AEM JOURNAL .ORG

Research on the Influence of Different Sewing Process Parameters on the Comfort and Forming Quality of Garment Seams

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ABSTRACT The traditional sewing procedure uses empirical parameter configuration, resulting in problems such as uncertain parameter correlation relationship and inadequate precision in performance control, which makes it challenging to concurrently optimize seam comfort and seam forming quality. In light of this problem, this study proposes a seam performance control approach based on multi-process parameters. Through the construction of the multi-dimensional parameter system of critical parameters, including stitch length, thread tension, pressure of the presser foot, and sewing speed, along with the integration of standardization and weighting fusion mechanism, the evaluation model of seam comfort and seam forming quality is developed. Additionally, multi-parameter coupling analysis and multiobjective optimization methods are applied to realize cooperative optimization and dynamic matching of multidimensional parameter configurations. The experiment shows that compared with baseline process parameters, the optimized parameter configuration leads to a higher seam comfort score of 0.88 versus 0.62, an improvement of about 41.9%, and a higher seam forming quality score of 0.90 versus 0.65, an increase of approximately 38.5%. Moreover, under various fabric conditions, the wrinkle index is reduced from 0.42 to 0.25.

INDEX TERMS garment seam performance, sewing process parameters, multi-objective optimization, smart textiles, wearable structure design

I. INTRODUCTION

As apparel consumers' needs shift from basic wear to a quality-driven experience, the seam's comfortability and shaping ability, which are essential components in garment structures, have gradually become decisive factors in terms of both functionality and experience of garments. In order to improve both seam comfort and shaping quality at the same time, this study tries to achieve a synergistic optimization of them. First, a multidimensional sewing process parameters framework was developed and a series of decisive factors, such as stitch density, thread tension, pressure of presser foot, and sewing speed, were defined as a systematic structure. Then, an integrated evaluating system for measuring and quantifying seam performance was developed based on the framework above. Finally, through both single factor and multi-factor coupled analysis, this study discovered the mechanism of how different process parameters affect seam performance and built a multiobjective optimizing model.

II. RELATED WORK

On the issue of designing and manufacturing of clothes, with the rise of the concept of green manufacturing as well as personalized demands, the related research area had been transformed from optimizing a single process or designing procedure into multi-directional researches including environmental assessment, innovative structural design, and cultural inheritance. Recent research in garment manufacturing has increasingly focused on the quantitative analysis of process variables. El-Salam E A investigated the relationship between stitch density and seam strength in lightweight woven fabrics, noting that excessive density can lead to fabric damage [1]. Moorthi M explored the impact of thread tension on seam pucker, utilizing image processing to quantify surface deformation [2]. Furthermore, recent studies have applied response surface methodology to optimize sewing speed and presser foot pressure for high-stretch knitwear, emphasizing the trade-off between production efficiency and seam elasticity [3, 4]. Innovative approaches using machine learning have also been proposed to predict seam slippage based on material properties and machine settings [5]. However, current literature lacks a systematic framework for the simultaneous synergistic optimization of both comfort and forming quality. In conclusion, the current literature has achieved some progress in environmental evaluation approaches, structural innovation design and application of cultural elements, but lacks systematic quantitative research on the impact of sewing parameters on seam properties, particularly in terms of multiparameter coupling mechanism and performance synergy optimization. Thus, it is essential to develop a comprehensive analysis and optimization approach for seam comfort and formation quality based on current research achievements to enrich the theoretical framework and engineering application pathway of garment manufacturing.

III. RESEARCH CONTENT

A. SEWING PROCESS PARAMETER SYSTEM AND COMBINATION DESIGN

1) Screening and Classification of Key Process Parameters

To achieve the synergistic optimization of seam comfort and forming quality, a parameter system centered on multi-source process variables is constructed. Let the sewing process parameter vector be:

$$\mathbf{X} = [x_1, x_2, x_3, x_4, x_5] \tag{1}$$

Here, x_1 represents stitch length, x_2 sewing speed, x_3 presser foot pressure, x_4 thread tension, and x_5 thread type (represented by discrete variable encoding).

Based on the differences in the physical properties of the parameters and their action paths, they are divided into three categories:

(1) Structural parameters: represented by stitch pitch, which mainly affect the stitch density and the stress distribution of the fabric. The stitch density can be expressed as:

$$\rho_s = \frac{1}{x_1}$$

(2) Equipment parameters: including sewing speed and presser foot pressure, which reflect the equipment operating status and the degree of fabric compression, respectively. The stitch formation frequency per unit time can be expressed as:

$$f_s = \frac{x_2}{x_1}$$

(3) Material parameters: The stress transmission and deformation characteristics of the joint area are determined by the line tension and the type of suture. The line tension can be abstracted as:

$$T = f(\delta, E_t)$$

where δ is the elongation of the suture and E_t is the elastic modulus of the suture.

The above classification enables the systematic mapping of different parameters in the three-dimensional space of "structure-equipment-material", providing a foundation for subsequent multivariate coupling analysis.

2) Parameter Value Range and Combination Scheme Construction

Based on the established parameter system, reasonable value ranges are set for each variable to form a parameter space:

$$x_i \in [x_i^{\min}, x_i^{\max}], \quad i = 1, 2, \ldots, 5$$

Further construct a multi-factor combination matrix:

$$\mathbf{X}_{comb} = \begin{bmatrix} x_1^{(1)} & x_2^{(1)} & x_3^{(1)} & x_4^{(1)} & x_5^{(1)} \\ x_1^{(2)} & x_2^{(2)} & x_3^{(2)} & x_4^{(2)} & x_5^{(2)} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{(n)} & x_2^{(n)} & x_3^{(n)} & x_4^{(n)} & x_5^{(n)} \end{bmatrix} \tag{2}$$

Where n is equal to the number of combination designs. In order to make the distribution of the parameter combinations representative and consistent, we use orthogonal design or Latin Hypercube Sampling technique.

Based on this, a standardized parameter vector can be defined

$$x_i' = \frac{x_i - x_i^{\min}}{x_i^{\max} - x_i^{\min}}$$

to eliminate the influence of different dimensions on the analysis results and improve the stability and comparability of subsequent model calculations.

In conclusion, through the construction of a multi-dimensional parameter combination space, a systematic description and structuring of sewing parameters have been accomplished, forming an integral input system for seam assessment and optimization analysis.

3) Construction of a Comprehensive Evaluation Method for Joint Performance

In order to obtain a standardized evaluation of the performance of seams in terms of various sewing operation parameters, a measurement system will be developed by incorporating two aspects: comfort and forming quality. Comfort relates to user experience, whereas forming quality relates to structural integrity and aesthetic appeal.

4) Comfort Evaluation Index System and Quantification Method

The comfort evaluation indicators are defined as follows: $C = c_1, c_2, c_3, c_4$ corresponding to pressure sensation, friction sensation, softness, and breathability, respectively. The definitions, quantification methods, and attributes of each indicator are shown in Table 1.

To eliminate differences in the dimensions of different indicators, the indicators are standardized:

TABLE 1. Evaluation Index System for Seam Comfort

Index	Meaning	Quantification method	Indicator	Attributes
c_1	oppressive feeling	Seams affect local pressure sensation on the human body	Measured by flexible tactile pressure sensors (kPa)	negative
c_2	friction	Degree of friction between seam and skin	Determined by KES-FB4 Surface Tester (MIU/MMD)	negative
c_3	Softness	Smoothness and fit of seams	Calculated from Bending Stiffness (B) via KES-FB2	positive
c_4	breathability	Air exchange capacity in the seam area	Measured by Air Permeability Tester (mm/s)	positive

$$c_i' = \frac{c_i - \mu_i}{\sigma_i}$$

Construct a comprehensive comfort evaluation function:

$$S_c = \sum\nolimits_{i=1}^{4} w_i c_i'$$

where w_i is the weight coefficient, and satisfies $\sum w_i = 1$, which is used to reflect the importance of different comfort factors.

5) Forming Quality Evaluation Index System and Unified Characterization

The forming quality evaluation index is defined as follows: $Q = q_1, q_2, q_3, q_4$ representing the flatness of the joint, the degree of wrinkling, the uniformity of the stitches and the structural stability, respectively. The index system is shown in Table 2.

The index is dimensionless by using interval normalization:

$$q_i' = \frac{q_i - q_i^{\min}}{q_i^{\max} - q_i^{\min}}$$

Considering the differences in indicator direction, a sign correction coefficient is introduced:

$$\eta_i = \begin{cases} 1, & \text{positive indicator} \\ -1, & \text{negative indicator} \end{cases} \tag{3}$$

Construct a comprehensive evaluation function for forming quality

$$S_q = \sum\nolimits_{i=1}^{4} \omega_i \eta_i q_i'$$

that satisfies $(\sum \omega_i = 1)$ the following conditions (ω_i).

6) Analysis of the Mechanism of Action and Coupling Relationship of Process Parameters

In order to explore the inherent connection between sewing technology parameters and seam comfort and quality, an analysis framework should be established based on two aspects: single-factor influence mechanism and multi-factored couping effects. Seam property is generally expressed by a (X) function of parameters vectors.

$$S_c, S_q = f(\mathbf{X}) = f(x_1, x_2, x_3, x_4, x_5) \tag{4}$$

Wherein, S_c represents the comfort evaluation value, and S_q represents the forming quality evaluation value.

7) Analysis of the Mechanism of Action of a Single Factor

While keeping other variables constant, the marginal impact of key process parameters on joint performance is analyzed separately. The single-factor response can be expressed as follows:

$$\frac{\partial S_c}{\partial x_i}, \quad \frac{\partial S_q}{\partial x_i}, \quad i = 1, 2, 3, 4, 5 \tag{5}$$

in:
x_1 Stitch spacing
x_2 Sewing speed
x_3 Presser foot pressure
x_4 Line tension
x_5: Thread type

To characterize the sensitivity of performance to parameter changes, a standardized sensitivity coefficient is introduced:

$$K_i = \frac{\partial S}{\partial x_i} \cdot \frac{x_i}{S} \tag{6}$$

Where (S) represents either the comfort evaluation index S_c or the forming quality index S_q, utilized to measure the influence strength of different parameters.

8) Analysis of the Multi-Factor Coupling Influence Mechanism

In actual sewing, there is a significant coupling effect among various process parameters, and the seam performance can be extended into a nonlinear response model:

$$S = f(\mathbf{X}) = \beta_0 + \sum_{i=1}^{5} \beta_i x_i + \sum_{i=1}^{5} \sum_{j=i+1}^{5} \beta_{ij} x_i x_j + \varepsilon \tag{7}$$

Where β_i represents the single-factor influence coefficient; β_{ij} represents the second-order interaction coefficient; ε represents the random disturbance term.

To further characterize the nonlinear coupling strength, a coupling degree index is introduced:

$$C_{ij} = \frac{2 \cdot S_{ij}}{S_i + S_j} \tag{8}$$

TABLE 2. Evaluation Index System for Joint Formation Quality

index	meaning	Quantification method	Indicator	Attributes
q_1	flatness	Smoothness of seam surface	Image contour deviation analysis (mm)	positive
q_2	degree of wrinkling	Degree of wrinkles in the seam area	AATCC standard visual grading / Height variance (mm)	negative
q_3	Stitch uniformity	Consistency of suture spacing	Standard deviation of stitch length via digital microscopy	positive
q_4	Structural stability	Seam deformation resistance	Seam strength and elongation test (N/cm)	positive

Where S_{ij} represents the x_i performance response intensity under the combined effect of parameters (S_i) and, x_j and S_j represent the intensity of single-factor effects.

$C_{ij} > 1$ At a certain time, it indicates a positive synergistic enhancement effect; $C_{ij} < 1$ at another time, it manifests as an inhibitory or conflicting effect.

Furthermore, the multi-parameter coupling relationship can be represented in tensor form:

$$S = \mathcal{F}(x_1, x_2, x_3, x_4, x_5) \tag{9}$$

This is used to describe the comprehensive impact of high-order interactions on seam performance, thereby revealing the nonlinear action mechanism and structural coupling characteristics of sewing process parameters in multi-dimensional space.

9) Multi-Objective Optimization and Process Parameter Matching Method

To achieve synergistic optimization between seam comfort and forming quality, the problem of selecting sewing process parameters is transformed into a multi-objective optimization problem. $\mathbf{X} = x_1, x_2, x_3, x_4, x_5$ The optimal solution is sought within the parameter constraint space, using the process parameter vector as the decision variable.

(1) Construction of multi-objective optimization model

With $S_c(\mathbf{X})$ and $S_q(\mathbf{X})$ defined as the optimization objectives, the following multi-objective model is constructed:

$$\max F(\mathbf{X}) = [S_c(\mathbf{X}), S_q(\mathbf{X})]^T \tag{10}$$

Its constraints are defined as follows:

$$x_i^{\min} \le x_i \le x_i^{\max}, \quad i = 1, 2, 3, 4, 5$$

Since there is usually a conflict between comfort and forming quality, a weighted comprehensive transformation model is introduced to transform the multi-objective problem into a single-objective optimization form:

$$\max F(\mathbf{X}) = \alpha S_c(\mathbf{X}) + (1 - \alpha) S_q(\mathbf{X}) \tag{11}$$

in: $\alpha \in [0, 1]$ This is a weighting coefficient used to adjust the priority between comfort and forming quality; When α the size increases, the optimization results are more biased towards comfort; conversely, they are more biased towards forming quality.

Furthermore, to avoid the influence of dimensional differences, a normalized objective function is introduced:

$$S_c^* = \frac{S_c - S_c^{\min}}{S_c^{\max} - S_c^{\min}}, \quad S_q^* = \frac{S_q - S_q^{\min}}{S_q^{\max} - S_q^{\min}}$$

The optimization model can then be expressed as:

$$\max F(\mathbf{X}) = \alpha S_c^* + (1 - \alpha) S_q^*$$

(2) Parameter optimization solution and application matching strategy

In the optimization process, the objective function can be globally optimized based on intelligent optimization methods (such as genetic algorithms or particle swarm optimization). The iterative process can be represented as follows:

$$\mathbf{X}^{(t+1)} = \mathbf{X}^{(t)} + \Delta \mathbf{X} \tag{12}$$

which $\Delta \mathbf{X}$ gradually approximates the optimal parameter combination.

The optimal parameter solution is obtained by solving for:

$$\mathbf{X}^* = \arg\max F(\mathbf{X})$$

Based on this, construct process matching strategy functions for different clothing types:

$$\mathbf{X}^* = g(GarmentType, FabricProperty, UseScenario) \tag{13}$$

considers the specific functional requirements of different apparel categories. Specifically, for ergonomic leisure wear and medical compression garments, the weighting coefficient α is adjusted to prioritize both high-precision pressure management and structural resilience. In contrast, high-performance outerwear and professional sports gear require a balanced optimization of joint flexibility (comfort) and seam durability (stability) to accommodate intense mobility while maintaining garment integrity.

IV. EXPERIMENTAL DESIGN AND RESULTS ANALYSIS

A. OVERALL EXPERIMENTAL DESIGN SCHEME

In order to prove the effects of various combinations of parameters on the comfortability of sewing seams and their forming quality, a multiple-factor controlled experiment design was used.

Experimental research mainly involved the "parameters combination and performance reaction" model, and a controllable process test system was established.

Experiment can be generally classified into three levels:
1) Process parameters control level;
2) Joint performance reaction level;
3) Experiment data analysis comparison level.

Controlled groups experiment was conducted with the purpose to remove any effect brought by random error in experiment.

B. SAMPLE AND SPECIMEN DESIGN

In this experiment, we chose common fabric materials for sampling carriers, which include all kinds of fabric materials with different mechanical characteristics (e.g., low elasticity, medium elasticity, and high elasticity fabric materials) to ensure that our findings are representative.

Samples are cut out according to identical standards, ensuring consistency in terms of sewing length, thickness, and structural integrity, thereby minimizing the impact of factors other than processing on the results. All samples went through a sewing procedure under identical parameters to achieve comparability among results.

On the other hand, to increase the statistical stability, each set of parameter combinations includes multiple sample repetitions, and random errors are minimized through repeat observations.

C. EXPERIMENTAL GROUPING AND VARIABLE CONTROL STRATEGIES

In this test, multi-factorial groups were used as the experimental design approach with stitch length, thread tension, presser foot pressure, speed, and thread material as controlling factors to form varying working condition combinations.

Variable control should be based on the following rules:

If one factor is varied, other factors are kept constant.

Orthogonal or uniform design is employed when more than one factor is considered.

Each group was subjected to identical experimental environment.

This leads to the integration of “single factor influence recognition” and “multi-factor combination influence”.

D. DATA ACQUISITION METHODS AND PROCESSING FLOW

Joint performance data were collected from various sources, such as:

Morphology data (data collection from imaging and contours extraction)

Mechanical data (data collection of contact pressure and deformations)

Perceptual data (ratings of experts or participants)

To ensure compatibility with high-precision mechanical data, subjective ratings were processed using the Fuzzy Comprehensive Evaluation (FCE) method. Qualitative descriptors were mapped to a 0–1 numerical scale using triangular membership functions to minimize individual cognitive bias. Subsequently, Z-score normalization was applied to align these fuzzy numerical scores with quantitative metrics such as image contour deviation and pressure sensor data. This process ensures that all variables in the fused analysis data matrix maintain a consistent mathematical dimension and weight distribution.

Data processing consists of the following steps:
1) Cleaning of raw data (outliers’ deletion);
2) Alignment of multi-source data (time and location synchronization);
3) Standardization (removal of units’ effect);
4) Fusion to create an analysis data matrix.

The final product is a data matrix for analysis and comparison purposes.

E. COMPARATIVE EXPERIMENT AND ANALYSIS DESIGN

In order to test the validity of various process approaches, the following comparative analysis framework was established:

Reference process team (conventional empirical data)

One variable optimization team (single variable optimal approach)

Multiple variable collaboration optimization team (multiple variable optimal approach)

By comparing the above three teams’ experiments, the differences in the effectiveness of different optimization paths in improving joint efficiency have been analyzed.

The aspects of comparison include:

Difference in efficiency improvement

Stability variation range

Adaptability difference of different materials

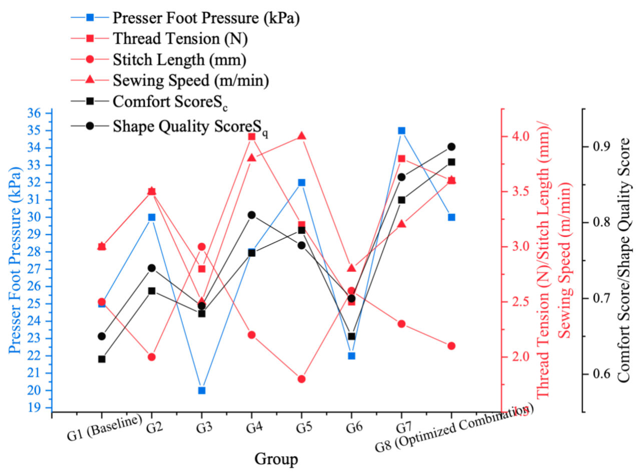

FIGURE 1. Seam performance response data under different combinations of sewing process parameters

As can be seen from Figure 1, different parameter combinations during the sewing process greatly influence not only seam comfort but also stitch quality. Both indices exhibit a parallel upward trend in terms of performance. Seam comfort increased by approximately 41.9%, and stitch quality increased by about 38.5% when the parameters were changed from the initial group G1 ($S_c = 0.62$, $S_q = 0.65$) to the optimized combination group G8 ($S_c = 0.88$, $S_q = 0.90$). It can be seen that the optimization of multiple parameters plays a prominent role in enhancing seam performance. Moreover, the synergistic relationship between presser foot pressure and sewing speed cannot be ignored. When the former ranges from 28 to 35 kPa and the latter is kept at 3.2–3.8 m/min (G4, G7, G8), the stability of the fabric pressing and sewing process is ensured, and wrinkling is minimized, thereby achieving a great improvement in stitch quality; while insufficient values of either index may result in poor performance (such as G3). To clarify the optimization results, the specific parameter configurations for the representative experimental groups are detailed in Table 3:

TABLE 3. Process Parameter Configurations for Experimental Groups

Group ID	Stitch Length (mm)	Sewing Speed (m/min)	Presser Foot Pressure (kPa)	Thread Tension (cN)
G1 (Baseline)	2	4.5	45	120
G4 (Intermediate)	2.5	3.5	32	100
G8 (Optimized)	3	3.5	30	90

TABLE 4. Comparison of the adaptability of optimized process parameters under different fabric types

Fabric type	Parameter combination source	Comfort rating (S_c)	Molding quality score (S_q)	Wrinkle Index	Joint stability	Overall performance
Low-elasticity cotton fabric	Reference parameters	0.69	0.72	0.31	middle	generally
Low-elasticity cotton fabric	Optimize parameters	0.86	0.88	0.18	high	excellent
Medium-stretched blended fabric	Reference parameters	0.66	0.7	0.36	middle	generally
Medium-stretched blended fabric	Optimize parameters	0.85	0.87	0.2	high	excellent
High-elastic knitwear	Reference parameters	0.61	0.64	0.42	Low	Poor
High-elastic knitwear	Optimize parameters	0.82	0.85	0.25	Medium and high	good

It is evident from the results provided in Table 4 that the optimized process parameters revealed remarkable improvements in adaptability to various types of fabric materials. In comparison with the initial values of process parameters, the seam comfort and seam quality of all the three types of fabric material demonstrated significant improvements. For example, for low elasticity cotton fabric material, the seam comfort increased from 0.69 to 0.86 and seam quality – from 0.72 to 0.88; for medium elasticity blended fabrics, these indicators increased from 0.66/0.70 to 0.85/0.87 correspondingly; while for high elasticity knitted fabrics, these values increased from 0.61/0.64 to 0.82/0.85 correspondingly. Thus, it can be concluded that the optimization of the combinations of process parameters resulted in positive impact on fabric materials of different mechanical characteristics. Speaking about structural morphology indicators, significant decrease in wrinkle index was observed for all three types of fabric materials: low elasticity cotton fabric – from 0.31 to 0.18; medium elasticity blended – from 0.36 to 0.20; and high elasticity knitted fabric – from 0.42 to 0.25. This fact means that the optimization of process parameters helped to reduce the problems related to localized deformation and wrinkle formation at seam location. In terms of seam stability, both low-elasticity and medium-elasticity fabrics were upgraded from "medium" to "high," with significantly enhanced structural stability; although high-elasticity knitted fabrics were upgraded from "low" to "medium-high," they were still slightly lower than other fabrics, reflecting that high-elasticity materials are more prone to deformation during sewing and require higher matching of process parameters.

V. CONCLUSION

In this paper, the study of the synergistic optimization of the comfort and forming quality of garment seam was conducted. The multi-dimensional sewing process parameter system was built. Multi-index evaluation method about the comprehensive assessment of seam forming performance was designed. With the help of single factor and coupled factor analysis, the impact mechanism of the sewing process parameters on the seam forming performance was analyzed. Then, a multi-objective optimization model was proposed to realize the synergistic optimization and dynamic matching of process parameter combination. Results indicate that the optimal sewing process parameters have a positive effect on the seam comfort and forming performance. In addition, the model demonstrates consistent stability and performance gains across the tested elastic fabric variants, suggesting high potential for adaptability within specialized precision garment manufacturing sectors. While further verification on non-elastic and composite materials is required to establish industrywide universality, the current results confirm the effectiveness of the proposed multi-objective matching framework. As for the limitation of the study, the proposed method is based on certain kinds of fabrics and sewing process parameters. However, some complex garment sewing processing scenarios were not covered. This means that the proposed model may not possess universality. Therefore, future study could integrate intelligent sensing technique and data-driven algorithm to conduct multi-source data acquisition and realtime dynamic optimization and matching of process parameters.

AUTHOR CONTRIBUTIONS

Chunjiao Zhang designed, collected and analyzed the data, and drafted the manuscript. Chunjiao Zhang conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Chunjiao Zhang participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

FUNDING

This research received no external funding.

ACKNOWLEDGEMENTS

Not applicable.

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