TRACTOR DESIGN ANALYSIS AND RESEARCH BASED ON KANO - AHP MODEL AND JACK
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基于 KANO—AHP 模型与 JACK 的拖拉机设计分析与研究

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ABSTRACT
In order to make the tractor better meet the needs of users under the premise of satisfying the use of functions, the Kano - AHP model is used to design the appearance of the tractor. Firstly, the emotional needs of users are collected, and the tractor modeling is designed according to the requirements combined with the Kano model. The design scheme is displayed through Rhino in the form of three-dimensional modeling. According to the design requirement index was summarized by Kano model, the tractor modeling hierarchical structure model was established by using analytic hierarchy process, the weights of each index were obtained, and the best design scheme was selected according to the weights. Finally, the selected best scheme was imported into Jack ergonomics simulation software for stress analysis and comfort analysis of the lower back, and the analysis results were used to check whether the scheme met the man-machine physiological standards.

摘要
为了使拖拉机在满足使用功能的前提下更好的满足用户需求，现使用 Kano—AHP 模型对拖拉机进行外观的造型设计。首先收集用户的情感需求，结合 Kano 模型并根据需求设计拖拉机造型，通过 Rhino 将设计方案通过三维建模的形式展现出来；结合 Kano 模型总结出的设计需求指标，使用层次分析法建立拖拉机造型层次结构模型，得出各指标权重，依据权重选出最佳设计方案。最后将选出的最佳方案导入 Jack 人机工程仿真软件进行下背部受力分析和舒适度分析，通过分析结果检验该方案是否符合人机生理标准。

INTRODUCTION
With the development of The Times, the innovation of agricultural machinery is also urgent, more agricultural personnel put forward higher requirements for tractors, not only to meet the needs of functional use, the appearance should also be more in line with the user's aesthetic, which puts forward higher requirements for designers. According to the research literature, such as *Wu, (2019),* in order to enhance the market competitiveness of tractor enterprises and improve economic benefits, the tractor's practical value and aesthetic needs are combined, so that the user is the center. *Li et al. (2023)* combined the analytic hierarchy process and fuzzy comprehensive evaluation method to evaluate the three tractor modeling schemes and screened out the best scheme. In the application of the analytic hierarchy process, the tractor modeling features are disassembled into different levels and elements, which are used to calculate the weight value of each design element. *Hridoy et al., (2020),* combined Analytic Hierarchy Process (AHP), Kano and Quality Function Deployment (QFD) to design the tractor seat. Based on the existing problems of the seat, the requirements were determined, and then the weights were calculated to guide the design. *Zhou et al., (2023),* combined the analytic hierarchy process with the analysis network process, obtained the humanistic design elements of the intelligent pension products, and put forward a new design model so that the humanistic design factors can be reasonably applied in the design. *Zhang et al., (2023),* used the man-machine simulation and analysis software Jack to improve the tractor cab, the overall comfort of the tractor cab was improved. *Shi et al., (2023),* combined the analysis of controllability, visibility, and working posture comfort in Jack, summarized the design defects of the driver's cab of an electric monorail crane, and put forward optimization strategies. *Wang et al., (2018),* carried out an ergonomic analysis of agricultural machinery cabs through Jack, including driving comfort point, back stress critical value, seat, control device, etc., to improve the comfort and safety of agricultural machinery cabs.

The above literature has achieved good results in identifying innovation needs and providing innovative methods, reducing the limitations of a single method, but in many cases, it still cannot solve practical problems. For example, the combination of Kano and AHP cannot verify whether the designed product meets the man-machine requirements; only Jack is used for man-machine inspection of existing products, but Kano and AHP cannot obtain and analyze user requirements.

To sum up, in this paper, a variety of methods will be used to combine the way of tractor modeling design. The first part is the combination of Kano model and analytic hierarchy process. In this part, the needs of target users, namely design elements, are obtained, arranged, and compared, and the needs with high priority are met first. According to the design elements, the hierarchical structure model is constructed to select the best solution. Finally, the selected scheme is imported into Jack for simulation analysis to verify whether it is reasonable in terms of ergonomics, so as to provide method support for the innovation of tractor modeling design.

Jack is a very classic man-machine simulation analysis software *(Li et al., 2013)*, but the research on how to apply it in tractor modeling and combine it with Kano and AHP to complete the design is still blank. The combination of Jack and the first two methods enables the man-machine aspect of tractor design to be further tested, thus improving the design efficiency and accuracy, which is also the main innovation point of this paper.

MATERIALS AND METHODS

Kano model is the overall data prioritization of user needs by obtaining user satisfaction with product shape and function. By using the Kano model, the product development team can comprehensively classify the user needs, and formulate corresponding product strategies according to the importance of each demand attribute, so as to improve user satisfaction and market competitiveness. This is shown in Figure 1. The X-axis coordinate is the degree of fulfillment of the user's needs and the Y-coordinate is the user satisfaction. Kano model proposes five demand attributes: Attractive attribute(A); One-dimensional attribute(O); Indifference attribute(I); Must-be attribute(M); Reverse attribute(R) *(Kano et al., 1984)*.

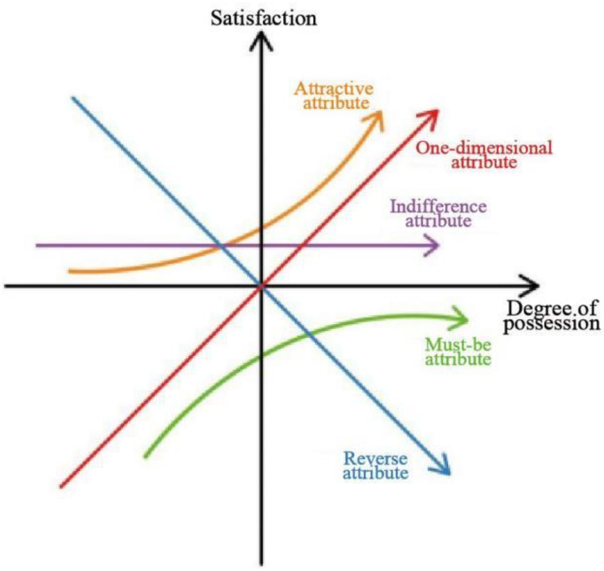

Fig. 1 - Kano model

The interpretation of each demand is as follows: Attractive demand (charm attribute): a function/service that exceeds the user's expectation, with a high degree of perfection of the function/service, the user's satisfaction will increase significantly, but without the function/service, the user's satisfaction will not decrease significantly; One-dimensional demand (One-dimensional attribute): a certain function/service will improve the satisfaction, without which the satisfaction will decrease; Indifference demand (Indifference attribute): the presence or absence of a function/service does not affect satisfaction; Must-be demand (Must-be attribute): the presence of a function/service does not increase satisfaction, but the absence of it decreases satisfaction; Reverse demand (reverse attribute): the absence of a feature/service leads to higher satisfaction *(Akao et al., 1994)*.

Table 1 shows the mapping between the questionnaire options and each requirement.

Table 1

Demand attributes

Functional Requirements		**Reverse problem**				
		Dislike	**Put up with**	**Doesn't matter**	**Rightly so**	**Like**
Positive questions	Dislike	Q	R	R	R	R
	Put up with	M	I	I	I	R
	Doesn't matter	M	I	I	I	R
	Rightly so	M	I	I	I	R
	Like	O	A	A	A	Q

By investigating the user intention, the demand type of the tractor design is obtained.

According to the Kano model, the questionnaire is designed and investigated. Each index attribute in the questionnaire contains forward questions and reverse questions so that the average satisfaction score of users on the functional index can be calculated. By classifying the subsequently obtained data, users' demand types for product functions can be obtained *(Cohen et al., 1996)*.

Better-Worse coefficient analysis is a demand satisfaction analysis method based on the Kano model that is used to determine the importance and priority of product features. This method determines which functions are of the greatest concern and priority to users through the comparison of different features.

The Better coefficient, the satisfaction coefficient, is:

$$Better = (A + O) / (A + O + M + I) \tag{1}$$

The Worse coefficient, i.e. the dissatisfaction coefficient, is:

$$Worse = -(O + M) / (A + O + M + I) \tag{2}$$

The absolute value of the Better-Worse coefficient is generally between 0 and 1, which represents the user's satisfaction with the existence of the function. According to the value of the coefficient, a four-quadrant distribution diagram of the demand attributes can be obtained.

The value of the Better coefficient is the vertical coordinate, the absolute value of the Worse coefficient is the horizontal coordinate, the average of the value of the Better coefficient and the absolute value of the Worse coefficient is the quadrantal dividing line, and the four-quadrant diagram of the better-worse coefficient is drawn. The first quadrant is the expected attribute; the function of this quadrant should be satisfied first. The second quadrant is the charm attribute; the function of this quadrant should be satisfied first. The third quadrant is the indifference attribute; the function of this quadrant is not usually provided. The fourth quadrant is the necessary attribute; the function of this quadrant must be satisfied *(Song et al., 2023)*.

The Analytic Hierarchy Process (AHP) *(Saaty et al., 1989)* is a multi-criteria decision analysis method designed to help decision makers deal with the complex relationship between multiple criteria and multiple alternatives. The core idea of this method is to hierarchize the decision problem, decompose the complex problem into several relatively simple sub-problems, and get the final decision result by comparing and judging each sub-problem.

According to the analysis of questionnaire data obtained by Kano model and the analytic hierarchy process, the hierarchical structure model of tractor modeling factor evaluation can be obtained.

According to the design elements, the 9-level scale method can be used to construct the judgment matrix *(Guo et al., 2023)*. The judgment matrix is a pairwise comparison between the indicators of the same layer, that is, the criterion layer and the sub-criterion layer are compared respectively, and the value is assigned according to the relative scale of 1-9, and the importance of the design elements is expressed according to the value. The scale table of the judgment matrix is shown in Table 2.

Table 2

Scale table of judgment matrix

Relative importance Degree assignment（i/j）	Implication	Scale specification
1	Equally important	Indicator i is as important as indicator j
3	Slightly important	Indicator i is slightly more important than indicator j
5	Obvious importance	Indicator i is obviously more important than indicator j
7	Strongly important	Indicator i is more important than indicator j
9	Extremely important	Indicator i is extremely important compared to indicator j
2，4，6，8	Use when you compromise	The degree of importance is determined according to the adjacent scale

According to the constructed judgment matrix, the weight of each element can be obtained by using the arithmetic average method.

1. Each column of the judgment matrix is normalized, that is:

$$\overline{x}_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \quad (i=1,2,3,...,n) \tag{3}$$

2. Sum the processed matrices by row, that is:

$$\breve{\omega}_i = \sum_{i=1}^{n} \overline{x}_{ij} \quad (i = 1,2,3,\dots,n) \tag{4}$$

3. The weight vector can be obtained by processing the result of the sum:

$$\omega_i = \breve{\omega}_i / n \tag{5}$$

After the relative weight of each design element is obtained, it is necessary to carry out a consistency test. First, it is necessary to obtain the maximum feature root of the judgment matrix according to the weight, and then obtain the consistency test value CI. Then, the test coefficient of the judgment matrix can be obtained according to the standard value of RI in Table 3.

1. Find the maximum eigenroot of the judgment matrix (where the weight is multiplied by the matrix, n represents the order of the matrix, and represents the weight of each row in the matrix):

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(AW)i}{nw_i} \tag{6}$$

2. Find the consistency test value of each indicator:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{7}$$

3.Calculate the test coefficient of the judgment matrix:

$$CR = \frac{CI}{RI} \tag{8}$$

Table 3

RI standard values

Rank	1	2	3	4	5	6	7	8	9
RI value	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46

Through the weight of analytic hierarchy process, the index that has a greater weight in the tractor modeling design can be obtained, but the evaluation and scoring of experts are more subjective, and it is impossible to know whether the best scheme meets the man-machine standard. Therefore, Jack *(Badler et al., 1992)* was used to analyze the stress and comfort of the lower back while holding the steering wheel.

RESULTS

According to the results of the questionnaire to obtain the user intention, two types of tractor design requirements are obtained, namely functional requirements and comfort requirements. Each requirement contains its specific indicators, i.e., six items each of functional requirements and comfort requirements, as shown in Table 4.

Table 4

Demand index of tractor modeling design

Type of demand	Number	Demand items	Instructions
Functional Requirements n	n1	Water heater	Provision of hot drinking water
	n2	Cab ceiling	Shelter from rain and sun
	n3	Sound insulation and noise reduction device	Effectively prevent transmission noise
	n4	Air conditioner	Optional cooling or heating
	n5	Windshield wiper	Clean the windshield
	n6	Floodlight	Work area lighting
Comfort Requirements m	m1	Instrument panel	Display driving information
	m2	Driver's seat	Stress on the lower back
	m3	Hand control device	Gear hanging comfort
	m4	Control panel layout	Operation control panel comfort
	m5	Steering wheel	Comfort on the steering wheel
	m6	Foot control device	Pedal comfort

Use questionnaires to collect data, so as to obtain the initial needs of users. A total of 150 questionnaires were issued and 135 valid questionnaires were collected.

According to formulas (1) and (2), attribute statistics are carried out on the questionnaire data, and the results are shown in Table 5, and the demand attribute quadrant diagram is shown in Figure 2.

Table 5

Statistics of tractor design requirements

No.	Number of selections						Better coefficient	Worse coefficient	Better-Worse classification
	A	O	M	I	R	Q			
n1	72	35	20	8	0	0	0.793	-0.407	A
n2	65	38	21	7	4	0	0.786	-0.450	A
n3	16	11	50	56	2	0	0.203	-0.459	I
n4	16	23	25	65	4	2	0.302	-0.372	I
n5	10	18	90	13	3	1	0.214	-0.824	M
n6	25	66	36	5	3	0	0.689	-0.772	O
m1	34	70	7	13	11	0	0.839	-0.621	O
m2	6	46	54	25	4	0	0.397	-0.763	M
m3	26	31	25	45	7	1	0.449	-0.441	I
m4	14	19	22	67	13	0	0.270	-0.336	I
m5	21	72	15	9	17	1	0.795	-0.744	O
m6	8	6	17	26	75	3	0.246	-0.404	I

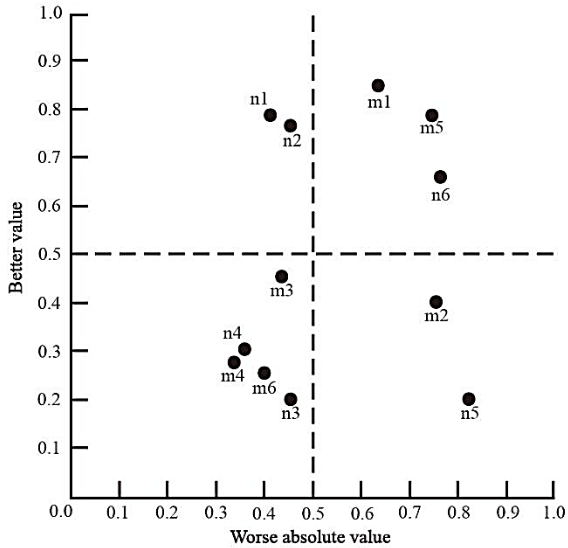

Fig. 2 - Quadrantal distribution of demand attributes

The results show that the following 7 requirements need to be met in the tractor design: the attractive demands are water heater n1 and cab ceiling n2; the One-dimensional demand is lighting function n6, instrument panel m1 and steering wheel m5; the Must-be demands are the wiper n5 and the driver's seat m2.

In the design of tractor modeling, the basic needs of users must be met, in addition to the need to try to meet the expectations of the needs and the excitement of the needs. According to this, the preliminary design of the tractor modeling is carried out, and the scheme is modeled with Rhino 7 *(McNeel et al., 2023)*. The design of the modeling scheme is shown in Figure 3.

(Option 1) (Option 2)

Fig. 3 - Tractor modeling scheme

The obtained hierarchical structure model of tractor modeling factor evaluation is shown in Table 6.

Table 6

Hierarchical structure model of tractor modeling factor

Target layer	**Criterion layer**	**Subcriterion layer**
Tractor modeling	Feature N_1	Water heater N_{11}
		Cab ceiling N_{12}
		Floodlight N_{13}
		Windshield wiper N_{14}
	Comfort N_2	Instrument panel N_{21}
		Steering wheel N_{22}
		Driver's seat N_{23}

Questionnaires were sent to 5 experts to evaluate and score each element according to the 9-level scale rule. According to the scoring results given by experts, a judgment matrix is constructed, in which:

The judgment matrix of the tractor modeling factor is:

M	N_1	N_2
N_1	1	2
N_2	1/2	1

The judgment matrix among indicators in the functional criterion layer is:

N_1	N_{11}	N_{12}	N_{13}	N_{14}
N_{11}	1	1/7	1/3	1/2
N_{12}	7	1	3	4
N_{13}	3	1/3	1	2
N_{14}	2	1/4	1/2	1

The judgment matrix among indexes of the comfort criterion layer is as follows:

N_2	N_{21}	N_{22}	N_{23}
N_{21}	1	1/5	1/7
N_{22}	5	1	1/2
N_{23}	7	2	1

Based on formula (3) - Formula (8), the weights of each evaluation index of tractor modeling design can be obtained, as shown in Table 7.

Table 7

Index weights of tractor modeling design evaluation system

Criterion layer	Criterion layer weight	Subcriterion layer	Subcriterion layer weights	Comprehensive weight	λ_{max}	CR
Feature N_1	0.667	Water heater N_{11}	0.074	0.049	4.021	0.008 < 0.1
		Cab ceiling N_{12}	0.568	0.379		
		Floodlight N_{13}	0.225	0.150		
		Windshield wiper N_{14}	0.134	0.089		
Comfort N_2	0.333	Instrument panel N_{21}	0.076	0.025	3.016	0.015 < 0.1
		Steering wheel N_{22}	0.334	0.111		
		Driver's seat N_{23}	0.591	0.197		

If CR values in the table are all less than 0.1, the judgment matrix passes the consistency test, and the data are valid data.

In order to obtain the best scheme, it is necessary to compare the two schemes, construct a judgment matrix, and combine formula (3) - formula (5) to obtain the specific index weights of each scheme layer, as shown in Table 8.

Table 8

Weights of specific indicators at the solution layer

Index	N_{11}	N_{12}	N_{13}	N_{14}	N_{21}	N_{22}	N_{23}
Option 1	0.333	0.250	0.667	0.333	0.667	0.167	0.143
Option 2	0.667	0.750	0.333	0.667	0.333	0.833	0.857

By the weight of each specific index, the total weight of the two schemes can be calculated: the weight of each index in the scheme is multiplied by the corresponding comprehensive weight, and then the result is added *(Su et al., 2018)*. The total weight of scheme 1 is 0.304; the total weight of scheme 2 is 0.696. According to the weight results, scheme 2 is the best scheme. Since the judgment matrices of the scheme layer are consistent matrices, no consistency test is needed and the data is valid.

The combination of the above two methods has been able to obtain a specific tractor design scheme, but from the actual effect, it may not be able to pass the man–machine inspection; if not verified, it is easy for users to use the tractor faster driving fatigue phenomenon.

According to the above methods and results, the conclusion was drawn that the steering wheel and driving seat have a large weight in the tractor modeling design, indicating that these two indicators are more important, so in order to exclude contingency, Jack should be used to carry out man-machine simulation analysis of the scheme to increase its objectivity.

The Rhino model of the best scheme was converted into .wrl format and imported into Jack(9.0), and the Chinese adult male virtual character model in the 50th percentile was constructed according to GB/T 10000-1988 *(Zhu et al., 2022)*, and its posture was changed to driving state, as shown in Figure 4 and Figure 5 respectively. Figure 4 shows the specific data of the virtual human model, and Figure 5 shows the posture display of the virtual human driving state.

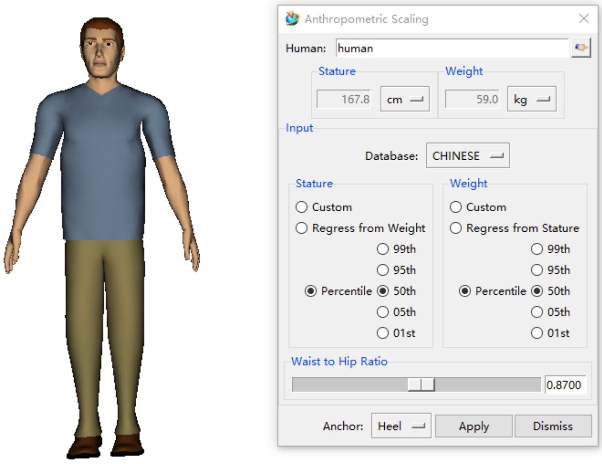

Fig. 4 - Human data model

Fig. 5 - The virtual person driving state

The comfort level of the seat is the most easily addressed, which is directly related to the stress on the lower back when holding the steering wheel. Only when the stress is within the appropriate range can the driver operate the tractor stably and comfortably. Therefore, the stress analysis on the lower back is one of the important analysis items in Jack's simulation analysis *(Liu et al., 2013)*.

When analyzing the stress on the lower back, the stress on the fourth and fifth lumbar vertebrae of the lower lumbar vertebrae of the driver was mainly analyzed, through which it could be checked whether the stress situation of the driver met the NIOSH standard *(Sun et al., 2022)*. The specific simulation analysis interface is shown in Figure 6.

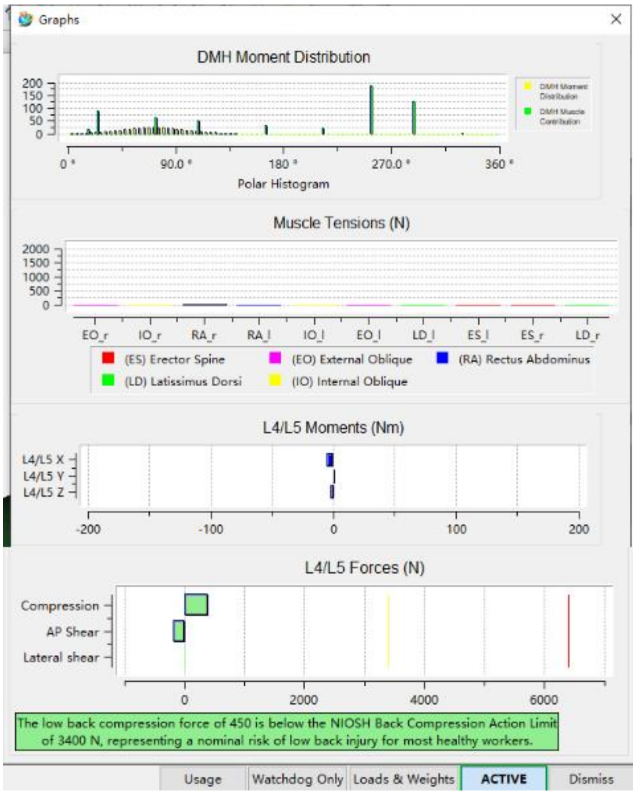

Fig. 6 - Stress analysis diagram of lower back

As can be seen from Figure 6, when the virtual driver is driving, the force on the fourth and fifth lumbar vertebrae of the lower back is 450N, while the pressure limit stipulated in the NIOSH standard is 3400N, so the driver is in a safe state.

The Comfort Assessment in Jack was used to analyze the driver's comfort *(Liu et al., 2022)*. The comfort value range given by Porter's data source is −60 to 60, within which the driver's operating comfort is considered acceptable. The green bar chart indicates the difference between the actual measured value and the standard value; if the yellow bar chart appears, it indicates that the joint is beyond the comfort range of the human body and causes physical discomfort.

Figure 7 is the analysis diagram of joint comfort, from which it can be seen that the driver's joints are all within the range of human comfort in the driving state.

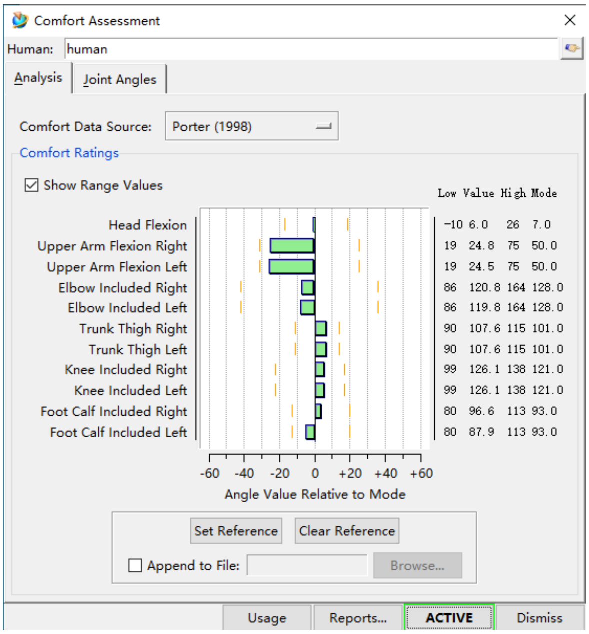

Fig. 7 - Analysis of Joint Comfort

Secondly, the Krist data source tool is used to score the joint comfort, ranging from 0 to 80. The smaller the number, the greater the comfort. The specific analysis interface is shown in Figure 8. It can be seen from the figure that the driver's comfort under this posture meets the man-machine standard.

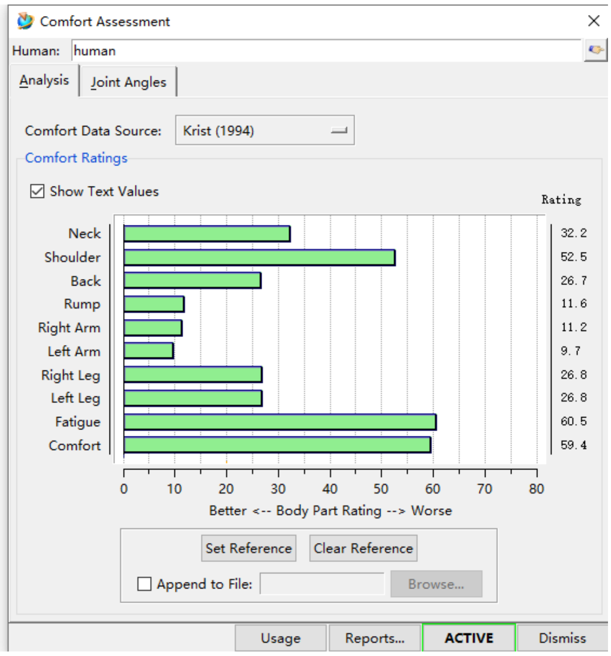

Fig. 8 - Comfort score

In order to increase the rationality of the design method in this paper, the model of scheme 1 is also imported into Jack for analysis, and the comfort score obtained is shown in Figure 9. Compared with Figure 8, it can be concluded that the comfort score of scheme 1 is generally higher than that of scheme 2.

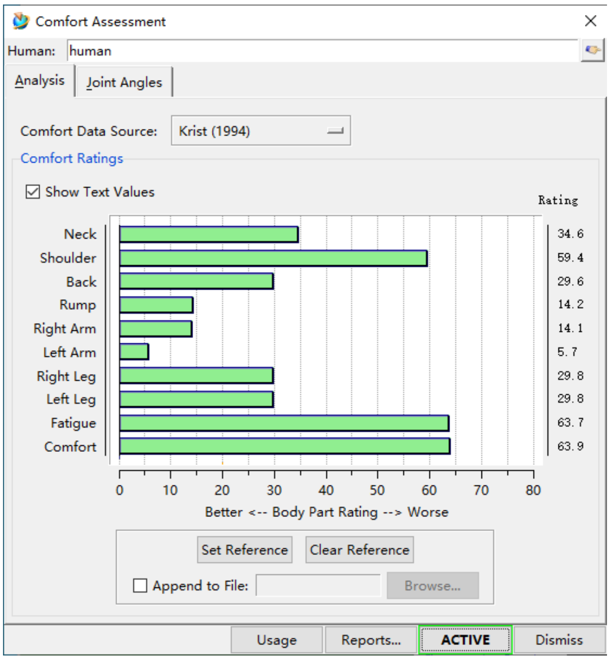

Fig. 9 - Scheme 1 Comfort rating

Through the use of Jack, it can be concluded that the tractor model designed in this paper is in line with the man-machine standard. With respect to appearance design in the field of industrial design, subjective and objective evaluation design methods are usually adopted. The application of Kano and AHP is the most common among subjective methods, while Jack is the most common among objective methods. Combining the three methods, on the one hand, the most commonly used methods in design are adopted, and the results are reasonable.

On the other hand, the combination of subjectivity and objectivity makes the result more convincing. In comparison, most other design methods have been eliminated and not used because of their greater subjective contingency. Therefore, the use of this combination method increases the efficiency of design from the side and shortens the design cycle.

CONCLUSIONS

For product modeling, especially for agricultural machinery design, in order to improve user satisfaction, it is more and more important to meet the functional and psychological needs of users. In this paper, Kano model is used to analyze user requirements and guide the design of tractor appearance. AHP is used to calculate the weight of each design element and select the best design scheme. Jack was used for simulation analysis of the best scheme to check whether it conforms to the man-machine physiological standard.

The results show that: Kano model and analytic hierarchy process can accurately express and screen out user needs, so as to guide the tractor appearance design and select the best scheme; For the inspection of the best scheme, Jack can provide better man-machine data support. By comparing the comfort scores of the two schemes, it is concluded that the scores of scheme 2 are generally 2-3 points lower those that of scheme 1, and the score of "shoulder" is 6.9 points lower. At the same time, the stress of the lumbar spine in the scheme is 450 N, which is far lower than the specified pressure limit of 3400 N. This shows that combining the three methods to design the appearance of the tractor is effective, and provides experience for the future product design.

Because of the difference in driving posture, the score of "left arm" in Plan 2 is 4 points higher than that in plan 1 in the comfort score, which is also a design accident and should be avoided as much as possible. Although the combination of various design methods has been adopted to meet the needs of users as far as possible, the demand analysis of this design is still incomplete due to the influence of other practical factors, such as the age of users and the color and material of the products, and other design-influencing factors have not been deeply considered, which is also an aspect that needs attention and the future design.

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