



Intelligent Monitoring Method for Static Comfort of Ejection Seat Based on Human Factors Engineering

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Abstract. In order to determine the factors that affect the static comfort of ejection seats, an intelligent monitoring method for static safety of ejection seats based on human factors engineering is proposed. Human factors engineering is used to analyze human motion, and different percentiles of human body size are used to simulate the leg motion range, so as to determine the travel and adjustment amount of the pedal. Combined with the size of the human body, the position of the seat reference point and the comfort Angle of each joint of the human leg, the comfort range of the pedal shaft is solved, and the pedal is optimized. The finite element model of the ejection seat is constructed by human factors engineering, and the linear elastic constitutive relationship is used as the material constitutive relationship of the ejection seat. The material density, Young's modulus, Poisson's ratio, shear modulus, bulk modulus and other parameters are defined to analyze the impact load of the ejection seat when it is ejected. The results indicate that the finite element model based on ergonomics is suitable for static comfort monitoring of ejection seats. The increase in seat cushion thickness has a certain trend of reducing the maximum and average pressure in certain areas of the seat cushion, and has almost no effect on the contact area. Increasing the protrusion of the waist can increase the maximum pressure on the waist, but it will reduce the contact area at the shoulder position. In the development of comfort, attention should be paid to the matching of the waist and shoulders to ensure the overall comfort of the backrest.

Keywords: Human Factors Engineering · Human Movement · Ejection Seat · Static Comfort · Finite Element Model

1 Introduction

Military aircraft has always played a very important role in the development history of air navigation. The two world wars showed that aircraft played a very important role in military affairs, but it was also very likely to be destroyed. In order to save aircrew after aircraft damage, special equipment must be used to enable them to get off the aircraft smoothly and land safely [1]. Long term flight missions often performed by pilots will

lead to deep vein thrombosis, which will lead to pressure ulcers, delayed response, and reduced operating ability, which will seriously affect the health of pilots and reduce the effectiveness of flight operations. Safety issues will be given priority in the design of ejection seats, so the comfort improvement of ejection seats is very limited, and the cushion is the most important part that can be improved and optimized, and can improve the comfort of ejection seats.

The uniform pressure distribution on the seat surface can reduce the probability of skin ulceration and tenderness. The local high pressure on the person seat interface will lead to the deformation of human soft tissue, which will hinder the blood circulation and nutrition supply, and make the human body feel uncomfortable or tired. Therefore, according to the physiological response, the stress distribution that is most suitable for sitting position can make the weight evenly distributed on the larger support surface, but not evenly distributed; And the body pressure distribution process should be smooth transition from small to large to avoid sudden changes. The maximum pressure at the ischial tubercle occurs on the seat surface, and the pressure gradually decreases outward from the ischial tubercle until the pressure is the minimum under the thigh that contacts the front edge of the seat surface. Because the sitting stress of the seat cushion affects the comfort performance of the seat to a large extent, the comfort performance of the seat can be significantly improved by improving the distribution of the sitting stress, so it is of great significance to study the sitting stress of the person seat interface for improving the comfort of the seat.

In domestic research, Han Yuhong et al. [2]. by designing the experiment, the independent variable is two different seats, and the dependent variable is the skin electricity reflex, heart rate variability, pupil diameter, and the user's subjective evaluation of the seat comfort. SPSS statistical analysis software is used to do independent sample t-test on the experimental data, and analyze their correlation. The results showed that there were significant differences in the changes of pupil diameter between the subjects sitting in two different seats, and there was no significant difference in the detection results of EDA and HRV. In the research of seat comfort evaluation based on psychophysiological measurement method, pupil index is relatively sensitive and has strong correlation with subjective evaluation. Under certain conditions, pupil data can be used to optimize seat comfort evaluation; There is no sufficient evidence to support that there is a significant correlation between the skin electric reflex and heart rate variability and seat comfort. In addition, the application of psychophysiological measurement methods such as eye tracking can, to a certain extent, reverse guide the improvement and design of seats. Longjiang et al. [3] can not establish an accurate seat comfort prediction model because the traditional BP neural network is sensitive to the initial value and easy to fall into the local optimal solution. In order to solve this problem, a method to predict the comfort of seats by using the BP neural network optimized by the artificial bee colony algorithm is proposed. 176 groups of pressure distribution sample data were obtained through the body pressure test, 89% of which were used as the training part of the model, and 11% of which were used as the model validation. Comparing the prediction results with the real values, the mean square error MSE of the ABC-BP prediction model was 0.0019, and the certainty coefficient R^2 was 0.946, which was 84.68% lower than the MSE obtained by the traditional BP neural network prediction model, and R^2 was 42.5%

higher. The results show that the prediction model of vehicle seat comfort established by BP neural network optimized by artificial bee colony algorithm is more stable and more accurate.

In foreign studies, Li M et al. [4]. By measuring the pressure distribution and EMG signal during short and long driving respectively, the driver's pressure index, EMG signal characteristic parameters and corresponding subjective evaluation are obtained. The changes of subjective and objective parameters of comfort, the differences in comfort and the body parts prone to fatigue were tested. The index screening was completed through correlation analysis. A new comprehensive weighting method, AHP restricted entropy method, is proposed to establish the mapping relationship between subjective comfort and objective indicators based on pressure distribution and physiological information during short-term and long-term driving. A quantitative evaluation method of driving comfort is obtained by applying pressure distribution, physiological information and subjective evaluation, which provides a theoretical basis for evaluating driving comfort.

In view of the lack of research on the comfort of ejection seat cushion, this paper applies ergonomics to the intelligent monitoring of static comfort of ejection seat based on the research on the stress distribution of vehicle seat, so as to improve the static comfort of ejection seat. In the research process of this paper, firstly, based on the three-dimensional coordinate system, the relative coordinate system fixed on each moving limb is established, and the human factors engineering is used to analyze the human motion and optimize the layout of the cockpit heading foot pedal. Then, considering the complex actual structure and use environment of the ejection seat, and trying to accurately calculate the impact dynamic characteristics of the seat, the linear elastic constitutive relationship is used as the material constitutive relationship of the ejection seat. Finally, by setting the boundary conditions, the finite element model of the ejection seat was constructed by human factors engineering, and the intelligent monitoring of the static comfort of the ejection seat was realized.

2 Design of Intelligent Monitoring Method for Static Comfort of Ejection Seat

2.1 Optimizing the Arrangement of Cockpit Heading Pedals

When the manikin simulates the pilot driving the aircraft, the pilot leans back against the seat, looks ahead, holds the steering stick with his right hand and the accelerator lever with his left hand. When simulating human movement, according to the state of the pilot when he is in a natural upright sitting position with head up view [5], the whole trunk is set to remain motionless, and only the hand and foot joints need to move within a reasonable range.

In human motion analysis, the position of the hand or foot in any space is determined by formula (1) by establishing a three-dimensional coordinate system (X, Y, Z) And then establish the relative coordinate system fixed on each moving limb (X_n, Y_n, Z_n) When the human body moves, the spatial position of the hand or foot in the base coordinate

system is shown as follows:

$$\begin{Bmatrix} X_n \\ Y_n \\ Z_n \end{Bmatrix} = T_n \begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix} + P_n \quad (1)$$

Where, P_n Is the coordinate system (X_n, Y_n, Z_n) Origin in base coordinate system (X, Y, Z) Coordinates in, T_n It is the transformation matrix from relative coordinate system to base coordinate system.

According to the analysis of human motion, the cockpit directional pedals are optimally arranged. For the pedal stroke and adjustment amount, the leg movement range can be determined only by simulating the human body size at different percentiles [6]. Combining the size of the human body, the position of the seat reference point and the comfort angle of each joint of the human leg, we can use Formula (2) to solve the comfort range of the pedal shaft and optimize the layout of the pedal.

$$\left. \begin{aligned} \alpha + \beta + \gamma &= 180^\circ \\ B \times \sin \gamma &= A \times \sin \alpha + C + E \\ F &= D + A \times \cos \alpha + B \times \cos \beta \end{aligned} \right\} \quad (2)$$

Among them, α Represents the thigh chamfer, β Represents the angle between the axis of the thigh and the axis of the lower leg, γ Represents the angle between the leg axis and the horizontal line passing through the pedal axis point, A Represents the thigh length, B Indicates the length of the lower leg, C Represents the longitudinal distance from the hip joint to the reference point, D Represents the transverse distance, E Represents the vertical distance from the reference point to the pedal, F The horizontal distance from the reference point to the pedal.

The finite element model of the ejection seat is built after the optimal layout of the cockpit directional pedals is completed.

2.2 Build Finite Element Model of Ejection Seat

2.2.1 Simulation Model

Human factors engineering takes the best matching of human machine environment system as an important goal pursued by the discipline [7], so that people under different conditions can work and live in an efficient, healthy, safe and comfortable manner, ensure high-quality operation and high work efficiency at the same time, and reduce or eliminate safety accidents caused by errors or misreading through comfort design.

Considering the complex actual structure and use environment of the ejection seat, and striving to accurately calculate the seat impact dynamic characteristics [8], the finite element model of the ejection seat is constructed using human factors engineering. The following basic assumptions are made in modeling:

- Except for the impact load bearing points of the structure, the entire structure only produces elastic deformation during the impact of the seat;
- The whole structure meets the continuity assumption and uniformity assumption;

- The materials used in the whole structure meet the basic assumption of isotropy.

In view of the complexity of the seat entity model, in order to effectively carry out the finite element modeling, the seat structure should be simplified and the main load-bearing structure should be retained. In the process of simplification, try to ensure that the overall stiffness is unchanged and the shape of key parts is consistent, so that the structure of key parts can be guaranteed more reliably. The simplified model is shown in Fig. 1.



Fig. 1. Finite Element Model of Ejection Seat

In the process of simulation calculation, the whole seat structure is properly simplified, and the main load-bearing structure in the actual impact process of the seat is retained, which greatly reduces the number of grids, shortens the calculation period and ensures the calculation accuracy. It can provide a reference for further analysis of ejection seats.

2.2.2 Material Parameters of Ejection Seat

The ejection seat is mainly made of aluminum alloy, which has a high strength to weight ratio. Based on the assumptions proposed in this paper and the study in this paper only considers the response of the seat in the linear elastic range [9], so the material constitutive relationship used in the calculation is linear elastic constitutive relationship.

In the linear elastic material mode, the material density needs to be defined ρ Young's modulus E Poisson's ratio μ , shear modulus G , bulk modulus K And other parameters. Only two of Young's modulus, Poisson's ratio, shear modulus and bulk modulus need to be defined, because the four have the following relationship:

$$G = \frac{E}{2(1 + \rho)} \quad (3)$$

$$K = \frac{E}{3(1 - 2\mu)} \quad (4)$$

There are two kinds of impact loads on the ejection seat. One is the acceleration impact load on the entire seat structure during the ejection process, and the other is the impact force on the seat basin during the pilot's ejection process. This paper mainly studies the dynamic response of the seat structure under these two impact loads.

It can be seen from the above brief introduction to the ejection seat that the seat basin and hook are the main parts of the seat when the machine falls. The two parts of the impact load are respectively loaded equivalently. The acceleration impact load borne by the seat during the actual crash acts on the entire seat structure in a vertical upward direction. In the simulation process, it is equivalent to the restraint hook part, and the entire acceleration load acts vertically downward on the seat structure; The impact load of passengers is applied to the seat basin. The impact load of passengers is equivalent to that applied to the upper surface of the front beam and the lower beam in a vertical downward direction. In the impact simulation process, due to the role of the passengers in the seat impact process, the dummy model with a mass of $m = 90 \text{ kg}$ is used to replace the passengers, so the force acting on the upper surface of the seat front beam and lower beam $F = ma$.

The displacement boundary condition is: since the slide rail is connected to the aircraft cabin through three pairs of pulleys, it is necessary to constrain the slide rail [10]. When constraining the front and rear directions and the left and right directions, the hook connected to the power ejection device is hung on the aircraft cabin. Therefore, full restraint is required on the arc surface of the hook, and the displacement in the three directions is zero.

According to the above process, the finite element model of the ejection seat is built to monitor its static comfort.

3 Experimental Analysis

3.1 Finite Element Model Verification

3.1.1 Comparison Between Simulation and Test Based on H-point Position

The H-point device is an important tool for human-machine detection. The H-point position value can correctly evaluate the relevant compression state of the seat and the measurement of the design parameters of the seat, so it can be used as an important reference index for the comparison of simulation and test results. In this paper, the H-point simulation test is introduced and compared.

Since the left and right sides of the dummy have been ensured to be symmetrical before the H-point test, so that the Y-coordinate of the H-point is kept at the design value of -355 , it is only necessary to refer to the X and Z coordinate values. Table 1 summarizes the X and Z coordinate values of the seat design H-point position, the design values of the backrest angle parameters, and the simulation and test results.

As the ejection seat product is inferior to other seats, the design contour of the seat surface often has a certain degree of deviation from the real object, and the general requirements of the OEMs for the measured H-point of the ejection seat are within 10mm relative to the design R-point, so from the summary results in Table 1 above, it can be seen that the seat H-point results of this test meet the corresponding design

Table 1. Comparison of H-point position simulation and test

Test items	X	Z	Backrest angle
Design	1280	415	25°
Test	1281.8	413.6	25.3°
Simulation	1285.9	411.4	25.9°
Error	4.1 mm	-2.2 mm	0.6°

requirements, and the seat H-point position simulation and test errors. The position state errors of simulation and design are within a reasonable range. This conclusion shows that the comfort simulation model of ejection seat established in this paper can accurately simulate the H-point position of ejection seat and the relevant design parameters of the seat.

3.1.2 Comparison Between Simulation and Test of Body Pressure Distribution Based on HPM Device

As the main objective evaluation of comfort monitoring, the body pressure distribution is further compared with the simulation and test of the seat comfort simulation model established in this paper. This paper mainly introduces the process of comparing the simulation and test of seat body pressure distribution using HPM device.

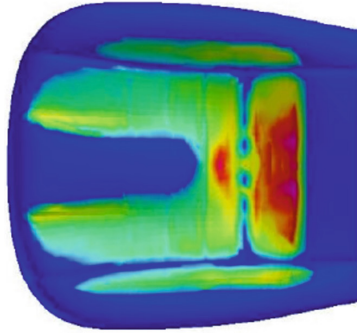
(1) Simulation Analysis of HPM Device Seat Interface Pressure Results.

The simulation analysis steps of body pressure distribution based on HPM device are executed according to the relevant dummy placement method in the process of seat H-point position measurement. After the final calculation results are completed, the cloud diagram of body pressure results can be output in the software, as shown in Fig. 2.

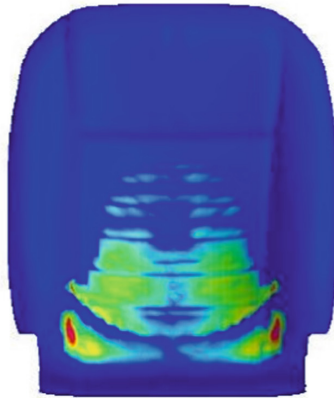
(2) HPM device seat interface pressure result test.

Test preparation: HPM dummy device, body pressure test pad, seat tooling, steel ruler (front and rear position measurement of slide rail), seat sample.

Test steps: first install the test equipment and place it according to the placement method of the body pressure test pad to ensure that the body pressure test pad is stable and can read the pressure image normally; Then place the HPM_0th dummy device, complete the placement of HPM dummy according to the dummy placement method when measuring at H-point, and ensure that the HPM_The 0th dummy is placed in the middle of the seat, and the left and right positions of the dummy are measured by the three coordinate measuring device to make the height of the dummy consistent; Finally, observe the body pressure test results, and record the measured values after the pressure data is stable.



(a) Simulation Results of Seat Cushion Body Pressure Distribution



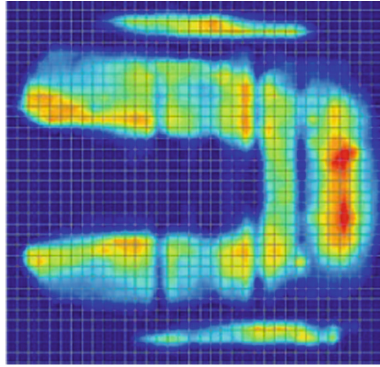
(b) Simulation results of backrest pressure distribution

Fig. 2. HPM based_Simulation results of 0th device body pressure distribution

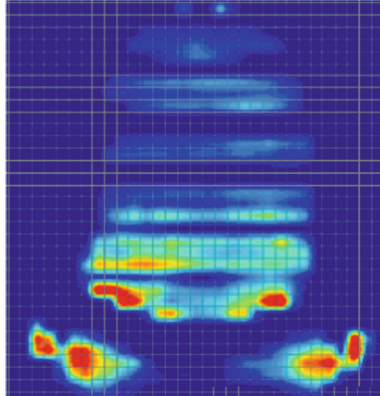
The body pressure test results after final stabilization are shown in Fig. 3. Figure 3(a) shows the test results of seat cushion pressure, and Fig. 3(b) shows the test results of backrest pressure. Part of the profile features of the seat can be clearly identified through this cloud picture.

(3) Comparison of HPM device seat section pressure based on simulation and test.

First, the pressure distribution forms of simulation and test are analyzed. It can be seen that the maximum pressure in simulation and test both appears in the dummy's hip area. In the back pressure distribution cloud chart, the local maximum pressure appears on both sides of the lower part of the back. The back pressure distribution appears faults near the style line of the seat cover. Neither simulation nor test has contact above the shoulder, The pressure contact contour nephogram form of seat cushion and backrest is consistent.



(a) Seat cushion body pressure distribution test results



(b) Backrest pressure distribution test results

Fig. 3. Test Results of Body Pressure Distribution Based on HPM Device

Secondly, the transverse and longitudinal pressure distribution curves are compared and analyzed. The statistical method of the curve is shown in Fig. 4 below. The transverse pressure distribution curve takes the left and right transverse position data of the seat as the abscissa, and the collected pressure sum of each column as the ordinate; The longitudinal pressure distribution curve takes the longitudinal position data before and after the seat as the abscissa, and the pressure sum of each row as the ordinate. The pressure distribution of the seat can be more intuitively analyzed through the statistics of the transverse and longitudinal pressure distribution curves, the trend of the pressure gradient change can be counted, and the abnormal pressure distribution can be found.

Figure 5 shows the pressure distribution trend of the seat cushion and backrest in different directions under the statistical simulation and test according to the transverse and longitudinal pressure distribution curve of the seat cushion and backrest.

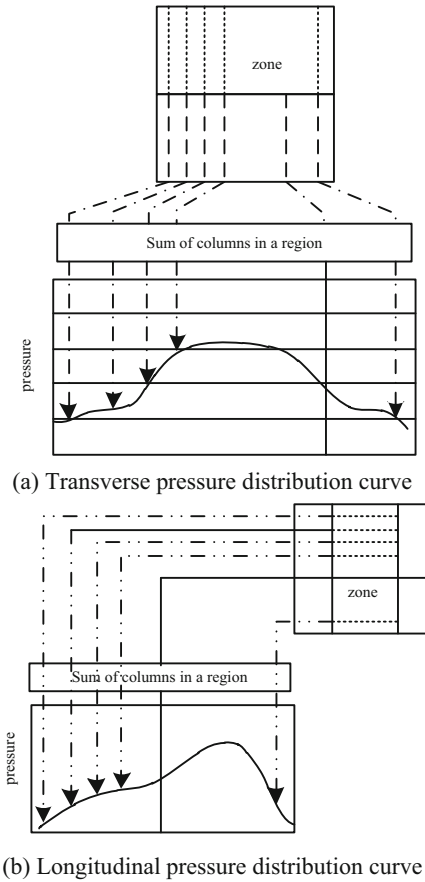


Fig. 4. Schematic Diagram of Horizontal and Longitudinal Pressure Distribution Curve of Body Pressure

From the comparison of the transverse and longitudinal pressure distribution curves, it can be seen that the curve distribution trends of simulation and test are consistent, and the pressure values are close. The longitudinal pressure distribution curve of the backrest fluctuates greatly, which is caused by the shape curve of the seat backrest, but the overall trend of simulation and test is still consistent.

Finally, in order to further and more intuitively compare and analyze the body pressure distribution results of simulation and test, the body pressure index values of the seat cushion and backrest in the statistical simulation and test, including the maximum contact pressure, average pressure, and contact area index values, are compared and summarized as shown in Table 2.

The results in the table show that the two are very close, and the maximum relative error is less than 10%. Therefore, the seat simulation model established in this paper can accurately reflect the H-point device seat body pressure distribution characteristics.

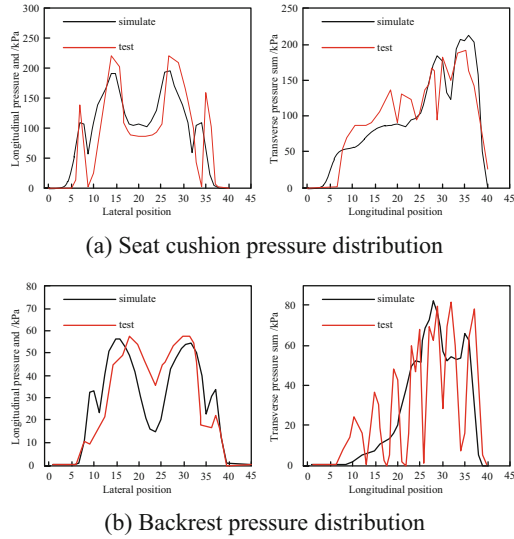


Fig. 5. Comparison between simulation and test of transverse and longitudinal pressure curves of seat cushion and backrest

Table 2. Comparison of body pressure indexes between simulation and test under H-point device

Region	Body pressure index	Test	Simulation	Error
Cushion	Peak pressure/kPa	12.24	12.68	3.59%
	Average pressure/kPa	4.21	3.90	-7.36%
	Contact area/cm ²	1093.55	1185.16	8.37%
Backrest	Peak pressure/kPa	9.31	8.92	-4.19%
	Average pressure/kPa	3.22	2.93	-9.01%
	Contact area/cm ²	595.48	643.8	8.11%

3.2 Analysis of Factors Affecting the Static Comfort of Ejection Seats

3.2.1 Influence of Cushion Thickness on Pressure Distribution of Cushion Body

The cushion thickness is an important factor affecting the riding comfort. Under certain density and hardness conditions, the thicker the cushion, the better the comfortable feeling of the human body will be. After actual seating, most of the weight of the human body is concentrated near the tubercle of the sitting bone, so the cushion under the buttocks should be thick enough to support the passengers. If the thickness is too small, the passengers will feel that the seat frame will collide when they are seated. However, if the cushion is too thick, the cost of the seat will increase. Therefore, it is necessary to consider a balance between the production cost and the comfort of the seat. In the early stage of cushion design, the cushion thickness at the corresponding position is usually determined according to the dummy layout and seat structure in the general layout. If

the cushion product can be determined to use a certain hardness in the design stage, and the comfort brought by different cushion thickness is known, the purpose of seat product design and production cost reduction will be accelerated.

In order to analyze the influence of the cushion thickness on the body pressure distribution, the thickness of the cushion is changed. In order to facilitate analysis and observation, the change amount of the setting scheme is that the cushion thickness is increased from 5mm to 20 mm, and a simulation test is carried out every 5mm of the cushion thickness. The body pressure simulation analysis is completed according to the same simulation conditions. The cloud pictures shown in Fig. 6 below represent the simulation results of the body pressure distribution of the seat cushion when different thicknesses are added to the original model.

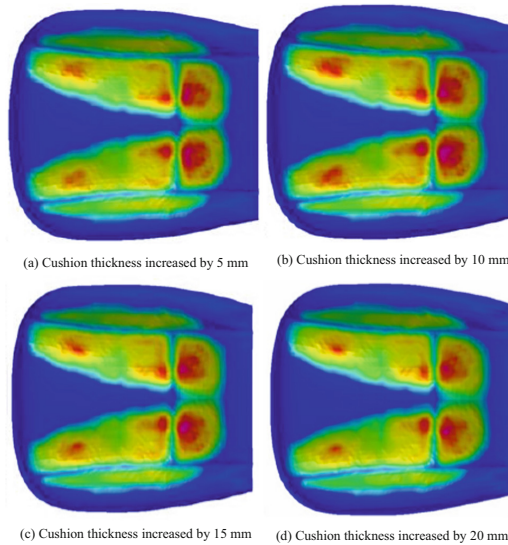
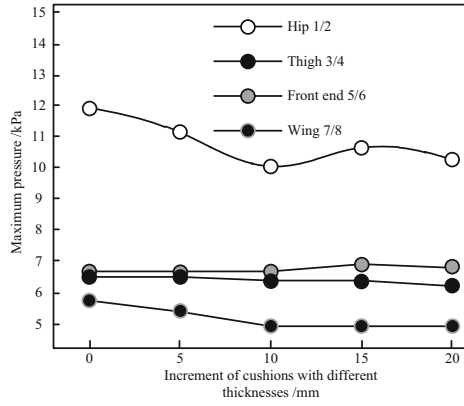


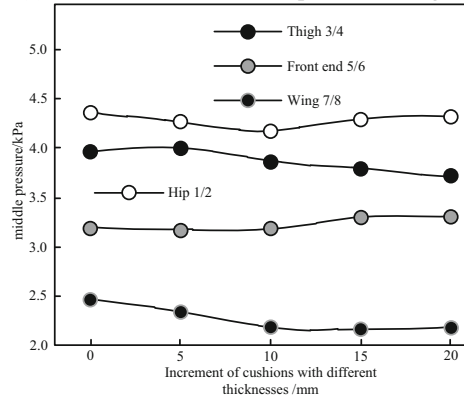
Fig. 6. Cloud Chart of Seat Cushion Body Pressure Distribution under Different Thickness

According to the form of pressure nephogram under different thickness of seat cushion added in Fig. 6, the concentration degree of larger pressure distribution in the hip area of seat cushion is greatly reduced, and there is no obvious change in contact area. The corresponding change trend chart is drawn according to the change of body pressure index in different regions, as shown in Fig. 7 below.

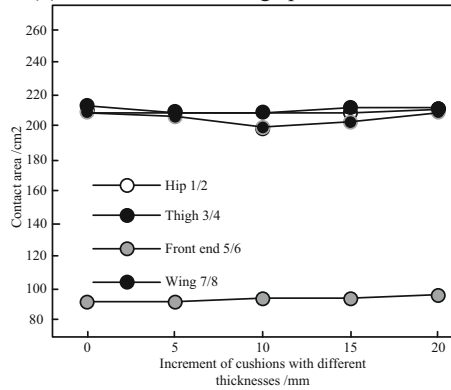
It can be seen from the trend chart that: on the original basis, with the increase of cushion thickness, the maximum pressure value is $1/2$ in the hip area and $7/8$ in the flank area, showing a downward trend; The average pressure value in the thigh area $3/4$, the flank area $7/8$ has a large degree of reduction, but in the hip area and the front of the seat cushion has no obvious change; The change of contact area in each area is not obvious. Therefore, the change of cushion thickness has a great impact on the maximum pressure and average pressure in some areas.



(a) Trend chart of maximum pressure change



(b) Trend chart of average pressure value



(c) Change trend chart of contact area

Fig. 7. Body Pressure Index Change Trend under Different Cushion Thickness

3.2.2 Influence of Lumbar Support on Backrest Pressure Distribution

The profile features that should be focused on in the design of the backrest profile are mainly the waist support and shoulder support. The passengers need to keep the natural curvature of the spine after sitting to reduce the fatigue and long-term discomfort of the waist. By changing the bulge thickness of the seat waist area, it shows the influence of the bulge thickness on body pressure. Set the bulge amount to increase from 0 mm to 30 mm, and conduct simulation test analysis every 10 mm. The simulation analysis of different waist support simulation models under the same parameters is carried out, and the backrest body pressure distribution results are obtained, as shown in Fig. 8.

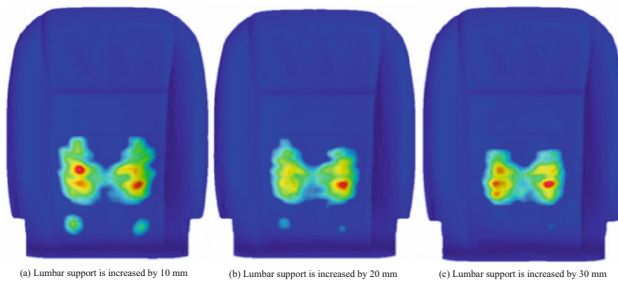


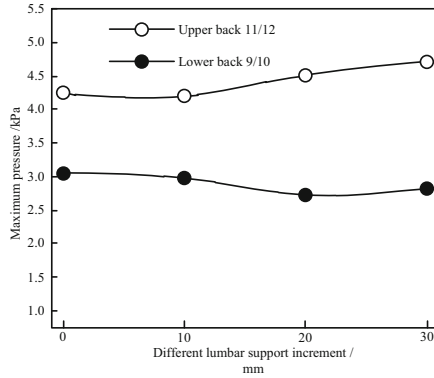
Fig. 8. Cloud Distribution Diagram of Body Pressure under Different Lumbar Support

It can be seen from the figure that when the lumbar support is small, there is a large concentrated pressure between the backrest and the lower back of the passengers, and the maximum pressure value of the backrest is small. With the increase of lumbar support, the overall contact area of the backrest gradually decreases, especially the contact degree between the upper shoulder area and the bottom of the lower back decreases, and the contact pressure area at the lowest part of the lower back of the backrest gradually decreases to disappear. At the same time, the pressure at the lumbar support position continues to increase, and the pressure gradually concentrates on the lumbar position.

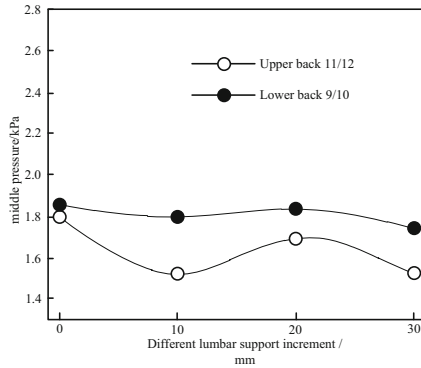
According to the statistical method of regional body pressure index and the regional pressure index change, the trend chart of each pressure index change is drawn as shown in Fig. 9 below.

Through the change of pressure index, it can be further analyzed that: with the increase of lumbar support protrusion, the maximum pressure value of 11/12 in the upper back area gradually increases, which is displayed near the waist, and the maximum pressure value of 9/10 in the lower back area decreases; The average pressure in the upper and lower back showed a downward trend; The overall contact area is significantly reduced.

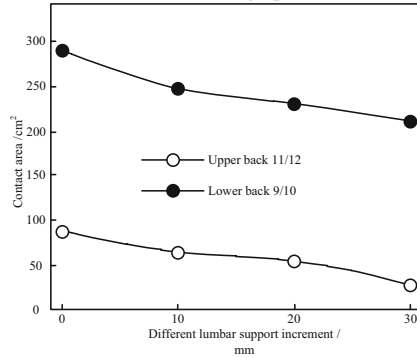
The simulation analysis results show that increasing the lumbar protrusion can increase the maximum pressure value of the waist, and can also reduce the resistance pressure of the lower part of the backrest in contact with the human body due to the small lumbar support, but on the other hand, it will bring a certain reduction in shoulder comfort, because it will greatly reduce the contact area of the shoulder position.



(a) Trend chart of maximum pressure change



(b) Trend chart of average pressure value



(c) Change trend chart of contact area

Fig. 9. Schematic diagram of index change trend in each area of backrest

4 Conclusion

This paper proposes an intelligent monitoring method for the static comfort of ejection seats based on human factors engineering. The results show that the cushion thickness and lumbar support will affect the static comfort of ejection seats. Although the research in this paper has achieved certain results, there are still many shortcomings. In the actual research and development of the seat, it is necessary to maintain the common matching between the waist and the shoulder of the backrest, to ensure the overall fit of the backrest and the back of the human body, so as to achieve the overall comfort of the backrest. In addition, this study found that the overall comfort of the seat back is closely related to the elastic properties of the cushion. In the actual development process of the seat, in addition to considering the thickness of the cushion and the waist support, we should also pay attention to the material and elastic modulus of the cushion. The appropriate material and appropriate elastic modulus can provide better support and buffering effect, so as to further improve the static comfort of the seat.

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