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Statistical Analysis and Computer Simulation of Random Occurrence of Stripes in the Seriplane Panel of Raw Silk

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Seriplane tests have played an important role in classifying the quality of raw silk since the early days of raw silk testing. However, the introduction of machine-based quality inspection has been strongly desired by users of raw silk who are not satisfied with the seriplane tests which depend on judges' personal feelings. In this paper, two probability models were applied to seriplane evenness tests to consider the statistical property of the tests. Under the first model, the probability of test panels judged as Evenness Variation II or III was evaluated. The results revealed the fundamental relationship between the seriplane evenness tests and the size deviation of raw silk. In the second model, the probability of stripes appearing in a seriplane panel was assessed. Computer simulation was carried out to verify the theoretical results.

Keywords: Seriplane test, Evenness test, Raw silk, Statistical model, Computer simulation.

INTRODUCTION

The seriplane test was first introduced by F. Schmutz in 1921, who was a silk quality inspector in the US. In the test, the unevenness variations of raw silk, which might cause the occurrence of stripes on silk fabric, are evaluated on the basis of standard photographic panels by skillful examiners.

There are so many drawbacks of this test method, including difficulty in maintaining the objectivity of inspections. The method also requires training of inspectors, skillfulness of judge, and needs many persons for the testing. Moreover, nowadays users of raw silk are not satisfied with results of the eye-check

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inspection.

Many research have been carried out on machine-based quality inspection (MBQI) methods of raw silk since the early 1960s to find out more appropriate and reliable tests than long-standing seriplane tests. Maekawa, H., (1981) introduced Uster Tester to investigate the quality of raw silk. Ishiguro, *et al.*, (1993) devised an electronic tester for evenness variation or neatness and cleanness defects of raw silk. Kawana, S., (1995) also constructed an electronic inspection system of the quality of raw silk. Recently, an electronic cohesion tester for raw silk threads was developed by Chen *et al.* (2004).

However, the MBQI system has not been established yet despite the expenditure of many people's efforts. The introduction of the MBQI has also been an important item on the agenda of the International Silk Association (ISA) conferences in recent years (Yoshikuni, 2003).

Before adopting the MBQI tests, we need to solve some problems including the creation of more satisfactory inspection methods for the MBQI, and such methods will have to consider the kinds of properties required for different types of target silk products.

The aim of this research is to construct statistical models to explain the occurrence of stripes due to the evenness variation of individual threadlines in a seriplane panel. Simulation was carried out to confirm the results obtained from the statistical models. We further presented the visual displays of simulated panels and compared them with standard photographic seriplane panels.

MATERIALS AND METHODS

Method for seriplane evenness tests

The seriplane evenness test is carried out in the following way. From 20 bobbins, silk yarn is wound round a panel with a length of 457mm and a width of 127mm. The number of threadlines in the seriplane panel is 80 per 25.4mm for raw silk with sizes between 17 and 26 denier, while it is 66 per 25.4mm for sizes between 27 and 36 denier. Three panels are prepared from each bobbin. A judge inspects those panels in a specially illuminated room and then classifies them on the basis of three fixed panels, V_0, V_1 and V_2, of the Standard Variation Photographs. When the intensity of variation of the test panel is greater than V_0 but does not exceed V_1, it is designated as Evenness Variation I. Evenness Variations II and III are similarly defined. When the intensity of variation is greater than V_1 but less than or equal to V_2, the panel is Evenness Variation II and when it is greater than V_2, it is an Evenness Variation III panel. The test result is expressed by the frequencies of the classified panels.

Statistical Model

Model 1

Hawkes (1980) has proposed a

stochastic model on the random occurrence of stripes in a fabric under several simple assumptions, calculating the probability of a defective fabric for various numbers of threadlines. Using his model, we considered the occurrence of stripes in a seriplane panel.

According to seriplane test directions, there exist 400 threadlines in a testing panel for 21d raw silk and 330 for 27d raw silk. Let $Z_i, i = 1, \cdots, n$ be a series of the size of 457mm raw silk in a panel. Then, we consider the difference between neighboring weighted means defined by

$$Y_s = \sum_{r=0}^{\infty} \phi_r Z_{s-r} - \sum_{r=0}^{\infty} \phi_r Z_{s+r+1},$$

$$\sum_{r=0}^{\infty} \phi_r = 1, \phi_r \geq 0. \quad (1)$$

For convenience, the equation is rewritten in the form of a stochastic process

$$Y_s = \sum_{r=-\infty}^{\infty} \theta_r Z_{s-r}, \quad \begin{matrix} \theta_r = \phi_r, r \geq 0 \\ -\phi_{-r-1}, r < 0 \end{matrix}$$

When we think of the fluctuation of Y_s, stripes in the seriplane panel can be defined in the following way. The panel has a stripe corresponding to Evenness Variation I if Y_s stay somewhere in the range of $d_0 < |Y_s| \leq d_1$, Evenness Variation II if $d_1 < |Y_s| \leq d_2$ or Evenness Variation III if $|Y_s| > d_2$, and then the resulting Evenness Variation of the panel is defined as the maximum Evenness Variation of the stripes.

Variance of Y_s is given by

$$Var[Y_s] = \sum_{r=-\infty}^{\infty} \theta_r^2 V[Z_{s-r}] + \sum_i \sum_{j(i \neq j)} \theta_i \theta_j Cov(Z_{s-i}, Z_{s-j})$$

$$= \sigma^2 \left\{ \sum_{r=-\infty}^{\infty} \theta_r^2 + 2 \sum_i \sum_{j(i<j)} \theta_i \theta_j \rho(j-i) \right\}$$

$$= \sigma_y^2 \quad (2)$$

Using Berman's theorem (1964, 1971), the number of stripes in a seriplane panel, t, follows a Poisson distribution with mean μ_n,

$$f(t) = \frac{\left(\frac{1}{\mu_n}\right)^t}{t!} e^{-\frac{1}{\mu_n}},$$

where $\mu_n(d) = 2\exp\left\{ -\left(\frac{d}{\sigma_y} - b_n \right) / a_n \right\},$

$$a_n = (2\log n)^{-\frac{1}{2}},$$

$$b_n = (2\log n)^{\frac{1}{2}} - \frac{1}{2}(2\log n)^{-\frac{1}{2}} \times (\log\log n + \log 4\pi)$$

d is a criterion for the occurrence of a stripe. If $d = d_2$, the probability of Evenness Variation III is $1 - \exp(-\mu_n(d_2))$.

Model 2

Minamisawa (1985) has pointed out that a stripe appears in a seriplane panel when more than or equal to 13 consecutive threadlines are smaller in thickness than neighboring threadlines. This means the number of threadlines for the weighted average in Equation (1) should be more than 13.

In model 2, we consider a series of

threads with a length of $13 \times 457 \times 2$ mm (11882mm), $s_1, s_2, \cdots, s_{31}$ based on the Minamisawa's result. We also suppose that the threads of $s_i, i = 1, \cdots, 31$ are random sample from a mixture probability distribution of $f(s)$ defined by

$$f(s) = p_1 f_1(s) + p_2 f(s) + p_3 f(s),$$

where $f_i(s)$ have normal distributions with means μ_i and variances σ_i^2. The three distributions show the size variations of thin, regular and thick threads.

Let the numbers of threadlines with three different thickness in a seriplane panel be n_1, n_2 and n_3, then the numbers follow a multinomial distribution of $p(n_1, n_2, n_3)$ expressed by

$$p(n_1, n_2, n_3) = \frac{N!}{n_1! n_2! n_3!} p_1^{n_1} p_2^{n_2} p_3^{n_3}.$$

The probability that stripes appear in a seriplane panel is given by the following equation,

$$1 - p(0,31,0) = 1 - p_2^{31} \qquad (3)$$

RESULTS AND DISCUSSION

Computer Simulation

The theoretical results of model 1 and model 2 were verified by computer simulation. We generated standard random normal deviates with unit variance from uniform random deviates over (0,1) by Box-Mullar method (Box and Muller, 1958). Each deviate was taken simultaneously to represent a threadline in a seriplane panel. Then, we regenerated 400 threadlines for each panel from standard normal deviates for 21 denier at different standard deviations.

We considered two kinds of stripe, one for thin places and another for thick places of yarn, in a seriplane panel. Let, d_{simu} be the size value of randomly generated threadlines and d_{ori} be the mean size value of raw silk. Two stripe criteria were used to determine stripes in a seriplane panel.

$$d_{simu} >= d_{ori} + t; \quad \text{for thick stripe; (4)}$$

and

$$d_{simu} <= d_{ori} - t; \quad \text{for thin stripe; (5)}$$

where, t is some specified tolerance level.

According to the above conditions, 10,000 panels were constructed and searched stripes in every panel. If d_{simu} exceeded the tolerance limit for thick and thin stripes, a stripe was deemed to be present in that panel. If any of the panels had not been found to contain a stripe, the count of panels was increased by one.

Shimizu and Komatsu (1967) investigated differences in the thickness of silk yarn between neighboring parts when stripes appeared in seriplane panels, showing the values of d_0, d_1 and d_2 are about 2.57denier, 4.78denier and 8.48denier respectively. The variance σ_y^2 of Y_s can be estimated from a series of the size of raw silk using equation (2).

We evaluated the probability of a panel being judged as Evenness Variation II or

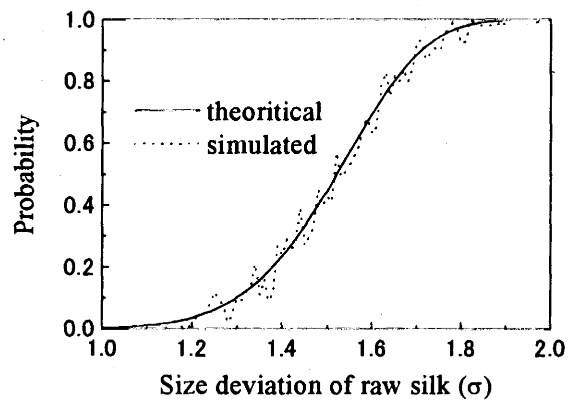


Fig. 1. A comparison between the simulation results and the theoretical probability (the solid line) of a seriplane panel with stripes being judged as evenness variation II or III on the basis of model -1.

III on the basis of Shimizu and Komatsu's result, revealing the relationship between

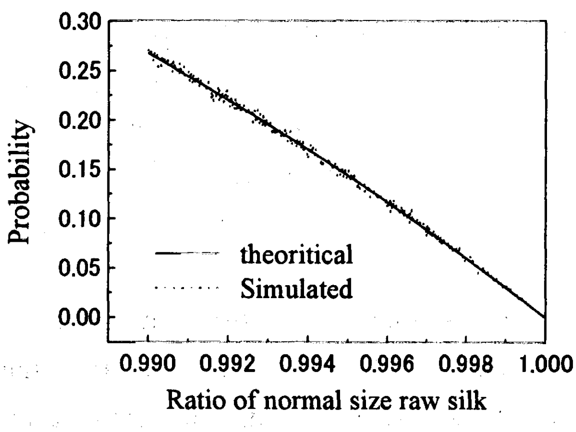


Fig. 2. A comparison between the simulation results and the theoretical probability (the solid line) that stripes appeared in a seriplane panel on the basis of model -2.

the probability and the size deviation of raw silk. The theoretical results were obtained by equation, $1-\exp(-\mu_{400}(4.78))$. The simulation results were obtained by the two stripe criteria, (4) and (5), where the tolerance limit was 4.78 for Evenness Variation II.

Fig. 1 shows a comparison between the simulated results and the theoretical probability (the solid line) of a panel with stripes. The graph revealed the fundamental relationship between the seriplane evenness tests and the size deviation of raw silk. It seemed that the probability of a panel being judged as Evenness Variation II or III was varied between size deviation (σ) 1.0 to 2.0. The simulated results were coincided with the results of theoretical probability model.

The probability of a panel with stripes was also evaluated by equation (3) based on model 2. A simulation was carried out to testify the model 2 results. Fig. 2 shows a comparison between the theoretical probability (solid line) of a panel exhibits stripes and the simulation results. The graph revealed a relationship between the probability of a panel with stripes and the ratio of normal size raw silk.

Visual Display

The graphical representations of standard photographic panels might play an important role to adopt an MBQI inspection system. We tried to represent the visual display of simulated photographic panels.

For visual display, at first 403 normal random deviates with standard deviation

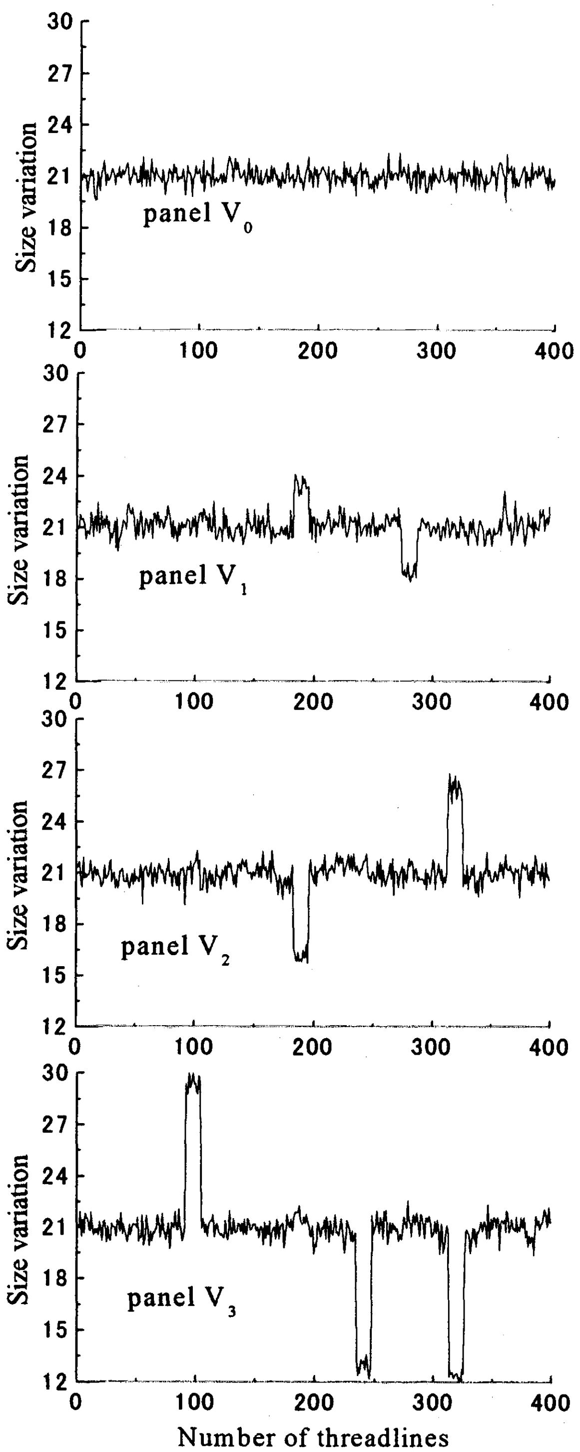


Fig. 3. Size variation curves of four seriplane panels, which were obtained by simulation methods for visual displays. panel V_0: no stripe; panel V_1: stripes value 2.57 denier; panel V_2: stripes value 4.78 denier; panel V_3: stripes value 8.48 denier;

1.8 were generated for 21-denier raw silk. Then, the mean size of successive 13 threadlines was calculated. Let d_{mean13} be the mean size of 13 successive threadlines and d_{ori} be the actual size of raw silk. Stripes criteria for displays were as follows.

$d_{mean13} >= (d_{ori} + 1)$ for thick stripe; (6)

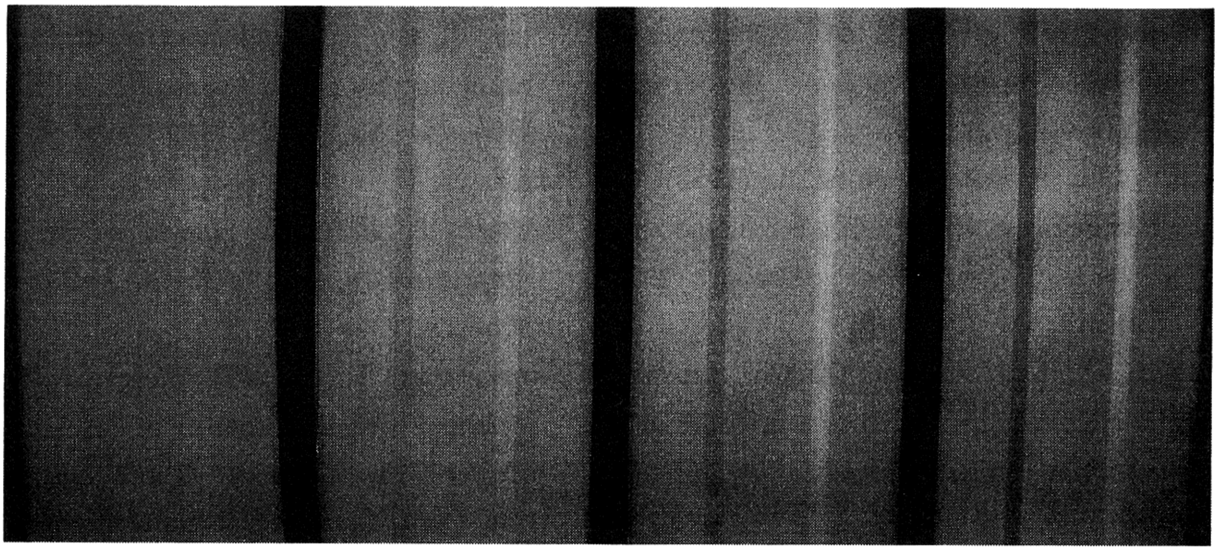
and

$d_{mean13} <= (d_{ori} - 1)$ for thin stripe; (7)

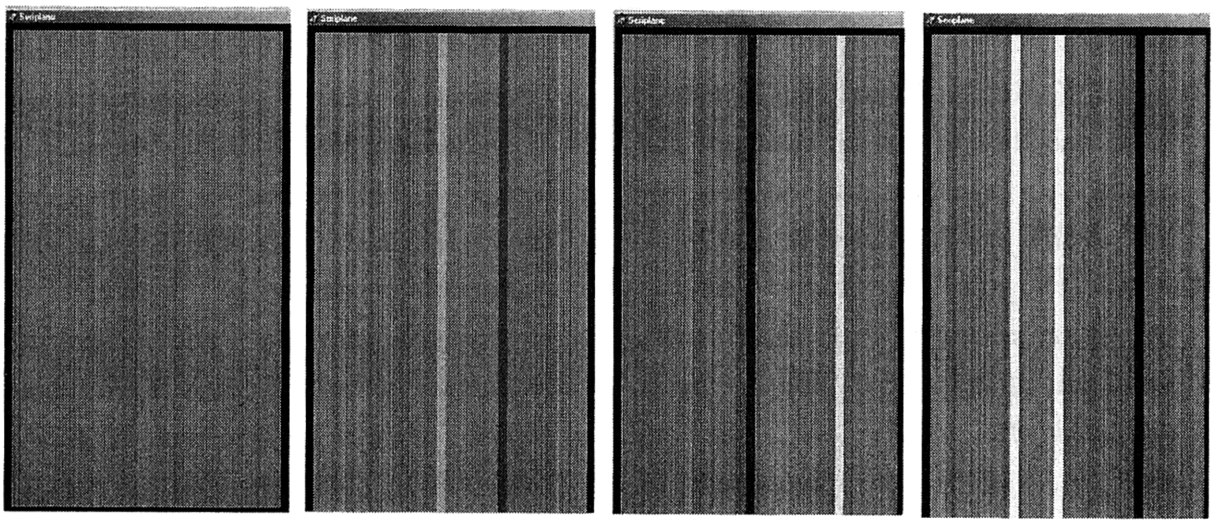
We used the same values as Shimizu and Komatsu's result for d_0, d_1 and d_2 of panels V_1, V_2 and V_3. Finally, from these 31 resultant size values, we randomly regenerated 403 threadlines with standard deviation 0.5 for a panel. Fig.3 shows the size variation curves of four panels. The graphs revealed that panel V_0 has no stripes, panel V_1 exhibited one thick and one thin stripe with the size value of 2.57 denier and panel V_2 exhibited one thin and one thick stripe with the size value of 4.78 denier. Panel V_3 exhibited one thick and two thin stripes with the size value of 8.48 denier. Visual displays for the four panels were constructed by using computer graphics.

Fig. 4 shows the visual displays of standard photographic panels and the results obtained by computer simulation. Each of the standard panel shows two fixed stripes, one for thick yarn and another for thin yarn. In our simulation, we considered random occurrence of stripes. Hence, the position and the number of stripes vary in each panel. The graphs revealed a clear difference in the intensity of stripes between panels.

(a) Actual standard seriplane panels.



Panel V_0 Panel V_1 Panel V_2 Panel V_3



(b) Simulated seriplane panels.

Fig. 4. A comparison between the real seriplane standard photographs and visual displays of four seriplane panels that were obtained by computer simulation. (a) Actual standard seriplane panels. (b) Simulated seriplane panels.

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生糸の品質検査において、セリプレーンによる糸むら検査は、長い間重要な役割を演じている。しかし、視覚検査であるため、判定が具体的数値ではなく検査員の個人的判断に依存するため、その信頼性について問題点が指摘されてきた。本論文では、セリプレーン上に出現する糸むらに対して，二つの統計的モデルを考え，これらのモデルに基づいてセリプレーンパネル上に糸むらが生じる確率について考察を加えた。この結果、セリプレーンによる糸むら検査と生糸の繊度偏差との関連，および，セリプレーンパネル上に糸むらが出現する確率について理論的解釈を与えることができた。また，理論的解析結果を具体的に示すためセリプレーンパネルをコンピュータ画面上に実際に近い形で表示する方法について考察し，その表示を試みた。