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WuXinzhou

IMPROVEMENT OF DESIGN TECHNOLOGY OF WOMEN'S DIVING WETSUITS

05.19.04 -Technology of garments

Brief of Dissertation
for the degree of candidate of sciences

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The work was carried out at the Ivanovo State Polytechnic University.Institute of Textile Industry and Fashion, the Department of GarmentDesign

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INTRODUCTION

The relevance of the work. Diving is becoming more common all over the world and the demand for diving suits from diving enthusiasts is gradually increasing. The use of diving suits (entertainment, professional work, military use, etc.) is gaining popularity all over the world, so the demand for diving suits is constantly increasing. The choice of materials, design, performance of a wetsuit is determined by its area of application. The main indicator of the anthropometric fit of a wetsuit is dynamic immersion comfort. To achieve high levels of comfort in a wetsuit underwater, information from various fields of knowledge is needed: human morphology, materials science, the effect of pressure on the human body, and so on.

Positive results for improving wetsuit design were obtained in the research of J.H. Choi, M.M. Naglic, and S. Petrak, etc. Nowadays, some researchers use new information technology as the main means to develop compression clothing.The human body scanner, as a mainstream tool for measuring dimensional characteristics, has been used in many countries (United States, United Kingdom, France, China, etc.) to develop national anthropometric plans and has improved the design process of human body clothing systems, in the works of Lo Yun, Li Yue (IGTA), V.V.Getmansteva (RGY), I.V.Cherunova (DGTU), I.V. Tislenko (IVGPU).At present, the rise of new 3D simulation software technology has provided beneficial help for rapid design of clothing and objective evaluation, especially in the works of Guo Mengna (IVGPU), Cheng Zhe (IVGPU).These new methods for wetsuit design will humanize the decision-making, increase the clothing comfort, and transfer the designers' opinions to the virtual environment in accordance with the "body-wetsuit" system. Designers can perform virtual fitting and evaluate the quality of art design decisions before actual manufacture.

The research has been done in 2016–2020 at the department of garment design at the Ivanovo State Polytechnic University according to the state assignment No. 2.2425.2017 / 4.6 on the topic “**Development of software for virtual design of static and dynamic systems “body-clothing” and virtual fitting of FashionNet**”.

The work corresponds to the following points of the passport of the scientific specialty 05.19.04: 1. Development of theoretical foundations and the establishment of general laws for designing clothes for bodies of typical and atypical physique; 2. Development of process and methods of clothing design on the base of rational sizing system, rules of ЕСКД and widely application of CAD, 5. Improvement of assessment methods and design of clothing with specified consumer and technical and economic indicators.

The degree of problem elaboration. Currently, there is no general design method for female wetsuit, and many aspects have not been studied and systematized, especially the aspect of dynamic fit control for different female morphologies underwater. The existing design mostly simply to add large negative ease to compress the human body, which obviously can not satisfy the different morphologies. From the perspective of optimizing the comfort and functionality of the wetsuit, these aspects need to be considered – female torso, material pressure, wetsuit pattern, and dynamic fit and comfort.

Currently, there is no general method for designing a women's wetsuit, the problems that arise have not been studied and systematized. One of the main design challenges is to provide freedom of movement underwater for various female morphologies. With the existing approach, negative ease are set for the compression of the human body, which, obviously, does not fully take into account its morphology. In order to improve the comfort and functional properties of a wetsuit, it is necessary to take into account the morphology of the human body, its susceptibility to material pressure, ensuring optimal articulation of the parts of the wetsuit, as well as dynamic fit and comfort.

Keywords: female body, wetsuit construction, pressure, dynamic fit

The aim of research is to improve design process of the female wetsuit.

The main tasks of the research are to solve the following tasks:

1.To study the modern design, manufacturing technology, and materials of the female wetsuit, summarize all related information, including material thickness, sewing stitch, and all the possible locations of their contour/internal lines on the surface of female bodies, and make artistic and constructive evaluations and analysis.

2.To develop a new scheme for grouping of female torsos based on the existing female body torso classification, for the optimal arrangement of division lines.

3.To study female dynamic soft tissue deformation range of different body parts based on basic diving postures and hydraulic pressure under two environments: above and underwater.

4.To study the dependence of the deformation of the material of the wetsuit and the change in the size of the areas of the body.

5.Measure the allowable pressure range and deformation limits for different areas of the body.

6.Develop an index that allows you to identify the dependence of the comfort of a wetsuit on its design solution.

7.Improve the method of designing a female wetsuit.

8.Evaluate and examine design techniques for wetsuit part templates based on the "Deformable Avatar-Wetsuit" system in the CLO 3D virtual environment.

9.Make approbation by evaluating and checking theoretical developments. The rationality of the design process for female wetsuits needs to be tested from a practical point of view and criteria for assessing the quality of the results obtained in the process of virtual modeling should be established.

The objects of research – female bodies of various anthropological types, female wetsuit, wetsuit materials, real and virtual systems “body(avatar) - wetsuit”, the process of construction and virtual simulation.

The subject of research – the process of designing female wetsuit.

Research methods and tools. To measure, read and visualize images of scanned bodies (called scanatars), a VITUS Smart XXL 3D scanner (Human Solutions, Germany, DIN EN ISO 20685 standard) with the Anthroscan program was used. The Kawabata Evaluation System KES (Japan) was used to test the mechanical properties of textile materials. The AMI-3037-10II (Japan) was used to record clothing pressure on the body. The CLO 3D virtual software was used for virtual body modeling and fitting. 3ds Max was used to edit polygon shapes.SPSS was used to analyze the measurement results using correlation and regression analysis, reliability analysis, and checking the normality of the distribution of the measurement results.

The scientific novelty is establishment of dynamic changes in the sizes of various parts of the female body under the influence of the aquatic environment and ergonomic postures and their application to obtain the development of wetsuit parts.

The following scientific results were obtained for the first time.

1. Developed a new method of grouping female bodies to improve the quality of the female wetsuit, based on new measurements of the front and back of the torsos.
2. The relationship between the deformation of the wetsuit material and the pressure exerted on the soft tissues of female bodies is established, equations are obtained for predicting pressure values, and an index of the compression ratio is proposed.
3. The permissible boundaries for changing the girths of female bodies for various parts of the body have been established.
4. The influence of hydraulic pressure and ergonomic postures on the change in the dimensional characteristics of female bodies have been established.

Provisions for the defense.

1. New grouping of female torsos.
2. A method for evaluating the compression of various body girths by the materials.
3. Dynamic changes of female bodies in conditions of being underwater.
4. A new method of designing a female wetsuit.
5. Digital twins of deformed female bodies in a virtual environment to test the design of a wetsuit and determine the compressive ability of materials.

The theoretical significance of the study is to establish the values of critical factors, including a new anthropometric grouping of female torsos, deformation of soft tissues under the influence of typical underwater positions and hydraulic pressure, to create dynamic comfort for a female wetsuit.

The practical significance of the study is to develop a method for measuring human figures and a 3D method for designing a female wetsuit with a simulation of a dynamic landing and a comfortable state under water. This will help designers to quickly modify and optimize designs, improve productivity and accommodate operating conditions.

The reliability of the results and conclusions is ensured by the convergence of the results of experimental and theoretical studies, the statistical adequacy of the obtained equations, the use of modern and trusted measuring instruments.

Approbation of the results. The results of the research were reported and received a positive assessment at the following conferences: the second international scientific-practical conference "Models of innovative development of textile and light industry based on the integration of university science and industry. Education-science-production" (**Kazan, 2016**); All-Russian scientific student conference "Innovative development of light and textile industry (INTEX-2016)" (**Moscow, 2016**); International scientific and practical conference "Modeling in engineering and economics" (**Vitebsk, 2016**); Information Environment of the University (**Ivanovo, 2017**); AUTEX world textile conference (**Istanbul, Turkey, 2018**); International conference Aegean international textile and advanced engineering conference AITAE 2018 (**Mytilene, Greece, 2018**); International conference on computational modeling and applied mathematics (**Wuhan, China, 2018**). International conference on advanced materials, electronical and mechanical engineering AMEME (**Xiamen, China, 2020**); International conference on technics, technologies and education ICTTE (**Yambol, Bulgaria, 2020**); in the educational cycle "New opportunities for everyone" of the national project "Education" in the course "Digital bows in virtual space: artistic and industrial design of 3D clothes in virtual reality" (**Ivanovo, IVGPU, 2020**).

The main results of the research were published in 12 papers, including 1 article in a Russian journal from the list of the Higher Attestation Commission (ВАК), 6 articles in English-language journals included in the Web of Science database, 5 abstracts and conference papers, the total volume of which is 3.625 p.l. (personal contribution 1.8 p.l.).

The structure of the dissertation. The dissertation consists of 5 chapters, set out on 165 pp., including 18 tables, 65 figures, 5 appendixes, 176 literary sources.

CONTENT

The introduction substantiates the relevance of the research, formulates the goal and objectives, and provides information on the scientific and practical significance.

The **first chapter** provides an overview of scientific information and design research in the relevant field. The scientific knowledge on the design of female compression clothing and the design of wetsuits is summarized. A comparative analysis of modern methods of designing compression clothing from the point of view of information technology is carried out. It is shown that measuring the degree of compression and soft tissues of the human body under the influence of the pressure of the material of a wetsuit is the main criterion for evaluating its design. As a result of the review, it was concluded that modern methods of designing female wetsuits use a limited set of initial anthropometric data corresponding to a static standing posture, with arms raised, squatting or other postures with legs resting on a horizontal surface.

For more than 300 modern wetsuits on the market, the configuration of the segmentation lines was analyzed (**Fig. 1**). The survey received feedback from 1000 members of a Chinese diving club. According to the survey, 57.5% believe that a wetsuit bought in a store or borrowed from a club is mostly unsuitable, and the problems mainly concern the shoulder area (**Fig. 2**).

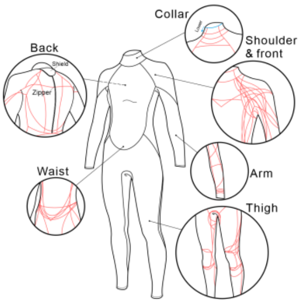


Fig. 1 – Multiple ways and areas of wetsuit structure line design

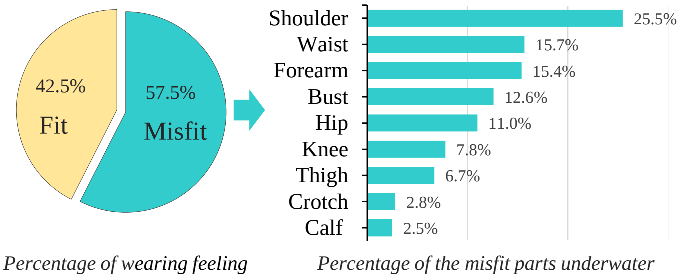


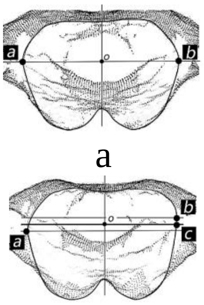
Fig. 2 – Order of wetsuit misfit areas underwater

In the **second chapter**, an anthropometric study of female bodies is carried out, a new way of grouping them is developed. The dynamic change in the dimensional features of the bodies was measured using a 3D body scanner (results were published in three articles).

According to a survey of diving clubs, they are usually attended by active young people, therefore, participants in the appropriate age group were selected. Measurements were taken for 96 Chinese women aged 18...27 years from Wuhan Textile University (China) with a height of 147.3...173.6 cm and a chest girth of 73.0...105.1 cm. Anthropometric data obtained by contactless 3D body scanning (on the floor) or by hand contact (on the floor and underwater).

Traditional groups Y, A, B and C were increased by two times by separating each group into two subtypes: Group I includes four subtypes Y1, A1, B1, C1 when the bust front segment (BG_F) is bigger than the bust back (BG_B) segment, $BG_F > BG_B$.Group II includes four subtypes Y2, A2, B2, C2 with an opposite situation, $BG_F < BG_B$.

The BG cross-section of BG_F and BG_B are divied by “a” and “b”, as **Fig. 3** shows. The profiles of standard types and the corresponding subtypes were overlapped based on WG position through real experiments (**Fig. 4**).



a

b

Fig. 3 – Divide BG in symmetrical cross section (a); in asymmetrical cross section (b)

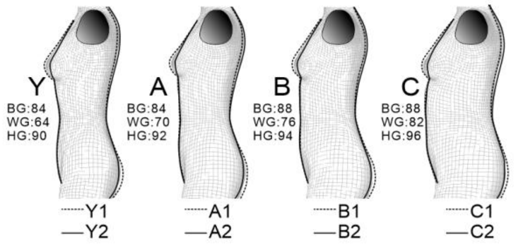


Fig. 4 – Profiles of standard torsos (Y, A, B, C) and subtypes

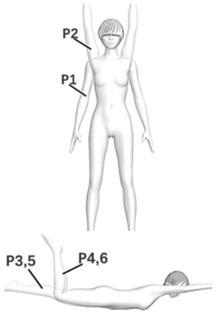


Fig. 5 – Dynamic postures

Based on collected results, the type A (A1 – 37.5%, A2 – 12.5%) accounted for the highest proportion, followed by the types Y (Y1 – 10.4%, Y2 – 11.5%), B (B1 – 14.6%, B2 – 6.3%) and C (C1 – 4.2%, C2 – 3.1%). The developed subtypes of the torsos create possibility of additional gradation of wetsuit according to the shape, and can also be used for individual production.

The dynamic body size difference is recorded when postures (based on typically diving actions) change. Four postures are constructed under the next conditions (**Fig. 5**):

– standing on a floor with hands down (P1) and hands up (P2);

– lie prone on a floor with face down - the arms stretch forward, the legs straight backward (P3); the arms stretch forward, and the feet draw up towards the hip, calf 90° with the body (P4);

– P5 and P6 were the same as P3 and P4, but all measurements were made underwater by means of manual tape.

P1…P6 correspond to basic body movements when swimming. In these positions, the change in girth of body was measured and the wetsuit fit was evaluated.

To figure out how each posture influences on body measurements, the average differences DIF between the same body in different postures were compared. DIF$(m\text{-}n)_i$ is the difference between i-measurements of Posture m and Posture n, e.g., DIF$(P2\text{-}P1)_i$.

Two kinds of differences were named as ΔG_{DIF} or ΔL_{DIF}: ΔG_{DIF} represents the changing of girths (**Tab. 1**), ΔL_{DIF} represents the changing of lengths (**Tab. 2**).

Tab. 1 –The maximum ΔG_{DIF}

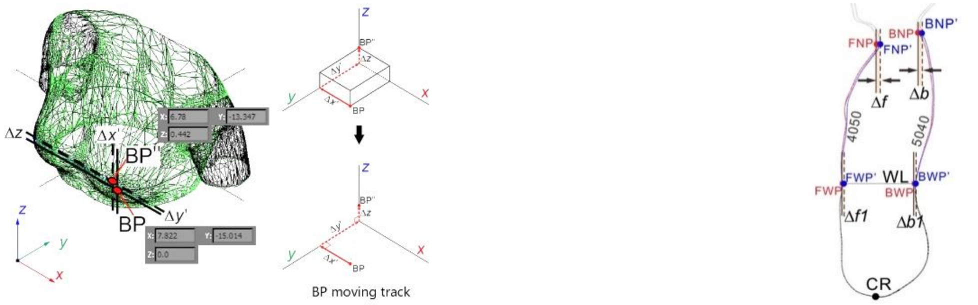
Subtypes	ΔG_{DIF} of full girths, front and back segments, %								
	BG	BG_F	BG_B	WG	WG_F	WG_B	HG	HG_F	HG_B
Y1	1.9	**-11.2**	19.4	-0.8	-4.4	1.5	-1.5	-1.8	-6.9
Y2	2.0	**-11.3**	16.2	-0.9	-2.3	-1.7	-1.7	-1.4	-5.2
A1	3.3	**-14.8**	17.9	-2.8	-3.8	-1.5	-2.6	1.3	-7.7
A2	3.0	**-15.5**	18.5	-3.1	-4.8	-0.6	-2.2	1.5	-5.5
B1	3.1	**-12.0**	18.7	-2.4	-4.1	1.4	-2.7	1.1	-6.7
B2	4.0	**-15.3**	19.0	-2.5	-3.3	-1.7	-1.3	0.8	-5.7
C1	3.5	**-12.5**	19.2	-2.2	-4.9	2.3	-2.6	-2.4	-5.9
C2	3.7	**-11.7**	17.9	-2.3	-7.3	5.3	-2.0	3.6	-7.4
Avg., S.D.	*3.1 ± 0.8*	***-13.0 ± 1.8***	*18.4 ± 1.0*	*-2.1 ± 0.8*	*-4.4 ± 1.5*	*0.6 ± 2.5*	*-2.1 ± 0.5*	*0.3 ± 2.0*	*-6.4 ± 0.9*

Tab. 2 –The maximum ΔL_{DIF}

Subtypes	ΔL_{DIF} of measurements, %						
	SL	FNP-WL	BNP-WL	W_{BF}	W_{BB}	W_{SP}	L_{Cr}
Y1	22.9	10.5	-18.0	-31.3	31.2	-38.2	0.7
Y2	23.5	13.3	-14.2	-30.1	30.2	**-32.0**	0.5
A1	30.4	11.4	-15.3	-29.2	31.5	**-43.8**	-1.3
A2	24.3	9.9	-11.7	-30.8	32.7	**-41.4**	1.3
B1	28.1	10.3	-13.5	-32.0	30.1	**-43.6**	0.4
B2	30.8	10.1	-17.5	-35.5	35.3	**-40.5**	1.5
C1	36.8	12.6	-22.5	-39.1	30.8	**-45.0**	4.4
C2	32.3	6.4	-11.2	-33.6	34.1	**-41.2**	2.3
Avg., S.D.	*28.6 ± 4.9*	*10.6 ± 2.1*	*-15.5 ± 3.7*	*-32.7 ± 3.3*	*32.0 ± 1.9*	***-40.7 ± 4.1***	*1.2 ± 1.7*

FNP-WL –neck front (FNP) to waist; BNP-WL – neck (BNP) to waist centre back; W_{BF} – across/bust front width; W_{BB} – across/bust back width; L_{Cr} – full crotch length; SL – side upper torso length; W_{SP} – cross shoulder width

The procedure for deformation of digital replicas torso of the female bodies have been modified in 3ds Max through editing the “mesh” with coordinates (**Fig. 6**), for more accurate construction and control of the deformed avatar.



a b

Fig. 6 – The digital twin of a female torso: a – polygonal mesh editing scheme of breast before and after changing the position of the hands; b – sagittal plane of the upper body tilt forward

The results obtained compiled an anthropometric database for the design of wetsuits.

In the **third chapter**, the compression influence of wetsuit materials on the female body girths is studied(the result was published in two articles).

To simulate the hydraulic pressure on soft tissues, the body was wrapped with a 10 cm wide material around the measured part of the body. The strip was tightened, creating a compression within the acceptable pressure range for the body. Investigated four types of composite three-layer materials M1, M2, M3, M4, which are used for sewing wetsuits. Gradually stretching the material in the uniaxial direction(**Fig. 7**), simultaneously measuring the change (decrease) in the girths of the body ΔG (**Fig. 8**) and the elongation of the material E until the moment when the pressure was critical for the human body.

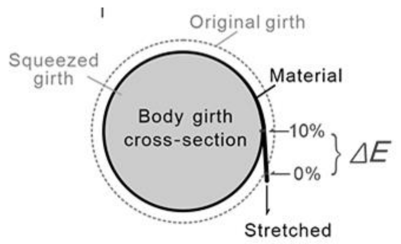


Fig.7 – Body girth deformation under materials elongation

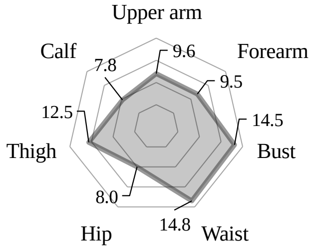


Fig.8– Values of maximum deformations of body girthsΔG_{max}, -%

The E_{max} and $P_{max}$of the four materialsare as shown in **Tab. 3**.

Fig. 7 and **Tab. 3** show the ΔG_{max}range is -14.8…-7.8%, the E_{max} range is 10.8…26.5%, and the P_{max}range is 1.90…2.39 kPa.

Table 3 – The average E_{max} of material M1…M4, %

	E_{max} values for materials				
Body position	M1	M2	M3	M4	*Avg.*
Upper arm	17.8	15.5	11.4	16.7	*15.3*
Forearm	17.5	15.6	12.5	15.8	*15.3*
Bust	22.5	16.7	13.0	18.4	*17.6*
Waist	22.0	15.0	11.9	15.5	*16.1*
Hip	**26.5**	**17.5**	**15.6**	**19.5**	*19.8*
Thigh	21.5	13.6	10.8	17.8	*15.9*
Calf	22.6	12.8	11.4	17.5	*16.1*
Avg.	*21.5 ± 3.1*	*15.2 ± 1.6*	*12.4 ± 1.6*	*17.3 ± 1.4*	16.6
	P_{max}, kPa				
Avg.	*1.90 ± 0.30*	*1.97 ± 0.20*	**2.39** *± 0.23*	*1.92 ± 0.17*	2.04

Then, to analyze and parameterize the effect of compression, using the ratio between material E_{max} and compressed body ΔG_{max}, the compressibility factor of the material was proposed as an index RC_m

$$RC_m = | E_{max} / \Delta G_{max} | \tag{1}$$

Where in $\Delta G_{max}$is the girth decreasing value, %; E_{max} is the material elongation value, %;RC_m is the compression ratio, kPa/%.

Table 4 – The average materials RC_m on key body parts,kPa/%

Bodyposition	Compressibility factor RC_m for different types of material				*Avg.*
	M1	M2	M3	M4	
Upper arm	1.85	1.61	1.18	1.73	*1.59*
Forearm	1.84	1.64	1.32	1.66	*1.62*
Bust	1.55	1.15	0.90	1.27	*1.22*
Waist	1.48	1.01	**0.80**	1.04	*1.08*
Hip	**3.31**	2.19	1.94	2.43	*2.47*
Thigh	1.72	1.08	0.86	1.42	*1.27*
Calf	2.90	1.64	1.46	2.24	*2.06*
Avg.	*2.09*	*1.48*	***1.21***	*1.69*	-

The RC_mcan be used to calculate and find:

–from the relationship between the measured ΔG_{DIF} and material RC_m can calculated the E_{min} for pattern design; the larger the RC_m value, the larger the result of E_{min} value (Equation 2).

–the degree from easily to difficultly deformable (compressible) of the female body girth is obtained. The larger the RC_m value, the more difficulty the girth compressed.

–to justify a suitable material, taking into account the compression properties to select: the greater the value of RC_m, the more extensible the wetsuit material.

$$E_{min} = RC_m \cdot \Delta G_{DIF} = (E_{max} \cdot \Delta G_{DIF}) / \Delta G_{max}, \qquad (2)$$

Where in E_{min} is the minimum ease value, %; RC_m is the compression ratio; ΔG_{DIF}change in girth value in dynamic poses, %

The $E_{min}$was calculated for keeping fit underwear (**Tab. 5**).

Tab. 5 – E_{min} of M1…M4 for 8 body types

Body position	Negative value of E_{min}, -%								*Avg.*
	Y1	Y2	A1	A2	B1	B2	C1	C2	
BG_F	13.6	13.8	18.0	18.9	14.6	18.6	15.2	14.2	*15.9*
WG	0.9	1.0	3.1	3.4	2.6	2.7	2.4	2.5	*2.3*
WG_F	4.9	2.6	4.2	5.4	4.6	3.7	5.5	8.1	*4.9*
HG	4.6	5.3	8.0	6.8	8.3	4.0	8.0	6.2	*6.4*
HG_B	21.3	16.1	23.8	17.0	20.7	17.6	18.2	22.9	*19.7*
ThighG	1.9	1.8	1.6	2.4	0.7	2.2	3.3	3.1	*2.1*
CalfG	4.8	4.0	4.3	4.0	5.0	2.5	7.3	5.3	*4.7*

It was found that the compressibility of the girths of the body increases in the following order– *waist, bust, thigh, upper arm, forearm, hip, calf.*

The $RC_m$is proposed to find and predict the female body ΔG under the action of a tight-fitting clothing material with relative elongation E.The index can be used to calculate the average elongation required to reduce body girth by 1%.

The ranges of the design ease E_{min} values for eight types are obtained to maintain the underwater tight and dynamic motions. The ranges of E_{min} were obtained for 8 types of bodies, providing a tight fit of the wetsuit to the body and freedom of dynamic movements.

In the **fourth chapter**, the indices of the physical and mechanical properties of four materials M1...M4 were studied on KES (Japan) (the result was published in 1 article).

To calculate the allowable pressure P_{max}, KES indexes with a high degree of correlation were selected. After measuring the property indexes, a statistical analysis was carried out to establish the relationships between them (Tab.6).

Tab. 6 – Correlation coefficients between P_{max}, E_{max}, and KES indexes

KES indexes	Material maximum pressure P_{max}		Material elongation E_{max}	
	Course	Wale	Course	Wale

LT	0.693	**0.973**	-0.937	-0.834
WT	**-0.988**	**-0.967**	0.496	**0.989**
2HG	0.822	**0.956**	-0.904	-0.818
F15	**0.959**	**-**	-	**-**

**LT* is tensile rigidity, *WT* is tension energy, gf.cm/cm^2; *2HG* is elasticity, gf/cm

Multivariable Equations (3…7) with the coefficients are obtained, *sig*. < 0.05 and Pearson correlation coefficient R-Square > 0.930, these selected equations have good fit.

in course

$$P_{max} = 2.70 - 78.81 / F15_c \tag{3}$$

$$P_{max} = 1.17 + 1.95 / WT_c \tag{4}$$

in wale

$$P_{max} = 0.81 + 2.45 / WT_w \tag{5}$$

$$P_{max} = 4.47 - 1.20 / LT_w \tag{6}$$

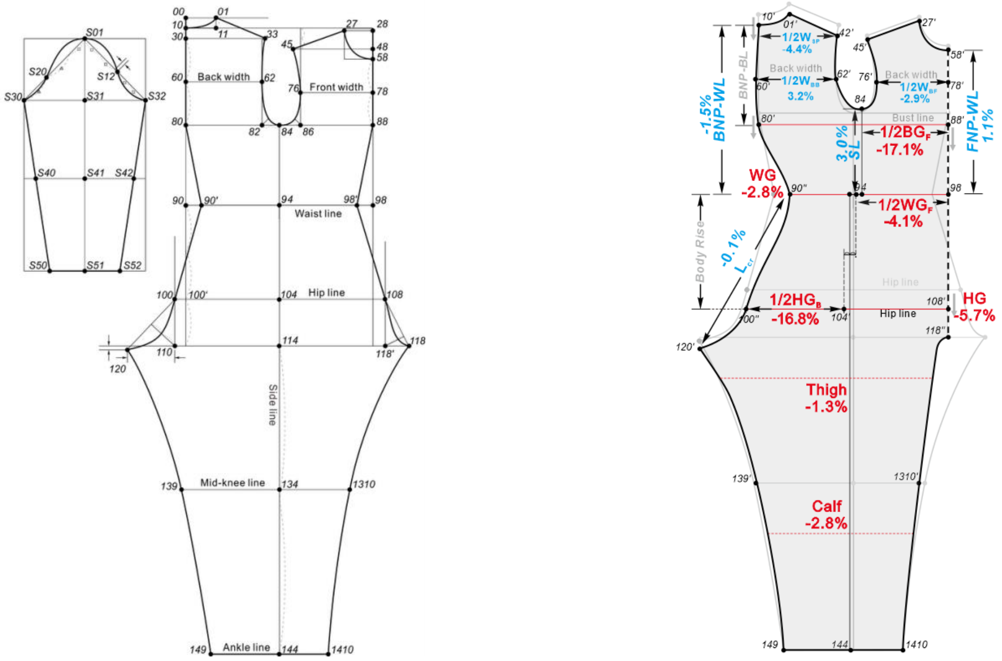
$$P_{max} = e^{\left(1.03 - \frac{1.96}{2HG_w}\right)} \tag{7}$$

wherein*e* is the natural base approx. 2.718; WT and LT are KES parameters of material tension properties; 2HG is the KES parameter of material shear properties. P_{max} is the maximum pressure value, the Eq.(3...7) can derive the pressure range during $0 < P_{max} <$ 4.47 kPa, Eq.(7) only can derive the pressure range from $0 < P_{max} <$ 2.80 kPa.

Thus, the equations obtained in this chapter between the various factors can be used to predict the pressure range.

In the **fifth chapter**, a new method for designing a female wetsuit was developed, a method for verifying the arising pressure in a virtual three-dimensional environment and a test was carried out in an industrial production environment (the results were published in 6articles).

Currently, there is no mature methodology for designing full-length wetsuit, so the method of construction without ease were taken as the basis (**Fig. 9 a**).A drawing of the basic design of the wetsuit (initial prototype) was built based on the research (**Fig. 8 b**).

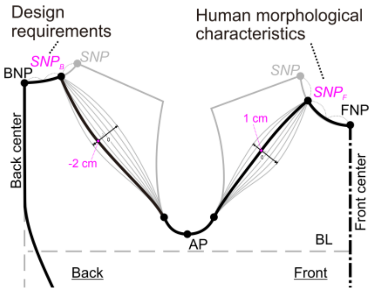


a b

Fig.8 – Initial prototype with zero increments (a) and wetsuit drawing diagram (b)

The drawing scheme takes into account new features of measuring dimensional features and ΔG_{DIF}, ΔL_{DIF}, and E_{min}.

In **Fig. 10** shows the sum of the absolute values of the differential pressure ΔP, measured in a virtual environment, for 49 configuration options of the structural lines (**Fig. 9**).And alsocarried out from a dynamic position to substantiate the structure of the raglan sleeve.



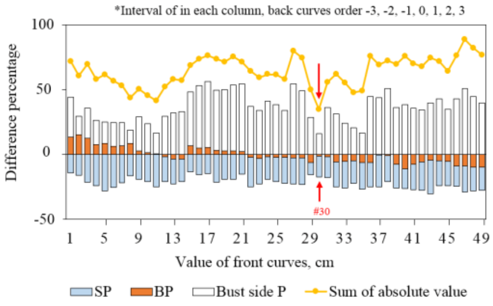


Fig. 9 – 49 raglan designs **Fig. 10** – Pressure differences of 49 sleeve designs

If the absolute value is the smallest, it means the corresponding ΔP in dynamic postures will be the smallest (minimum fluctuation), and the design helps to maximize improve the dynamic fit on the shoulders.

Fig. 11 shows the wetsuit digital replica of the body, and virtual try on.

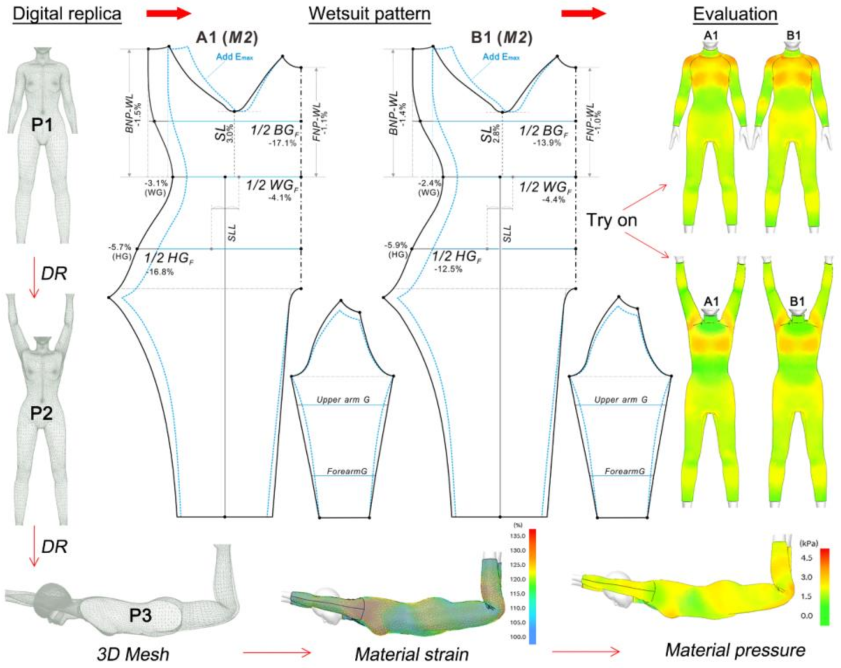


Fig.11– Stages of designing virtual twins of bodies and virtual try on in the CLO 3D program

Wetsuits in a virtual environment were carried out in the ClO 3D and 3ds Max programs.The negative E_{min}(back line) and E_{max} (buledot line, the narrower pattern) used in the construction of the drawing take into account new dynamic anthropometric data, indicators of material properties, compression pressure, deformation properties of clothing material and allowable pressure levels on body parts.

The optimized design of the wetsuit templates is shown in **Fig. 12**.

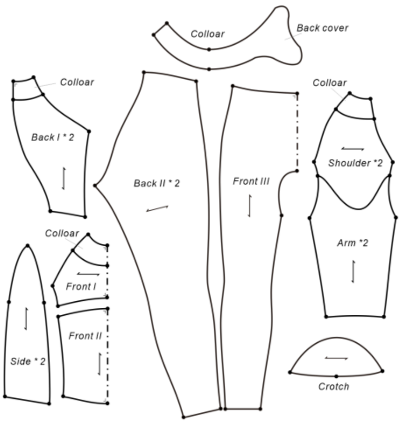


Fig. 12 – The designed wetsuit pattern blocks

Fig. 13 – Appearance of wetsuitsDW1 and DW2 made of M2 and M3

The results of the virtual test showed that the wetsuit has a high degree of comfort and provides admissible static and dynamic pressure.

Then the industrial test of the new technology was carried out in the conditions of the JINMING apparel company (Wuhan, China) by making an experimental batch of 10 wetsuits. In **Fig. 13** show two materials wetsuit with a good fit – there is no slack in the material and sufficient freedom of movement.

The subjective evaluation of feeling was carried out according to a 7-level evaluation on the Likert Scale: “1-extremely dissatisfied” to “7-very satisfied”.Static and dynamic scores indicate that the lower satisfaction ranking (average 4.1 in static and 3.0 in dynamic) are found at front knee (squatting), bust side, waist side, back, shoulder and upper arm.Static and dynamic results of the expert evaluation showed an average result of 6.7 points. This evaluation is necessary and sufficient for the start of mass production of wetsuits.

Fig. 14shows photographs taken during suit testing at the Wuhan Diving Center in Wuhan, China, which is part of the PADI$^{®}$ Dive Center.The real product has a good fit with good functionality.

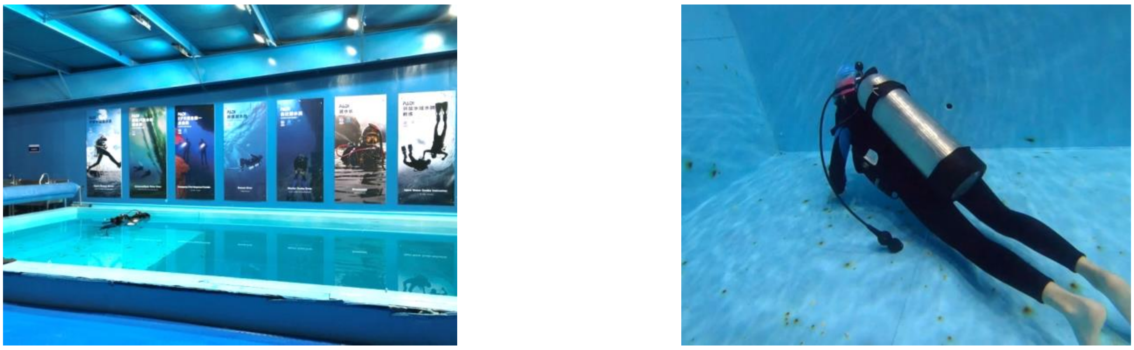


Fig. 14 – Wetsuit testing in the pool

Thus, the advantages of the developed suit, obtained using the improved design technology, and the possibility of transferring the design results of the "avatar-wetsuit" system from the virtual to the aquatic environment have been proved.

RESULTS OF THE PERFORMED RESEARCH

1. Based on the analysis of the functional and aesthetic characteristics of wetsuits, modern methods of designing them and an expert survey of diving enthusiasts, the main design directions in the direction of increasing comfort, including from the standpoint of studying changes in anthropometric data and functional structural optimization, were determined.
2. A new grouping of female bodies has been developed and a database has been formed in the form of anthropometric measurements, which includes dynamic changes in the size of bodies when swimming underwater. The areas of the greatest dynamic changes in the size of the bodies when performing movements during swimming are established.

3. The relative changes in the dimensional characteristics of female figures under the action of hydraulic pressure were measured, which made it possible to calculate the allowable ranges of structural increases in wetsuits.

4. A new indicator characterizing the compression ability of wetsuit materials is proposed. Recommendations have been developed for calculating the constructive dynamic gains of clothing for eight types of bodies.

5. Dependences for calculating the upper limits of the allowable comfortable pressure of a wetsuit on the indicators of the deformation properties of the material used have been established.

6. The found relationships between the deformation of the clothing material and the change in the dimensional features of the body are used to generate digital twins of the bodies. Digital Twin bodies are created in dynamic positions corresponding to swimming conditions for virtual modeling of the dynamic system "body-wetsuit" underwater, fitting and evaluation of the wetsuit.

7. In a virtual environment, the design of the raglan sleeve was optimized from the standpoint of optimizing the configuration and achieving reasonable pressure in dynamics.

RECOMMENDATIONS, PROSPECTS FOR FURTHER DEVELOPMENT TOPICS

The results of the work should be used in the process of higher education for the preparation of bachelors and masters specializing in the design of compression clothing, in related areas of designing light industry products; Wetsuit industries need to improve the current design concept of CAD elements to develop and optimize new diving products.

Thanks to the improvement of anthropometric measurement programs, it is possible to identify morphological differences in female bodies, in order to customize products and improve the quality of clothing in conditions of mass consumption, to eliminate the shortage of products in the existing market.

Further development of the "digital twin" concept can be developed simultaneously in two directions - for an expanded set of standard bodies in mass production (ready-to-wear), as well as for an individual approach (e-bespoke).

The results of the work can be used in the field of practical artistic and industrial design, education and advanced training for a qualitative change in existing concepts and the development of new economies focused on digitalization.

The main results of the work are published:

in the journals from the list of VAK:

1. У, С. Алгоритм проектирования костюма для подводного плавания / Синьчжоу У, В. Е. Кузьмичев // **Известия вузов. Технология текстильной промышленности**. – 2019. – № 3. – С. 121-127 (0.5/0.25 п.л.).

in the journals indexed by Web of Science:

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