fully comply with the medical requirements. This work is devoted to the adaptation of application of the estimated finite-element computer program ANSYS in 3D system during the design of the compressive article.

Investigations performed at the Department of Clothing Technology, Faculty of Textile Technology together with Institute of Mechanical Engineering, University of Riga, have been going in the above direction. A new method for computerized 3D garment design on a virtual body model has been developed. The basic model for the design of the compressive article is a hosiery product.

2. 3D DESIGN OF THE MODEL

The estimation program ANSYS is based on the method of finite elements in the variational formulation. This method enables during the estimation and designing of medical compressive knitted articles to take into account the following: tension and deformation state produced on the surface of the contact of the compressive article with the human body; real complex geometry of the specific part of the human body (e.g. of the leg); geometry, interlacing class and physical mechanical characteristics of the material of the compressive article.

In order to elaborate the methodology of calculation of distribution of tensions in the membrane of the compressive article and on the surface of its contact with the model of the leg, first of all it is required to build the mathematical model, which will allow to adequately describe the functioning of the whole structure consisting of the compressive knitted article (hereinafter referred to as “the membrane of the article”) and of the human leg (hereinafter referred to as “the model of the leg”).

Computer technologies enable to automate the geometric description of the object under examination of any shape and configuration in the 3D coordinate system. This work, by using one of such programs, “Three-dimensional apparel CAD system’’, "Computer Graphics" [8], presents the standard geometric model of the leg (size five) in accordance with the requirements of the State Standard 26456.1-89 with respect to the division of typical figures according to sizes. The elaborated geometric model of the leg is the base-model in the case of designing and calculation of compressive articles (Fig. 1).

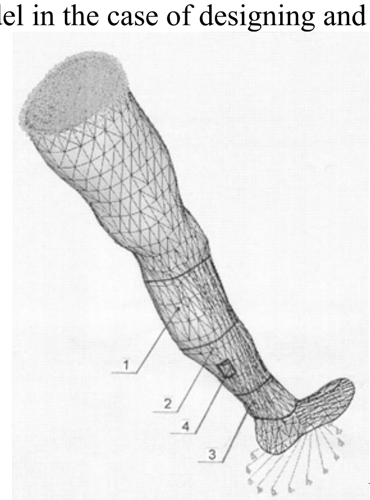


Fig.1. The model of the leg (size five)

Model of the leg on the considered section (of the lower leg) includes in itself: 1 - proximal part of the lower leg starting from the popliteal site to the middle of the shin muscle (m. gastrocnemius); 2 – distal third of the shin section; 3 – ankle section; 4 - the local section there is shown finite element in which divided all model of the leg.

The shin area was chosen and considered more detail for two reasons:

- following the manufacture of the compressive knitted product, the quality test (physical and mechanical characteristics) is carried out in the area of the cervix of the lower part of the compressive knitted product, which allows to verify the correctness of the technology mode of the manufacture of the product;
- taking into account the fact that in most cases the distal 1/3 part of the shin becomes a target for chronic venous insufficiency, and pursuant to the doctors' recommendations, the pressure in this area should be maximal, with a gradual decrease towards the proximal part of the shin.

The knowledge of the distribution of pressure on the surface of contact of the leg model and the product's membrane enables to secure the efficient treatment of chronic venous insufficiency and lymphostasis in the case of conservative treatment as well as to create comfortable conditions in the post-operative period.

The principle of operation of this program is based on transversal scanning of the subject of inquiry and recording of coordinates of boundary points according to the perimeter of the object. At the same time, each fixed coordinate of the boundary point is the coordinate point of the respective finite element, which are used in the calculating computer program ANSYS. The coordinate position points are entered in accordance with the following algorithm (in the cylindrical coordinate system (R; θ; z)):

$$\{K;\ Nr.p.k.;\ x(R);\ y(\theta);\ z\},$$

where: K – point key; Nr.p.k. – point number; x(R) - radius of curvature; y(θ) – turn angle; z – level according to the height of the model of the leg. Numerical value of point's coordinates is presented in the paper [9].

3. EXPERIMENTAL METHOD OF MODEL DEFINITION FOR ANY SIZE OF LEG

This method includes transformation of ones standard model into model of really geometrical form for any sizes.

Based on the adopted estimated model of the leg described by 1359 key points (Fig. 1), using as the basis the program ANSYS, there was elaborated the program enabling, by using the developed automated process of analytical description of any surface of the model of the leg, to estimate and analyze the tension and deformation state in the membrane of the article along the surface of the contact with any model of the leg. For this purpose, for the description of geometry of the surface of the model of the leg, a range of fixed perimeters of the leg in levels (A, A_1, B, C, D, F, G) have been entered into the estimation program, and these levels comply with the characteristic levels along the length of the model of the leg (Z, Z_1, Z_2, Z_3, Z_4, Z_5) (this direction is marked by Z coordinate in Fig. 2).

LATVIJAS REPUBLIKA
RĪGAS STARPTAUTISKAIS MEDICĪNAS ZINĀTNES UN FARMĀCIJAS CENTRS

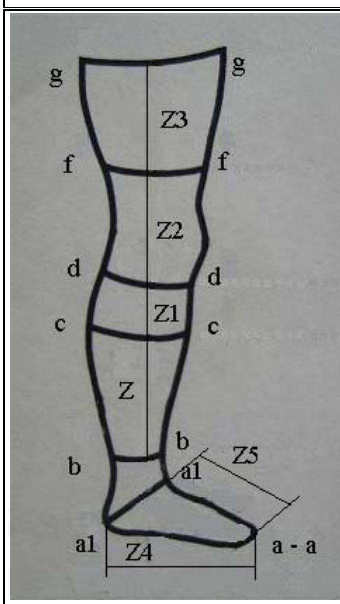
RECEPTE

Pacients ____200 ___g.”___”_________
Vārds, Uzvārds

Izstrādājuma veids	Pusgarās zeķes	Zeķes	Zeķbikses	1-kājas zeķbikses

Rekomendētā kompresijas klase (CCI)	**1 A**		**1 B**			**2**			**3**	**4**	
Rekomendējamais spiediens pie potītes, mm.Hg.	12	15	18	20	22	24	26	30	34	40	

IZMĒRU TABULA



Izmērs	1	2	3	4	5	6	7
	46-49	50-52	53-55	56-59	60-63	64-67	68-72
	40-42	43-46	47-49	50-52	53-56	57-59	60-63
	27-30	31-33	34-36	37-40	41-43	44-47	48-50
	30-33	34-36	37-40	41-44	45-48	49-51	52-54
	19-20	21-22	23-24	25-27	28-30	31-33	34-36
Pēdas izmērs (sievietēm)…..	35-36	36-37	37-38	38-39	39-40	40-41	41-42
Pēdas izmērs (vīriešiem)…..	-	38-40	41-42	43-44	45-46	-	-
Pacienta svars, kg (siev.)…..	40-50	48-58	55-68	65-78	75-85	85-100	100-120
Kājas garums………………	S – līdz 70 cm.				L – virs 70 cm.		

z	Z	Z_1	Z_2	Z_3	Z_4	Z_5
Izmērs, mm						

Medicīnas iestāde ___________________
Ārsta zīmogs _______________________

Fig. 2. A copy of the prescription for the indication of the compressive knitted article

In Fig. 2, there is a copy of the prescription (registration number of the prescription № 031294 2003-2008 LV) effective in Latvia by a medical doctor's recommendation to use the appropriate compressive article. This prescription indicates the scheme of the model of the leg with the adopted model of the leg with graphical symbols according to its levels and the table of leg perimeters for appropriate levels.

For the purpose of the generalized scheme of the model of the leg, geometrical position point coordinates according to the adopted model of the legs (Fig. 2) are entered into the estimation program ANSYS in accordance with the following algorithm:

- for each of the specified levels (A, A_1, B, C, D, F, G), which have been previously "attached" to the specific node points of the basic model of the leg and comply with the chosen levels of the basic model (Fig. 1), according to the given leg perimeters (according to the measured sizes of the leg, which are reflected in the prescription) are estimated in the following manner:

- radii recorded under the coordinate keys as $x(R) = (D/2\cdot\pi)$, (mm), where: $x(R)$ – radius of curvature of the model of the leg (mm); D – perimeter of the leg, mm; π, rad.;

- $y(\theta)$ – one step of turn angle is 90^0 (0; 90^0; 180^0; 270^0);

z – the level according to the height of the model is adopted in accordance with the specified value according to the prescription (Z, Z_1, Z_2, Z_3, Z_4), (mm).

In order to create an arbitrary model of the leg, there are activated step by step the coordinates of the four points (according to $y(\theta)$) by levels of the model of the leg and only new values are entered for $x(R)$ and z:

A-A: K, 1336, 2, 0, $\mathbf{Z_4}$; K, 1342, 1, 90, $\mathbf{Z_4}$; K, 1348, 2, 180, $\mathbf{Z_4}$; K, 1354, 5, 270, $\mathbf{Z_4}$.

A_1-A_1: K, 1009, $\mathbf{D/2\cdot\pi}$, 0, $\mathbf{Z_5}$; K, 1015, $\mathbf{D/2\cdot\pi}$, 90, $\mathbf{Z_5}$; K, 1021, $\mathbf{D/2\cdot\pi}$, 180, $\mathbf{Z_5}$; K, 1027, $\mathbf{D/2\cdot\pi}$, 270, $\mathbf{Z_5}$.

B-B: K, 961, $\mathbf{D/2\cdot\pi}$, 0, **Z**; K, 967, $\mathbf{D/2\cdot\pi}$, 90, **Z**; K, 973, $\mathbf{D/2\cdot\pi}$, 180, **Z**; K, 979, $\mathbf{D/2\cdot\pi}$, 270, **Z**.

C-C: K, 793, $\mathbf{D/2\cdot\pi}$, 0, $\mathbf{Z_1}$; K, 799, $\mathbf{D/2\cdot\pi}$, 90, $\mathbf{Z_1}$; K, 805, $\mathbf{D/2\cdot\pi}$, 180, $\mathbf{Z_1}$; K, 811, $\mathbf{D/2\cdot\pi}$, 270, $\mathbf{Z_1}$.

D-D: K, 601, $\mathbf{D/2\cdot\pi}$, 0, $\mathbf{Z_2}$; K, 607, $\mathbf{D/2\cdot\pi}$, 90, $\mathbf{Z_2}$; K, 613, $\mathbf{D/2\cdot\pi}$, 180, $\mathbf{Z_2}$; K, 619, $\mathbf{D/2\cdot\pi}$, 270, $\mathbf{Z_2}$.

F-F: K, 265, **D/2·π**, 0, $\mathbf{Z_3}$; K, 271, **D/2·π**, 90, $\mathbf{Z_3}$; K, 277, **D/2·π**, 180, $\mathbf{Z_3}$; K, 283, **D/2·π**, 270, $\mathbf{Z_3}$.

G-G: K, 1, **D/2·π**, 0, 0; K, 7, **D/2·π**, 90, 0; K, 13, **D/2·π**, 180, 0; K, 19, **D/2·π**, 270, 0.

In accordance with the abovementioned algorithm, Fig. 3 presents the adopted geometrical schemes of the model of the leg of size 3, 5 and 7 (in accordance with the table values in accordance with the appropriate sizes Fig. 2).

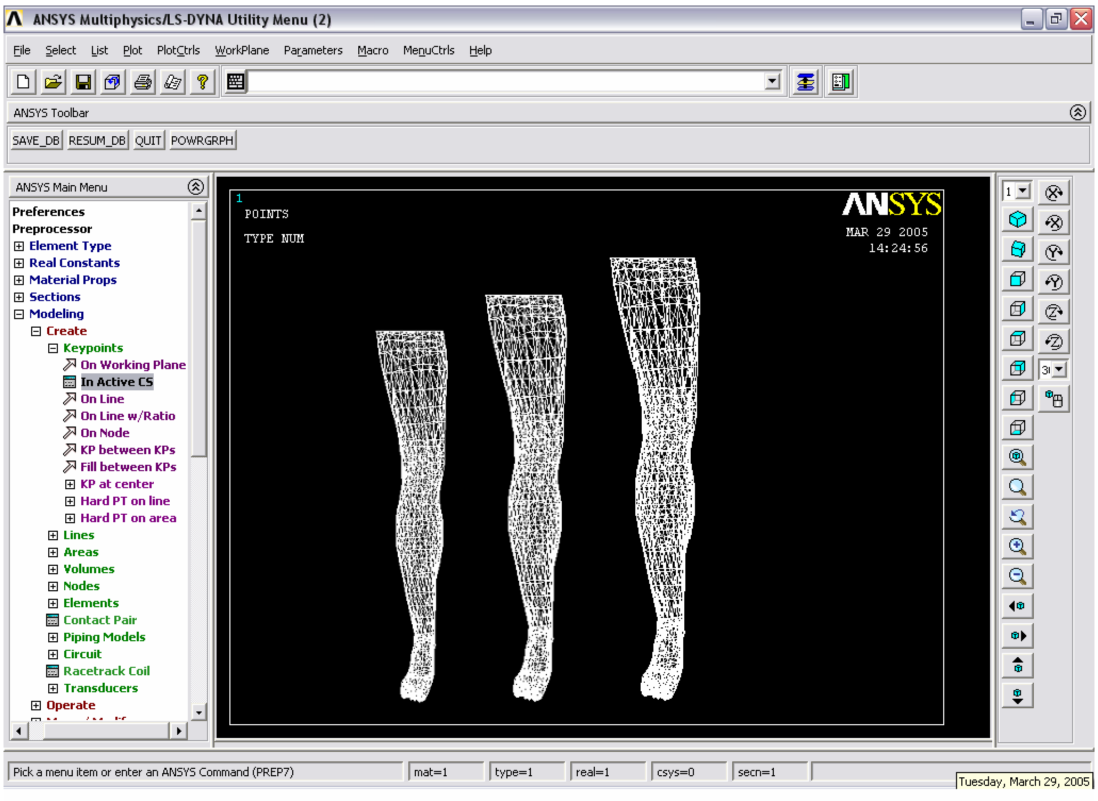


Fig. 3. Geometric model of the legs of size 3, 5 and 7

It should be noted that the above-mentioned algorithm enables, by introducing additional parameters of the leg according to its levels, to describe the geometric model of the leg of any individual.

In order to elaborate the computational solution of distribution of tension produced by the membrane of the article on the surface of the contact with the model of the leg, by applying the program ANSYS, the following estimation algorithm is to be performed:

- to set the type of the finite element, into which the model of the leg is divided;
- filled in tables (Fig. 4; Fig. 5), in which there are recorded the physical and mechanical characteristics of the material of biological tissues for each section of the leg, taking into consideration the age and the sex of an individual [10];

- boundary conditions are applied, taking into account the method of securing of the construction of the model of the leg. In particular, along the coordinate axes *z* and *y*, there are set the displacements and respective turnings of the structure, and along the *x* axis there is set the value of flexibility of the muscular tissue of the leg [11] for the specific period (taking into consideration the sex of the person).

Similar operations of information input are repeated while using the computer program ANSYS for the membrane of the article. The difference lies in the fact that in accordance with the set parameters of the leg (Fig. 2), at first, there is carried out a technological estimation of geometric parameters of the compressive article, and later the calculation results are entered into the program as design geometric sizes for the membrane of the article. The numerical value of physical and mechanical characteristics of the material of the membrane of the article is set experimentally [12], taking into account T (tex) of threads and the class of interlacing.

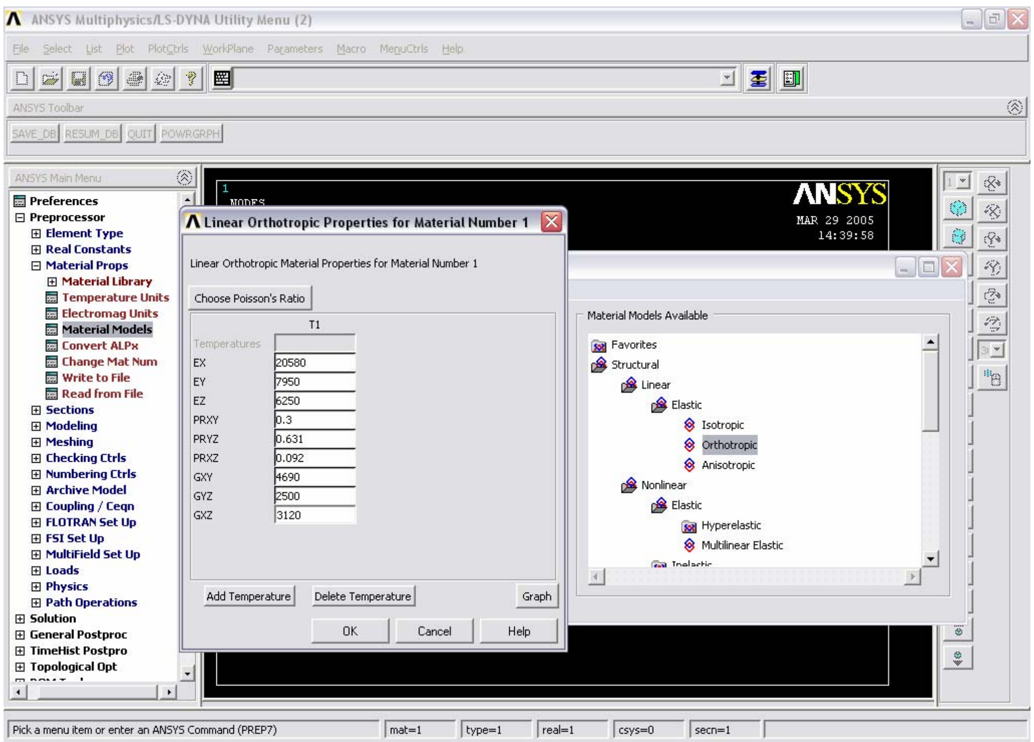


Fig. 4. Mechanical characteristics of orthotrophic material of the compact bone tissue

The given methodology of calculation of distribution of tensions in the membrane of the article along the surface of its contact with the model of the leg enables to more reasonably calculate and choose the technological characteristics of the compressive article (type of elastomeric threads, type of interlacing and geometry of arrangement of elastomeric thread in the structure of the fabric) already at the stage of designing hereof. It does not only enable to increase the efficiency of medical effect of the compressive article, but also to substantially reduce finance charges at the stage of designing of a compressive knitted article.

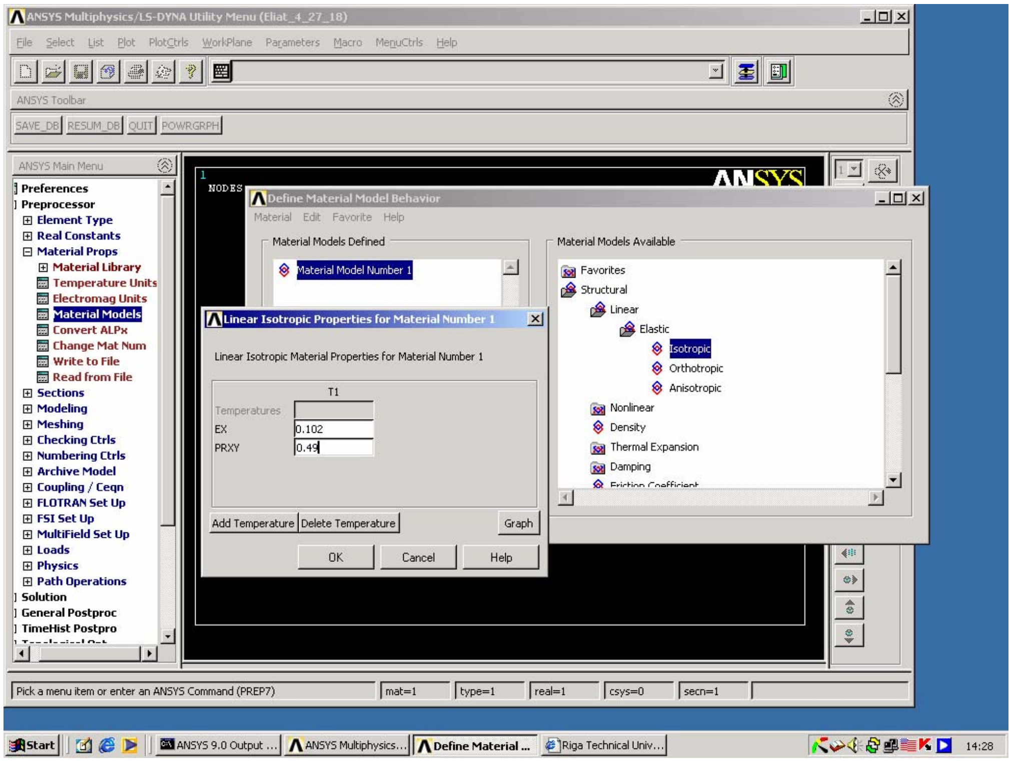


Fig. 5. Mechanical characteristics of orthotrophic material muscular tissue

It has been proved as a result of the calculations that the pressure of the membrane of the article on the human body is determined not only by the distributed stretching force effective in the median surface of the membrane of the article, but also on the configuration of the human leg at the contact hereof with the compressive article as well as the effect of rigidity properties of the biological material on the total flexibility of the model of the leg in the course of time.

4. CONCLUSIONS

1. The elaborated method of description of geometry of the model of the leg based on the introduction of parameters of the perimeter of the leg according to the levels of lengths hereof enables to automate the geometric description of the model of the leg of any individual.

2. Based on the computer program ANSYS, a numerical method was elaborated enabling to acquire the following: distributions of tension and deformation in the membrane of the article during the contact with the model of the leg; distribution of pressure produced on the surface of contact of the compressive article and the model of the leg. It has been indicated that the estimated tension and deformation values essentially depend on the material of the membrane of the article, its geometric shape and class of interlacing as well as on the geometry of the model of the leg and physical and mechanical characteristics of its material.

3. The analysis of acquired tension and deformation characteristics in the product membrane along the surface of the contact with the model of the leg enables to more qualitatively and reasonably calculate and design the technological parameters of compressive articles, by providing the implementation of any medicine requirements, and by substantially broadening the range of compressive articles, by more comprehensively taking into account individual peculiarities of each individual.

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