Photoelectric Measurement of the Fineness of Raw Silk

Wan-chun FEI(费万春)[1,2]
(1. *College of Textile and Clothing Engineering*, *Soochow University*, *Suzhou* 215021, *China*;
2. *National Engineering Laboratory for Modern Silk*, *Suzhou* 215123, *China*)

Abstract – In order to precisely measure the diameters for obtaining the fineness of rolling raw silk, the physical features of raw silk are analyzed. By means of Fresnel principle, diffractions caused by different transparent raw silk filaments are analyzed and simulated. Image data of raw silk filament measured by digital CMOS camera are analyzed and processed for obtaining the precise diameters of the filament with the relative error of less than 1%. On the assumption of appropriate elliptic cross-section of the filament, the cross-section area is calculated as the fineness of the filament. Measurement experiments are carried out. Finally, some suggestions are proposed for photoelectric measuring the fineness of raw silk.

Key words – fineness of raw silk; photoelectric measurement; simulation; image processing

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1 Introduction

China is the origin of sericulture, where has a splendid silk culture history of thousands of years. Almost 80% of raw silk in the world is produced in China nowadays. Silk manufacturing is a typical traditional industry, using many traditional standards and measuring methods. The conventional measuring methods and standards about the fineness measurement of raw silk are still used in silk industry for measuring the quality of raw silk. On the other hand, measurement science and technology are developing rapidly in recent years. It is necessary to study new measurement methods of the fineness of the filament to adopt the traditional industry innovation in modern times.

The denier value has been used as the size (fineness) of raw silk filament from a century ago in silk industry, including manufacturers and markets. This value is calculated by the weight (g) measured at 9 000 m segment filament length. Till now, the size in denier is still used as the fineness measurement of raw silk filament. It is important to evaluate the quality of raw silk through the items of the fineness and deviation.

There are two main types of electronic measurement, photoelectric and capacitive methods, for the fineness of raw silk[1]. The principle of the photoelectric measurement is that the luminance on the shadow varies with the fineness (diameter) of raw silk; hence the fineness can be sensed by photoelectric sensors. The principle of the capacitive measurement is sensing the varying fineness through the varying medium on a certain length of the thread between the capacitance plates.

There are some researches for optical measurement of the diameter of transparent filaments[2-4], the complex optical device is vital problem for precise dynamic measurement of raw silk fineness in practical application. The electronic measurement of raw silks fineness has not been accepted in practical condition. Measurement is an important tool to recognize and research the nature. There will be no precise science if there is no measurement. In this study, using the experience of existing measurement method, a new precise and efficient method for the fineness of raw silk is explored by modern measurement science and technology. As a result, a series of data of the fineness of raw silk is obtaind.

2 Physical features

Raw silk is a type of natural biological protein filament which has following physical features.

On optics, unlike fibers such as cotton and so on, which have some hairiness on the fiber surface, the raw silk filament has a smooth surface. Therefore, it is feasible to measure the fineness by the optical method. Some of the light transmits through the filament and the other reflects from the surface. The optical features vary with the breed and place of the silkworm, the process of silk reeling, and so on. Because of variant transparency of raw silk, the diameter of raw silk should not be simply measured through the luminous flux.

On specific gravity, strictly speaking, the specific gravity of raw silk is not a constant. It varies with the breed, place and feed of the silkworm, the process of silk reeling, and so on. Therefore, the fineness or the diameter could not be obtained by the size only with a constant specific gravity.

On the cross-section shape, unlike synthetic fibers having a certain cross-section shape, the cross-section of raw silk is an irregular polygon, varying repeatedly. Most of the cross-sections of raw silk can be approximately regarded as an ellipse. Therefore, orthogonal measurements of two diameters should be carried out for obtaining the ellipse cross-section area of raw silk. On the diameter, generally, the diameter of raw silk is about tens of micrometers controlled by size detectors in a reeling machine[5]. In order to inspect the indexes about the fine-

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Corresponding author: Wan-chun FEI (feiwch@suda.edu.cn)

ness reliably and dynamically, the relative error of the measured diameter of raw silk should be less than 1%.

On the basis of the above analysis, regarding the cross-section shape of raw silk as an ellipse, by use of modern techniques including the computer, photoelectron and digital CMOS image sensor, orthogonal measurements[6] of two diameters of raw silk in rolling are studied by build up an experiment device and sampling the diameters to obtain the fineness (the cross-section area) of the raw silk filament.

3 Diffraction simulations

Diffraction effects will happen if a fine thread is illuminated by a beam of light. As a fine thread with the diameter about tens of micrometers, the image of the raw silk filament measured by photoelectric method is simulated by the computer.

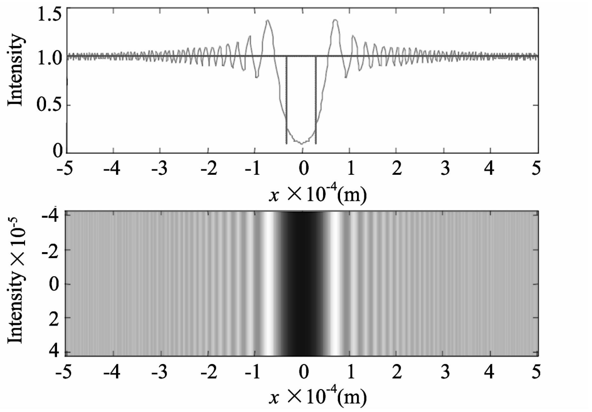

Fig. 1 Opaque line diffraction

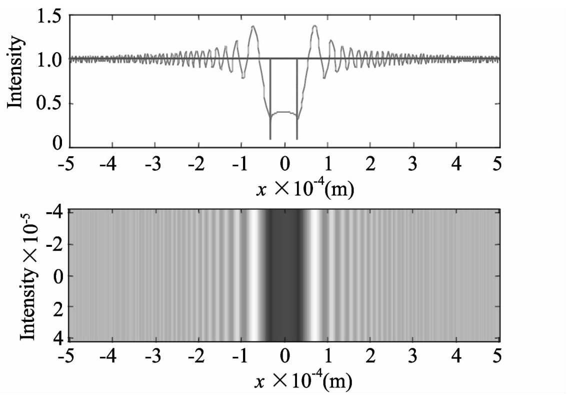

Fig. 2 Transparent line diffraction

Suppose a segment of raw silk filament is with the diameter of 60 μm; the distance between the filament and the imaging screen is 5 mm; ingoing light is blue with the wave length of 470 nm; the filament is opaque or (30%) transparent, Fresnel straight line diffractions are simulated, as shown in Fig. 1 and Fig. 2 respectively, where the spans between the two parallel dashed lines in the upper figures are 60 μm. Because of variant transparency of raw silk, the diameter or fineness of raw silk should not be simply measured by the luminous flux. It should be measured through the image area shadowed by the filament.

4 Measurements

4.1 Photoelectric method

On the basis of above optical analysis and simulation, it is possible to measure the diameter of the raw silk filament by image sensors; the measurement error of the diameter caused by diffraction is so insignificant that it can be ignored. In this study, in order to measure the diameter, a raw silk filament is irradiated by parallel blue rays. The diagram of the diameter measurement is shown in Fig. 3.

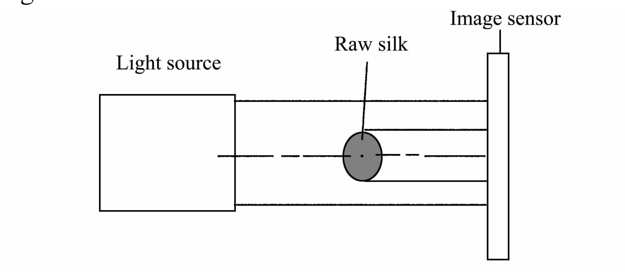

Fig. 3 Diameter measuring diagram

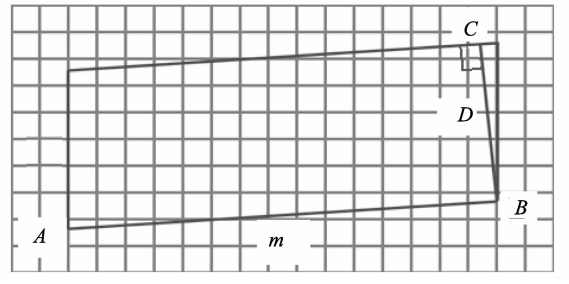

Fig. 4 An image of the filament on the sensor

4.2 Material

A hank of raw silk filament with the size of 20/22 denier, whose diameter is about 50~60 μm, is measured in this study. A segment of nylon filament with the diameter of 63.75 μm is used for measuring the calibration and determining the threshold value.

4.3 Devices and instruments

Two CMOS digital cameras with the resolution of 640×480, image record speed of 25 pictures per second and the width of about 10 μm between adjacent pixel centers, are connected to the computers through USB connectors. Two blue light sources with the wave-length of about 470 nm. A rolling device with the line velocity of about 16 cm/s. A fiber fineness tester WV-CP240EXCH with 450 magnifying power. Computers for sampling measurement data.

4.4 The principle of the precise measurement of the diameter

Suppose a segment of raw silk within the length of hundreds of micrometers has a uniform diameter. The segment's diameter measured by a digital image sensor as shown in Fig. 4. denotes the angle of inclination between the filament and the horizontal pixels of the sensor, where m denotes the number of horizontal pixels between the ends of the segment A and B. Suppose the grid side length is d, which equals the width between the adjacent pixel centers. $AB = md/\cos\theta$. Suppose there are total n shadowed pixels between A and B by the filament segment. The area of shadowed pixels will be $S = nd^2$. The diameter

$$D = BC = S/AB = nd\cos\theta/m = nd\sqrt{1+m^2},$$

where $\cos\theta = m/\sqrt{1+m^2}$.

Now analyze the measurement error. The absolute error of the measured diameter is not greater than $\delta = d/m$. Suppose $D = 50\ \mu m$. If $d = 10\ \mu m$ and $m > 20$, $\delta < 0.5\ \mu m$, the relative error $(\delta/D) \times 100\%$ of the measured diameter of the filament will be less than 1%.

4.5 The fineness of the filament

Regarding the cross-section of raw silk as an ellipse, by the use of photoelectron and digital image sensors, two diameters of the rolling raw silk are orthogonally measured, by building up an experiment device (as shown in Fig. 5), and sampling the diameters to obtain the fineness (the cross-section area) of raw silk $F = \pi D_1 D_2/4$.

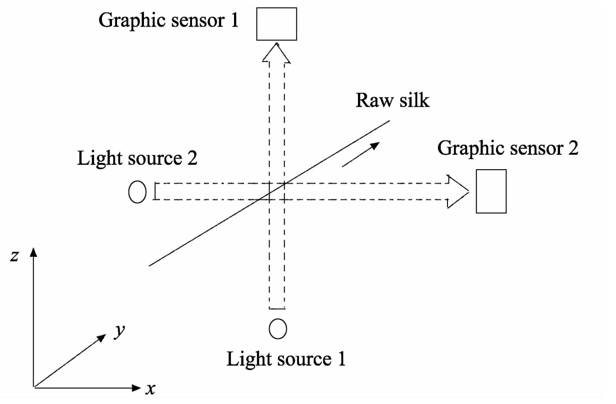

Fig. 5 Diagram of the orthogonal measurements of two diameters of raw silk

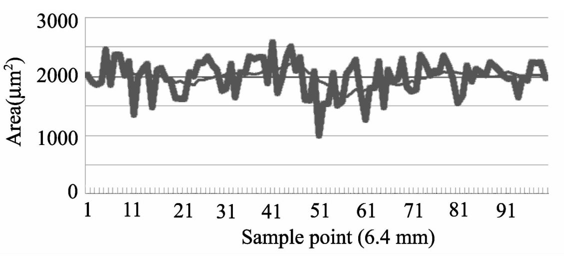

Fig. 6 A segment of the fineness series and its moving average of raw silk

4.6 Static measurements

A segment of raw silk was statically measured by two methods per 10 mm. The results are shown in Tab. 1. The data measured by WV-CP240EXCH based on the assumption of the cross-section of raw silk is circular.

4.7 Dynamic measurements

Another segment of raw silk is dynamically measured by the proposed method. The sampled fineness series data and the moving average are shown in Fig. 6. The length between the adjacent points in abscissa is about 6.4 mm. The results are shown in Tab. 1.

Tab. 1 Static and dynamic measurement data

Measurement	Index	Static (50 sets)	Dynamic (100 sets)
By proposed method	Avg diameters (μm)	$D_1 = 50.43$ $D_2 = 50.37$	$D_1 = 53.93$ $D_2 = 50.48$
	Avg fineness (μm²)	1 817.00	2 137.03
	The variance (μm⁴)	36 200.91	31 071.12
By WV-CP240EXCH	Avg diameters (μm)	50.37	51.87
	Avg fineness (μm²)	2 009.34	2 189.57
	The variance (μm⁴)	133 641.26	181 729.90

5 Conclusion

Precise measurements of the diameters of the raw silk filaments by photoelectric and digital image cameras are proposed. The relative error of the measurement is less than 1%. On the assumption of appropriately elliptic cross-section of raw silk, orthogonal measurements of the two diameters are proposed to obtain the fineness (cross-section area) of raw silk.

The measurement devices are built up and the measurements experiment are carried out. The proposed method is feasible according to the results of the measurement experiment.

It is necessary to improve the measurement devices including adjusting the rolling speed and higher sampling rates for the practical use. The inspection standard for the production quality of raw silk by photoelectric measurement should be also studied.

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