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Optimize the Process Parameters of The Paper Feeding Mechanism Based on The Response Surface Method

Xiaobin Yan[1, 2], Jianxin Wu[1, 2], Guohuan Wu[3, *], Xiaojie Xiang[3], Xiaolong Gao[1, 2]

[1]ZHEJIANG ZENBO INTELLIGENT MACHINERY CO..LTD., Wenzhou, China
[2]Zhejiang Zhengbo Intelligent Paper Bag Machine Equipment Provincial Enterprise Research Institute, Wenzhou, China
[3]Wenzhou Polytechnic, 325035, Wenzhou, China
[*] Corresponding author

Abstract: In order to solve the problem of lateral deviation during the short-distance conveying process of paper, this paper adopts the response surface method (RSM) to establish a regression model of the paper deviation amount with respect to the feed speed, pressing force and friction coefficient. The accuracy of the model is evaluated through variance analysis, fitting accuracy analysis, residual analysis and the comparison between predicted values and experimental values. The influence of various factors on the paper deviation amount is analyzed by means of three-dimensional response surfaces and contour plots. In addition, the optimal process parameters are obtained by utilizing the Numerical function in the Design-Expert software, and the reliability of the model is verified through experiments. The research results show that the optimized process parameters are as follows: the feed speed is 42.14 bag/min, the pressing force is 0.29 kg, and the friction coefficient is 0.29. The errors between the predicted values and the measured values are all within 5%, which proves the high accuracy and reliability of the regression model. This study provides a reliable theoretical basis for the optimization of the paper feeding mechanism process in the production process of environmentally friendly paper bags and has important practical application value.

Keywords: Paper conveyance; paper misalignment; response surface methodology; experiment.

1. Introduction

Paper feeding is the first process in the production of environmentally friendly paper bags and an indispensable part of bag-making production. However, the problem of lateral paper offset often occurs during the production of environmentally friendly paper bags. Besides being caused by the feeder that separates the papers, the mutual cooperation, handover of various transmission control components during the paper transmission process, and the quality of the components are all important factors affecting the accurate paper feeding. Taking the paper feeding section of the ZB1260SF-450 single-sheet fully automatic handbag-making machine as an example, this paper uses the Response Surface Methodology (RSM) to analyze the influences of the conveyor belt feeding speed, the compressing force between the conveyor belt and the paper, and the coefficient of friction on the paper offset during the paper transmission process.

2. Materials and Methods

2.1. Experimental Raw Materials, Reagents and Instruments

2.1.1. Experimental Raw Materials and Reagents

The prepared environmentally friendly paper bags have a size of 190 × 80 (bellows) × 225 (bag height). The papers used are Kraft paper, white cardboard and coated paper with a basis weight of 130g, which are sourced from Zhejiang ZENBO Intelligent Machinery Co., Ltd.

2.1.2. Experimental Instruments

The main experimental instruments selected include the paper conveying unit of the ZB1260SF-450 single-sheet fully automatic handbag making machine, a tensile force measuring instrument, a coefficient of friction measuring instrument, etc., all from Zhejiang Zhengboy Intelligent Machinery Co., Ltd.

2.2. Experimental Methods

The paper conveying unit of the ZB1260SF-450 single-sheet fully automatic handbag making machine was placed in a sealed laboratory. Kraft paper was put into it to conduct the experiment on the measurement of paper conveying deviation. The paper feeding speed was controlled within the range of 40 - 70 bags per minute, the compaction force was controlled within the range of 0.1 - 0.3 kg, and the paper friction coefficient was controlled within the range of 0.291 - 0.321.

Figure 1. Paper Conveying Unit of the Single-sheet Fully Automatic

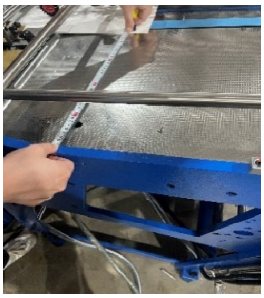


Figure 2. Measurement of Deviation Handbag Making Machine

3. Experiment Results and Analysis

3.1. Experiment Design and Results

According to the principle of the response surface Box - Behnken experimental design, with the feed speed, compression force, and paper friction coefficient as independent variables and the paper offset as the response value, a 3 - factor - 3 - level response surface experiment was carried out to optimize the variables related to the paper offset. The experimental parameter design and its level coding are shown in Tab.1, and the experimental design and experimental results are shown in Tab.2.

Table 1. Factor design and horizontal coding

level	A Feed speed	B Compression force	C Coefficient of friction
-1	40	0.1	0.291
1	70	0.3	0.321
0	55	0.2	0.306

Table 2. Test design and test results

Serial number	Feed speed (bag/min)	Compression force(kg)	Coefficient of friction	Deviation (mm)
1	55	0.3	0.321	1.1
2	55	0.1	0.321	3.2
3	40	0.2	0.321	1.4
4	70	0.2	0.291	2.1
5	55	0.1	0.291	2.2
6	40	0.3	0.306	0.3
7	70	0.1	0.306	4
8	55	0.2	0.306	1.4
9	70	0.2	0.321	3.5
10	55	0.2	0.306	1.3
11	40	0.1	0.306	2.4
12	55	0.2	0.306	1.2
13	55	0.2	0.306	1.4
14	70	0.3	0.306	1.3
15	55	0.2	0.306	1.1
16	55	0.3	0.291	0.8
17	40	0.2	0.291	0.5

3.2. Experimental Model and Analysis of Variance

It can be seen from the measurement results that the paper conveying offset shows an obvious decreasing trend with the increase of the compressing force, and continuously and slowly increases with the increase of the feeding speed. In order to further analyze the influence of the three factors on the paper offset in the experiment, the test results were input into the Design-Expert software for response analysis, and a quadratic polynomial regression equation of the process parameters (feeding speed, compressing force, friction coefficient) on the paper offset was obtained:

In the equation, A represents the feed speed, B represents the compressing force, and C represents the coefficient of friction.

Table 3. Analysis of variance of regression model

Source	degree of freedom	Adj SS	Adj MS	F value	P value
Model	6	15.4675	2.57792	13.04	0.00032
Linear	3	15.1925	5.06417	25.61	0.00005
A	1	4.9612	4.96125	25.09	0.00053
B	1	8.6113	8.61125	43.55	0.00006
C	1	1.6200	1.62000	8.19	0.01689
Interaction between two factors	3	0.2750	0.09167	0.46	0.71398
AB	1	0.0900	0.09000	0.46	0.51518
AC	1	0.0625	0.06250	0.32	0.58634
BC	1	0.1225	0.12250	0.62	0.44946
Error	10	1.9772	0.19772		
lack of fit	6	1.9092	0.31820	18.72	0.0678
pure error	4	0.0680	0.01700		
Total	16	17.4447			

In order to confirm the reliability of the quadratic polynomial fitting model and the influence of each factor on the offset, an analysis of variance was conducted on the model. The test results are shown in Table 3. Among them, the P value of the model is less than 0.001 and the P value of the lack-of-fit term is greater than 0.05, indicating that the model is reliable. In the response surface, the F value is used for statistical significance testing, and the P value is used to test the significance of each regression coefficient. When $P < 0.05$, it means that the established regression model has a significant correlation; when $P > 0.05$, it is not significant. The P values of A, B, and C are all less than 0.05, indicating that the primary effects of these three factors have a significant impact on the offset. Combining the F value and the P value, the degree of influence on the offset from large to small is B > A > C. Among the interactions of these process parameters, the P values of the AB, AC, and BC interactions are all greater than 0.05, indicating that the interactions between the factors have a weak influence on the offset.

Table 4. Analysis of fitting accuracy of regression model

Standard deviation	Average	C.V./%	R2	Adjusted R2	predicted R2	Adequate precision
0.25	12.45	13.51	0.9601	0.9361	0.8158	22.430

Tab.4 shows the fitting parameters of the regression equation for the paper feeding offset. The R value of the regression model is 0.9601, indicating that this model can explain 96.01% of the variation in the response values with a relatively small error and good fitting performance. This proves that it is feasible to optimize the paper feeding offset using the response surface method. The closer the values of Adj R^2 and Pred R^2 are, the closer the experimental values are to the predicted values. In this experiment, the difference between the two is 0.111, which is less than 0.2, proving that the values predicted by the model are in good agreement with those obtained from the experiment. The coefficient of variation (C.V.) represents the ratio of the standard value to the average value and is mainly used to measure the precision of the data. Adequate precision is used to evaluate the effectiveness of the model. In this experiment, 13.51% is less than 15% and Adeq precision = 22.43 which is greater than 4, indicating that the model has a high level of precision and reliability.

3.3. Residual Analysis

The prediction and residuals of the response model for the paper feeding offset are shown in Fig.3. By comparing the actual measured values of the paper feeding offset with the predicted values of the model, it can be seen that due to systematic errors, there are a few data points that are relatively far from the center point. However, the overall data are distributed relatively compactly on both sides of the fitting function and show a linear pattern, indicating that the overall fitting effect of the model is good and can support subsequent analyses. In the plot of the fitted values and residuals of the paper feeding offset, each residual value is randomly distributed without a regular pattern. Combining the sequential observed values of the offset with the residual plot, the residual values of the offset model equation randomly fluctuate up and down near the center line, indicating that there is no correlation between the residuals, which further indicates the effectiveness of the experiment. The percentage of the normal residual plot is close to 95%, indicating that the normality of the residuals of the offset response model is good and they are normally distributed. In conclusion, it shows that the errors of this model mainly come from systematic errors and are within a controllable range. Through the above analysis, it can be considered that this model effectively expresses and predicts the influence of factors such as the feed speed, the compressing force, and the coefficient of friction on the paper feeding offset, and can complete the optimization of a lower paper feeding offset with a fewer number of experiments.

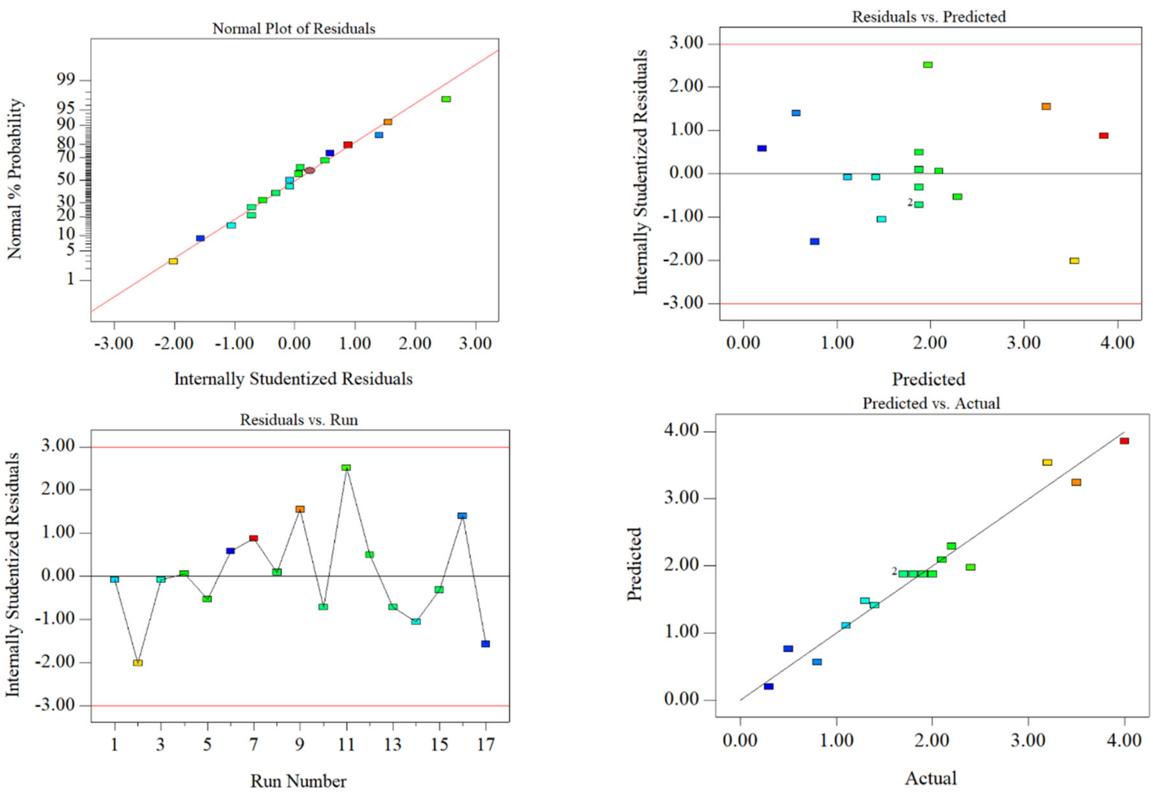
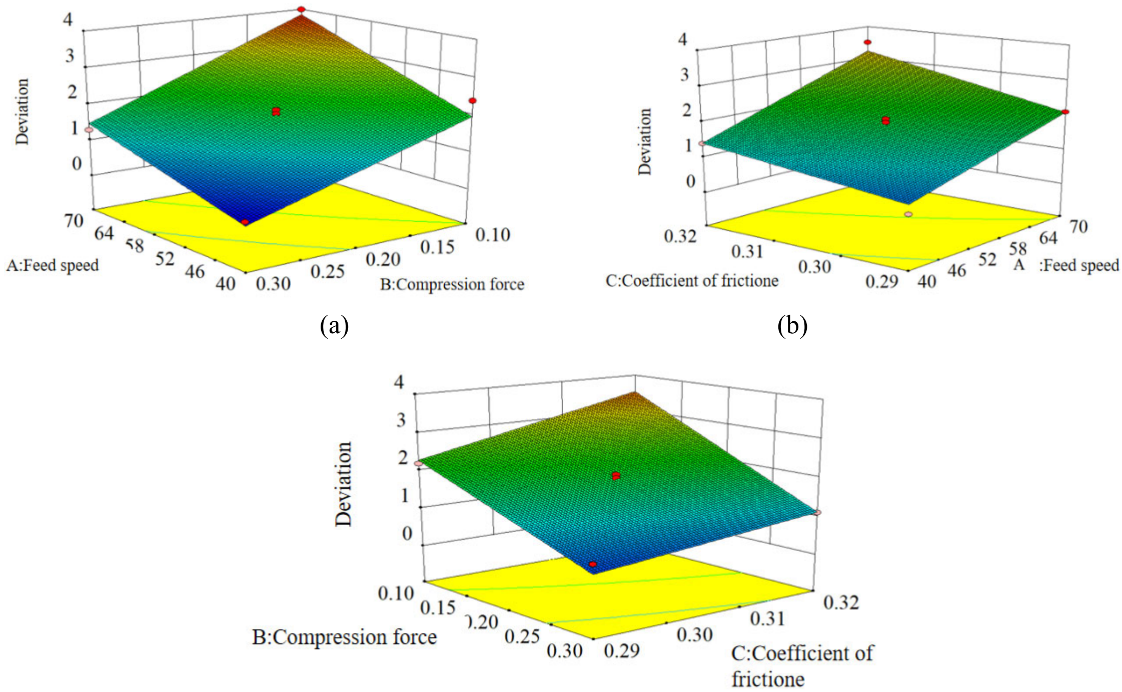


Figure 3. Residual Analysis Chart of Regression Model

3.4. Response Surface Analysis

Fig. 4 shows the response surface plots of the interaction effects of various factors on the paper feeding offset. As can be seen from Fig. 4(a), under different feed speeds, as the compressing force increases, the offset gradually increases, while the offset is less affected by the change in feed speed and basically remains unchanged. Therefore, the influence of the feed speed on the offset is the non-sensitive direction of this interaction, and the compressing force is the key control parameter under this interaction. Fig. 4(b) is the change graph of the interaction surface between the feed speed and the coefficient of friction. It can be seen from the figure that the surface is gentle and the interaction is very weak. Fig. 4(c) shows the interaction surface plot of the compressing force and the coefficient of friction. The influence of their interaction on the offset is similar to that in Fig.4(a), and the response surface presents as an inclined slope.



(a) (b)

(c)

Figure 4. Response surface of the influence of each factor on the index

3.5. Optimization and Experimental Verification

The regression model established was optimized and solved using Design-Experts 8.0.6.1 software to obtain the optimal combination of process parameters when the paper offset is minimized. In order to verify the correctness of the predicted model, a paper feeding experiment was carried out using the above optimal combination of process parameters. The comparison between the response surface optimization results and the experimental results is shown in Tab.5. It can be seen from the table that the errors between the predicted values and the actual values of temperature, glue coating thickness, humidity, paper laminating time, and paper peeling strength are all within 5%, indicating that the predicted model has high precision. Therefore, the established model can be used in the optimization experiment of paper peeling strength and has practical application value.

Table 5. Response surface prediction model verification test results

	Feed speed (bag/min)	Compression force(kg)	Coefficient of friction	Deviation (mm)
Predicted value	42.14	0.29	0.29	0.228
Test value	42	0.29	0.3	0.231
Error/%	0.33	0	3.33	1.32

4. Conclusion

(1) Based on the Box-Behnken experimental design method in Response Surface Methodology (RSM), a regression model of conveying speed, compressing force, coefficient of friction, and paper offset was constructed. The multiple correlation coefficient of the model is 0.9601, and the difference between the adjusted correlation coefficient R^2 and the predicted correlation coefficient R^2 is 0.111, indicating that the constructed model has high prediction accuracy and good fitting performance.

(2) By utilizing the Numerical optimization function of Design-Expert, with the conveying speed, compressing force, and coefficient of friction as multi-objective optimizations, the optimal proportion was obtained: the feeding speed is 42.14 bag/min, the compressing force is 0.29 kg, and the coefficient of friction is 0.29. Through experiments, it was found that the errors of various performances are all within 5%, which proves the reliability and accuracy of the model prediction. This research provides a theoretical basis for

optimizing the paper feeding process of environmentally friendly paper bags

Acknowledgments

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