An Overview Of The Research Status And Development Trend Of Dynamic Pressure Distribution Testing For Clothing

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Abstract. Clothing pressure can be divided into dynamic pressure and static pressure. When measuring dynamic garment pressure, it is difficult to accurately measure dynamic garment pressure due to the complexity of measuring device and the influence factors such as sliding between skin and fabric during movement. To understand the influencing factors of clothing pressure, clothing pressure measurement technology and the existing dynamic pressure distribution prediction model, so as to achieve accurate prediction of dynamic pressure distribution of clothing, can provide ideas for future research on dynamic pressure comfort of clothing and provide scientific basis for clothing design.

1. Introduction

In the state of rest, the human body is mainly affected by the mass pressure generated by the weight of the garment and the binding pressure generated by the different tightness of the garment. In a dynamic state, the human body is mainly subjected to surface pressure from clothing, such as pressure caused by stretching, compression, shearing and bending, etc. Due to the curvature change of different parts of the human body, the physiological reaction during movement and the slippage between skin and fabric during movement, it is more difficult to accurately measure the dynamic clothing pressure. Therefore, it is very important to establish dynamic pressure evaluation criteria for clothing. Understanding the influencing factors of clothing pressure, clothing pressure measurement technology and the existing dynamic pressure distribution prediction model can provide ideas for future research on dynamic pressure of clothing, realize accurate measurement of dynamic pressure distribution of clothing, and provide scientific basis for clothing design.

2. Influencing factors of clothing pressure

The influencing factors of clothing pressure are mainly analyzed from the perspectives of clothing and human body.

2.1 Garment layer

The material type, structure and density of the fabric can affect the dynamic pressure of the garment. Liu Chan et al. [1] analyzed the factors affecting the dynamic pressure on the elbows of knitted blazer by using the orthogonal test method, including raw materials, tissue structure and density. The results showed that the primary and secondary influencing factors of the dynamic pressure of elbow joint were the density > tissue structure > yarn material.
The physical and mechanical properties, such as tensile, shear and flexural stresses, vary with the fiber content and type of fabric. In 2010, Yao Yuan [2] conducted relevant studies on the performance of elastic knitted fabrics and clothing pressure, and found out the relationship between the physical and mechanical properties of fabrics and clothing pressure and pressure fatigue characteristics through comparative analysis of experiments. He found that there was a close relationship between the garment pressure and the shear, bending and tensile elasticity of the fabric. The elastic modulus, transverse shear property and transverse bending property of the fabric are positively correlated with the clothing pressure factor, while the elastic recovery property of the fabric is negatively correlated with the clothing pressure factor. In addition, the quantitative relationship between the garment pressure and the mechanical properties of fabric is given quantitatively through multiple regression analysis. The analysis shows that the elastic properties of elastic knitted fabrics have the greatest influence on clothing pressure.

2.2 Human level
In the design of sportswear, due to the complexity of the human body, it is necessary to consider the state of the human body during sports, such as the speed and range of motion, as well as the physiological and psychological impact of the human body on the dynamic pressure of the garments to evaluate the factors that need to be considered in the apparel design, so as to design more humanized clothing.

In 2013, Zhige Chen et al. [3] measured the pressure of clothing on different parts of the human body when the arm was raised to different positions. The subjective evaluation of clothing pressure and the analysis of experimental results show that clothing pressure is influenced by clothing size and human movement. The increase of clothing size makes the pressure value decrease. In 2019, Chen Xiaona et al. [4] studied the dynamic pressure of the sports bra under different movement speeds from the perspective of the human body's movement speed, so as to determine whether the influence of speed should be considered when designing the sports bra. The study showed that the speed of movement had a significant impact on the average pressure and maximum pressure in the lower bra area.

3. Clothing pressure measurement system
Clothing pressure measurement methods at present can be divided into direct measurement and indirect measurement techniques, direct measurement technology available sensor technology combined with computer acquisition platform, can get a specific point of clothing pressure data directly, but due to the complexity of equipment operation, and in the human body is in a state of movement, the sensor with clothing or skin slip easily lead to inaccuracy of measurement point data. Indirect measurement mostly uses computer simulation technology to build the human body to predict the distribution of clothing pressure, which requires interdisciplinary knowledge in clothing design, contact mechanics, human biomechanics and computer technology, etc. In the research process, existing models need to be iteratively optimized. At present, the research methods of clothing pressure model mainly focus on finite element method and Laplace geometric equation, while some new research methods are emerging, such as neural network prediction model and 3D virtual reality technology.

3.1 Direct measurement system of clothing pressure

3.1.1 Wearable pressure test system. The pressure testing device of clothing has developed from the airbag type at the very beginning to the research of the pressure testing device which is mainly composed of flexible sensors. To realize the accurate measurement of clothing pressure, the probe of the sensor should be light, flexible and capable of measuring the pressure on the human body surface [5]. Therefore, the sensor should have good flexibility, stretchability and flexibility, as well as good strain sensing characteristics and stretch/release response.

Wang Jinfong et al. [6] designed a weft knitting flexible fabric sensor and woven silver-plated yarn into seamless underwear as a pressure sensor. Through the change of sensor resistance and the relationship between sensor resistance and tension, the pressure on human abdomen before and after wearing was determined.
3.1.2 Intelligent human body pressure model system. It is easy to cause sports injury during sports, and the sensor is easy to slip between human skin and clothing due to sports, which is inconvenient for fixation. When wearing the same sample for a long time to measure the dynamic pressure of clothing, it is impossible to maintain the consistency of the performance of all aspects of the human body. Therefore, the fake human model plays an important role in the measurement of clothing pressure. Donghua University[7] developed a smart model with a standard female body size, which is used to measure clothing pressure. The mannequin has a hard inner layer and a soft surface. It has eight built-in pressure sensors on its surface. Sensors detect the pressure exerted by wearing clothes and feed the data simultaneously to the acquisition device. The mannequin can be stretched horizontally at the front and back lines up to a maximum height of 5 cm, which mimics different body sizes.

This type of mannequin with built-in sensors and adjustable dimensions enables the design of downforce suits of different sizes. In the measurement of dynamic pressure, the dummy can also be considered to simulate the movement behavior to explore the influencing factors of dynamic pressure under the condition of controlling the motion speed and other variables.

3.1.3 3D deformation contact pressure test system. In 2010, Wang Yongrong et al. [8] used a self-designed system to measure the dynamic pressure behavior. This direct measurement method is based on a rigid hemisphere with five pressure sensors distributed on its surface. (As shown in FIG. 1(a)(b)). Dynamic pressure is measured over time during the three-dimensional deformation of the fabric. Pressure distributions at the basic five locations are accepted as measured results. In 2018, Eren Oner et al. [9] developed a new test device for measuring the compression performance of standard medical socks, a new test device consisting of a computer-controlled artificial leg. The view of the device is shown in Figure 2. The test device has a sensitive mechanical artificial leg with pressure and force sensors that can change size just like a human leg. The device consists of an adjustable artificial leg, a sensor, a stepping motor, a micro-stepping driver, a control card, a power control unit and a computer with management software. The device provides consistent, effective, reliable and repeatable pressure measurement results.
3.2 Garment pressure indirect measurement system

3.2.1. Geometric mathematical model. In 2015, Wang Yongrong et al. \cite{10} established a THREE-DIMENSIONAL geometric model of fabric deformation and mechanical behavior based on the self-developed three-dimensional deformation dynamic pressure system, which can be used to simulate fabric elongation in the dynamic compression process, and deduced the relationship between compression depth and fabric elongation.

On the other hand, based on Laplace equation, the tension curve of the fabric is obtained, and the radius of local curvature of a certain section of human body is obtained, then the pressure value of this point can be calculated.

In 2020, Hafiz Faisal Siddique et al. \cite{11} modified Laplace's law by introducing some new parameters such as deformation width, true stress and true/logarithmic strain, and established two mathematical models based on true Young's modulus and engineering Young's modulus, and compared them with Hooke's law and Laplace's Law. The results show that the newly developed model is more accurate and accurate than the existing one.

Laplace equation regards human body as rigid body, and the measured pressure value is quite different from the actual value.

3.2.2 Theoretical model based on contact mechanics. Previous finite element studies regarded clothing as a shell structure. In 2002, X. ZHANG et al. \cite{12} proposed a mechanical model for numerical simulation of three-dimensional dynamic pressure of clothing using finite element method. Clothing is regarded as geometrically nonlinear elastic shell and the human body is assumed to be rigid. The contact between human body and clothing is modeled as a dynamic sliding interface. Compared with the measured value of clothing pressure reported in literature, the predicted pressure value is close to the measured value of experiment. Due to the assumption that the human body is rigid, the model has some limitations. In 2014, Li Yanmei et al. \cite{13} used a THREE-DIMENSIONAL human body scanner to obtain the point cloud data of the shank contour, and used reverse engineering software to fit out a multi-layer finite element model of the shank containing skin, muscle and bone. The calculated results of the model are basically consistent with the pressure test values of the key points.

The calculation precision of finite element method is high, but the time is long, so the balance between the calculation precision and speed should be grasped to control the cost.

Compared with the finite element model, the mass spring model is faster, but one of its main disadvantages is that isotropic and anisotropic materials are not easy to generate and control. Another problem is that most materials found in nature maintain a constant or quasi-constant volume during deformation (this is well known to muscles, but also to inanimate materials). The mass spring model does not have this property. But even in the spring system with a small-time step, the grid is not evenly balanced. The grid vibrates and requires a smooth program. \cite{14} In 2010, Yosuke Horiba et al. \cite{15} discussed a particle-based mechanical model for numerical simulation of clothing pressure. The particle system of human body and clothing is expressed as elastomer, and the collision between human body and clothing is expressed as a model based on impulse force. The validity of the proposed model is verified by two simulations. In order to evaluate the accuracy of static clothing pressure prediction, the clothing pressure on an elastic cylinder with cloth surface is predicted. The accuracy was confirmed to be 0.08kPa, but there was still room for improvement in the edge prediction. Although the grid resolution (particle distance) is considered to be the cause of the problem, it is important to choose an appropriate grid resolution because it is directly related to computation time. The numerical instability is caused by the time step and the collision model between clothing and human body.
3.2.3 Pressure prediction model based on neural network. In 2018, Han Tao et al. [16] proposed a neural network structure of deep long-term memory (LSTM), which is used to predict the pressure information of several other key parts from the pressure information of one part of the body when wearing sports tights, so as to realize the pressure information data prediction of all key points of the upper body. Experimental results show that the proposed deep LSTM neural network structure has higher prediction accuracy than other algorithms. In 2020, Zhou Jie et al. [17] proposed a genetic algorithm-back propagation (GA-BP) neural network method to predict the garment pressure under different poses. The results show that the prediction error of the GA-BP neural network model is 0.41652, less than the prediction requirement of 0.5. Therefore, the model has an acceptable accuracy in predicting banded pressures. Finally, the internal calculation function equation of GA-BP neural network is derived.

3.2.4 Other methods. In 2011, Sonoko Ishimaru et al. [18] used numerical methods to predict the pressure distribution of clothing. A technique based on numerical analysis was developed to simulate garment pressure. On this basis, a fabric deformation model considering anisotropy and nonlinearity is proposed. In this model, the fabric is divided into isotropic and anisotropic units, and nonlinearity is assigned to both. A two-step fitting method was used: the fabric was first applied to the temporary mannequin (intermediary), and then to the formal mannequin. The pressure value calculated by this method is very close to the measured value of rigid mannequin. Luo Shunhua et al. [19] innovatively adopted Matlab cubic spline interpolation method to transform the discrete static pressure values of 12 decomposition actions in a cycle cycling process into dynamic pressure in order to analyze the change rule of lower limb dynamic pressure during cycle cycling.

4. Clothing pressure performance evaluation index

In order to quantitatively evaluate the contact pressure performance of knitted fabrics and establish a relatively complete evaluation system, Wang Yongrong et al. [20] defined a new dynamic pressure performance characterization index, namely dynamic pressure stiffness, to represent the variation of pressure under unit deformation of knitted fabrics. Static pressure fatigue and dynamic pressure fatigue represent the attenuation degree of dynamic and static pressure after repeated jacking. The research results show that can be directly used to static pressure, dynamic pressure and dynamic pressure stiffness is knitted a deformation and contact pressure in the performance of the characterization, dynamic pressure and static pressure fatigue characterization of knitted fabric in repeated deformation of contact pressure attenuation degree, the two parts together to build a knitted fabric three-dimensional deformation and contact pressure in the performance of the evaluation system.

At present, no fixed pressure performance evaluation index has been formed, and further research is needed in the future.

5. CONCLUSION

The pressure produced at a particular point in the body depends not only on the shape and size of the area, but also on the softness and hardness of the tissues and muscles involved. Both human body and clothing are elastomers, which will produce displacement and sliding in the process of mutual extrusion. In addition, due to physiological factors such as sweating during sports, the clothing pressure will also change under dynamic conditions. When studying the influencing factors of dynamic clothing, we should not only consider the factors of human body and clothing, but also link clothing and human body together for analysis.

In the direction of clothing pressure test system, flexible sensors that are more suitable for continuous measurement of clothing pressure will be further developed in the future. Under the condition that the performance of the sensors is not affected, the virtual test system can be used to realize continuous measurement of clothing pressure. To further improve the intelligent dummy system, in addition to using more suitable materials to simulate real people, on the other hand, the dummy can also imitate some sports actions to make it have certain flexibility, improve the accuracy of dynamic pressure measurement,
and provide reference standards for the comfort and functional evaluation of pressure clothing in the future.

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