MEASUREMENT OF YARN DIAMETER AND TWIST ANGLE WITH IMAGE PROCESSING SYSTEM

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Abstract

A special image processing system was developed by the Department of Polymer Engineering and Textile Technology TU Budapest and the KFKI Research Institute for Materials Science Budapest supported by OTKA Fund of Hungary.

The system is suitable for measuring the diameter of fibres and yarns. The hardware system based on a Projectina Projector Microscope and a CCD camera connected with a image aquisition card. In addition to the testing of fibres and yarns the menu-driven software frame provides also general image processing services and possibilities for special statistical evaluations.

To demonstrate the applicability of the system some kinds of yarn were tested.

Keywords: image processing, textile testing, diameter of fibres and yarns, twist angle.

Introduction

There are several conventional measuring methods and equipment for determining the different properties of fibres and yarns in the textile research and industry. Most of these are the measurements of the geometry or the strength of the given specimen.

The determination of the diameter of a yarn or a fibre or the twist angle of a yarn with the help of a microscope is considered to be a conventional method. In both cases mentioned above doing a lot of measurements for determining the diameter or the twist angle is rather difficult. Furthermore the results depend on the person who does the measurements.

The image processing system working with a video camera gives a new and exact way for determining the diameter of fibres or yarns or the twist angle of yarns. This method compared with the conventional method is very quick. The report of the measurements with the results is printed

out with the help of the computer. The steps of the measurements can be programmed and so there is no possibility for doing the measurements in different ways and getting incorrect results.

A lot of measurements have been done on this equipment to determine the suitable settings and image operations in order to obtain correct results for different fibres and yarns.

The measuring method and system were developed in cooperation with the Department of Polymer Engineering and Textile Technology and the KFKI Research Institute for Materials Science supported by the OTKA Fund of Hungary.

1. The Structure of the Image Processing System and the Ways of Measurement

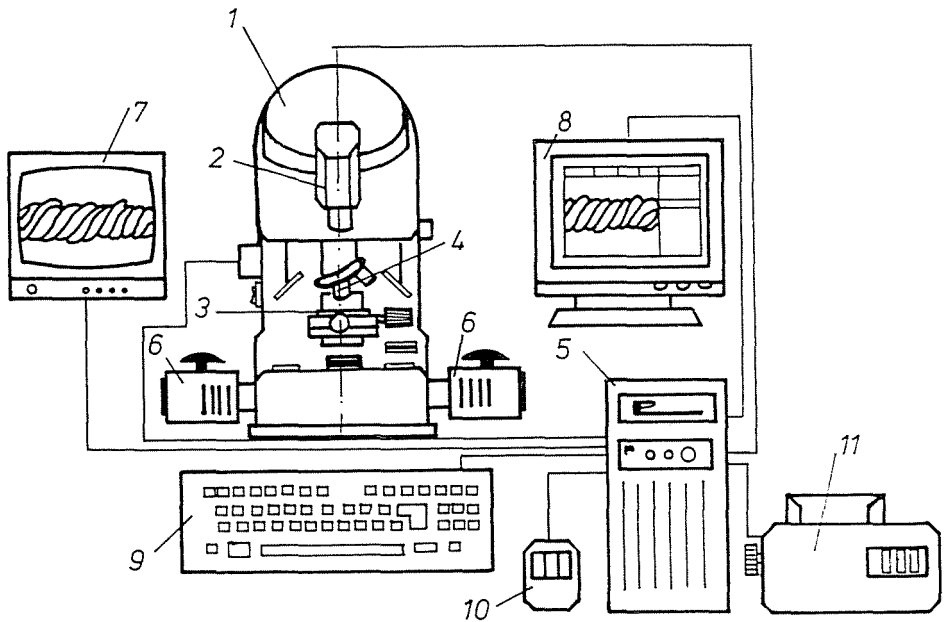*Fig. 1* shows the structure of the image processing system.

Fig. 1. Structure of the image processing system for testing fibres and yarns

There is a projection microscope type Projectina 4011–4016/MMA (1) the centre of the measuring system. The CCD video camera (2) is fastened on the microscope instead of the eyepiece. Its task is to send the picture what

we get with the help of a micro or macro objective (4) from the specimen (3) clipped on the stage to the computer PC/AT 486 (5). The adjustment of the stage in vertical direction that is focusing the picture can be made by a stepping motor (12).

Two quartz-iodide lamps give us the light we need for the measurements. The 2/3" CCD camera with a resolution of 760 × 576 pixels is connected direct to the computer through the video-digitizer card providing the whole video picture (760 × 576 pixels).

The sampling frequency is 15 MHz and the number of the picture planes [5, 6] is 2. The real-time video recording is carried out with the help of a double access memory of 2 Mbyte for the image.

Further hardware elements are:
– the input/output gray-tone converter;
– the high speed real-time 8-bit-video-bus plug for the real-time convolution arithmetic unit.

There are two monitors for showing the picture we get from the specimen. One of them is a simple mono monitor for real-time displaying (7), the other is an SVGA monitor (8). The keyboard (9) and the mouse (10) are our means to make the image processing program work. The pictures and the reports can be printed out with the printer (11).

There are two different ways to measure with the system. The local diameter of a fibre can be determined in micro mode while in macro mode the local diameter and twist angle of a yarn can be measured. In both modes the proper lighting of the specimen is very important (see *Fig. 2*).

In micro mode of the microscope the light goes through the stage (slideprojector mode). In this case the light beam is shown (6, 7, 1, 3, 10 and 4) in *Fig. 2*.

In macro mode the combination of the tangentional light (5, 8, 9 and 1)(episcope mode) and the light beam going through the stage are used. In this case not only the shape of specimen contour is important but the system needs the picture of the specimen surface to distinguish the layout of the fibres on the surface in order to determine the fibre orientation that is the twist angle. The way of the light beam from the specimen surface is the same as that in the micro mode (1, 3, 10, 4).

2. How the Local Fibre and Yarn Measuring System Works?

The program installed in the computer – similarly to other conventional image processing systems – is menu-driven (*Fig. 3*).
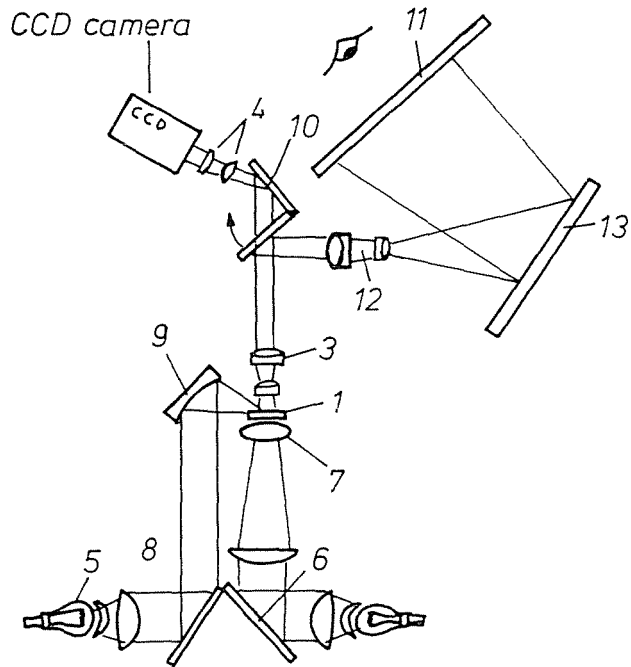
Fig. 2. Scheme for the optical system

There are four choices in the main menu:
- SETUP
- MEASURE
- TOOLS
- IMAGE

In the SETUP program there are commands we need for calibrating the system. This program makes it possible to choose between the different cursor modes, e.g. hidden or not (PROGRAM...). In the SEGMENT subprogram the suitable display mode can be chosen.

In the FIBER and STATISTICS programs of the MEASURE menu the diameter of fibres and yarns as contour width and the twist angle of yarns can be determined and statistically evaluated.

With the help of the TOOLS program we can change or modify the image in the computer. In the GRAY LEVEL program these changes are [5, 6]:
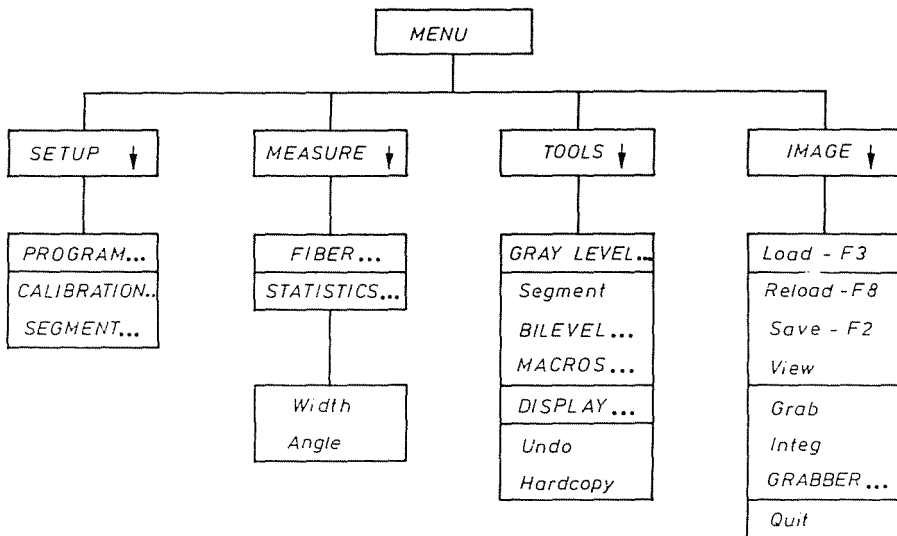- amplifying the contours of the picture (LAPLACE, SOEBEL operators, INCREASE CONTRAST operation);

Fig. 3. Menu structure of the software

- filtering the picture (LOW1, LOW2, HIGH1, HIGH2 filters and the USER-DEFINED-FILTER).

On the two tones image obtained in the SEGMENT program some special image processing operations as the DILATATION, EROSION, OPENING, CLOSING, FILL HOLES, etc. [5, 6] can be carried out in the BILEVEL menu.

The MACROS program stores the steps of the measurement. Doing a lot of measurements the use of this can be very effective.

The IMAGE program reads the picture grabbed by the camera system and stores it in the computer memory. The screen picture of the GRAB-BER program can be seen in the Fig. 4. The small window shows the real-time picture of a yarn segment to help with the proper setting, and in the big window the grabbed and stored picture, i.e. image can be seen.

The MEASURE and the TOOLS menus provide possibilities to store or to print the grabbed image or a part of that marked by opening a window as well as to print out the report of the measurements and the chosen diagrams.
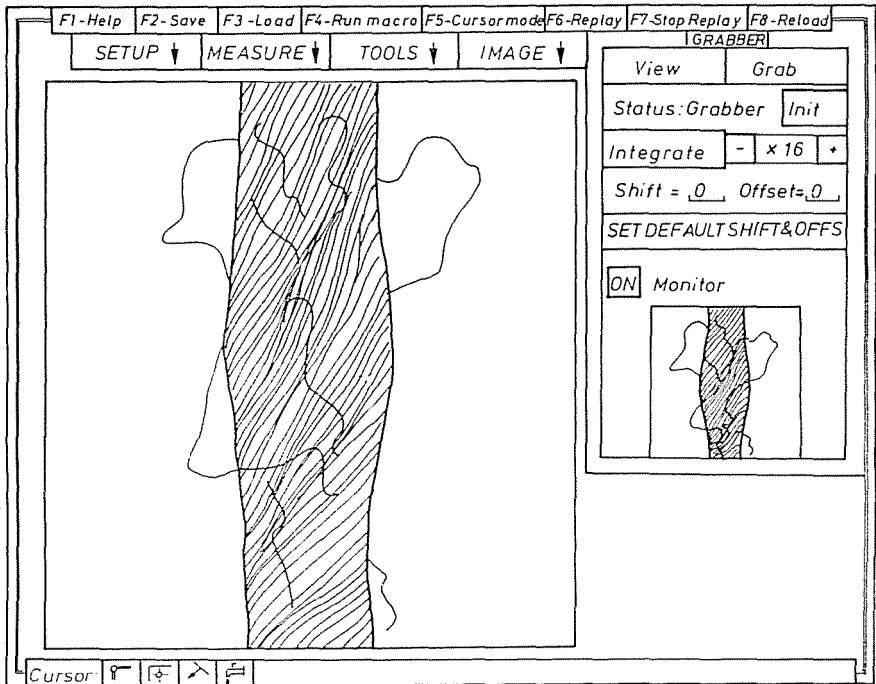
Fig. 4. Calibration with an optical lattice pattern

3. Calibration of the Measuring System

For calibrating the system we used optical lattice pattern. (*Fig. 5*). The period of the calibrating pattern can be 50, 100, and 200 μm. The magnification of the system determines which pattern we need for the calibration. The calibration can be performed only in the case when at least one whole period of the pattern can be seen on the screen in both X and Y directions. The period of the pattern in X direction can be seen in window 1 and the same in direction Y in window 2. The transition from dark to bright on the pattern is shown with a curve with inflexion in the *Fig. 5*. We can move two cross-hairs on the curves (3, 4 in direction X and 5, 6 in direction Y). It is necessary to move them into the inflexion points. It happens manually, not automatically. From these data the program can calculate the X and Y dimensions on the screen.

These data as setting parameters for the measurements will be stored and are valid until the next calibrating procedure.
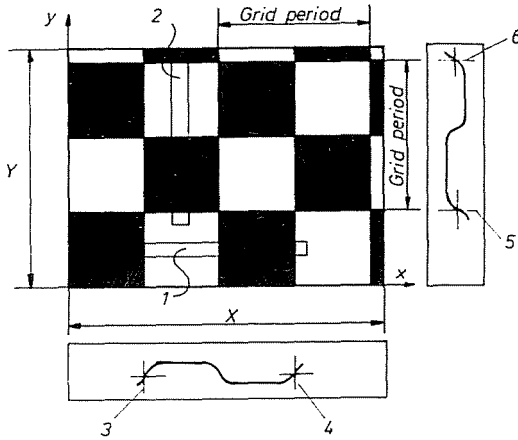
Fig. 5. Screen picture of grabbing an image

4. Determining the Fibre and Yarn Diameter

At diameter measurement we use the micro mode for fibres and the macro mode for yarns and certainly different objectives. Setting the axis of the fibre or the yarn into the direction Y, in both cases the measurement of the average diameter happens in a window opened on stored picture (*Fig. 6*). The evaluation software calculates first the transition curves of the density that is the gray level at every row on the picture around the contours. The program calculates the average of these at each point and gives three choices to determine the average local diameter as the average contour width.

The method INFL gives the distance of the two inflexion points of the transition curve as the diameter. The PERC method gives the distance of points determined by given percentages of the maximum density value. The diameter determined with the MANU method is the distance between two manually movable cross-hairs.

In the case of automatic measurement the choice of the first two methods is preferred. If the enlightment of the specimen is suitable the INFL and the PERC methods give almost the same result assuming the chosen percentages are 50 %.

In the textile testing it often occurs that several measurements along the same fibre or yarn specimen are carried out at the same time. In this case the program calculates the so-called average profile of the cross-section of the specimen tested. This average profile is determined as the average of the individual gray level histograms obtained from different measurements computing that separately at each point. The last one of the individual profiles is called the last profile.
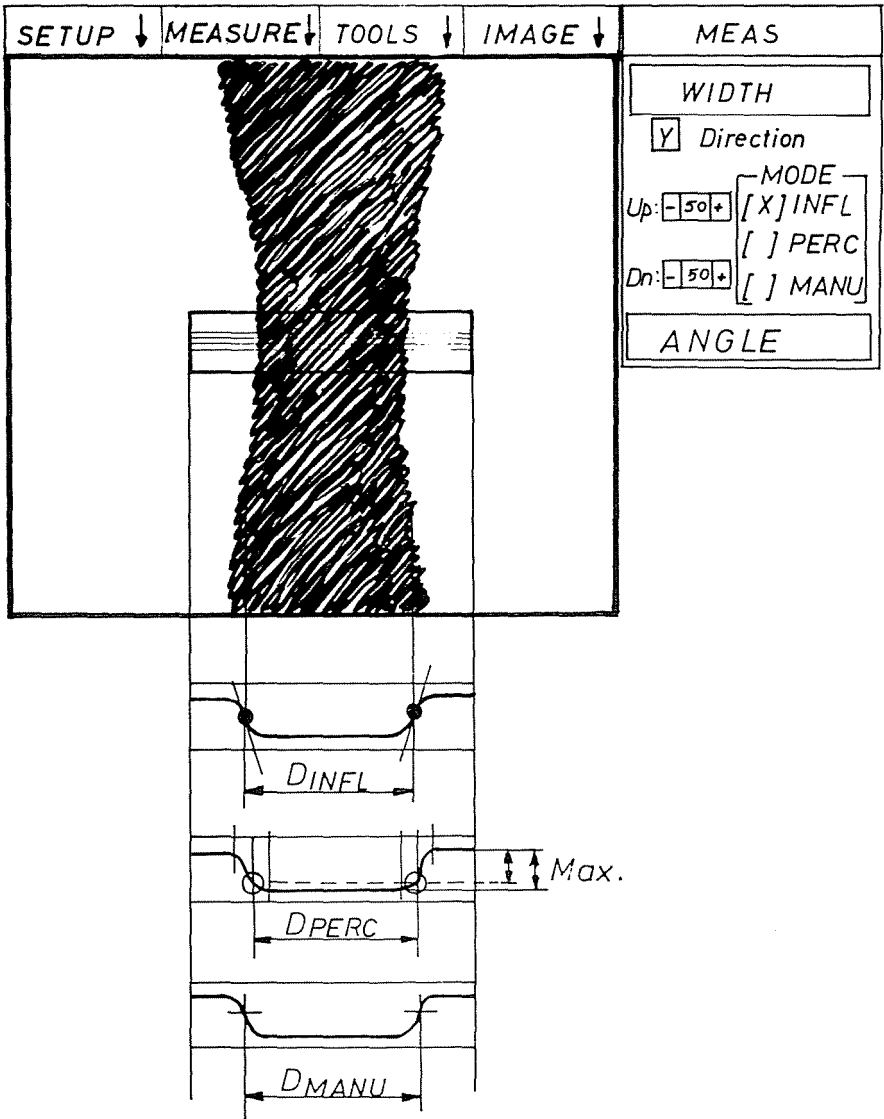
Fig. 6. Calculation methods for determining the local diameter (contour width) of a yarn segment using the gray level frequency histogram

5. Determining the Twist Angle

In the case of yarn measurement in macro mode, it is possible to measure the local twist angle on the surface of the yarn. The yarn axis must be set

in the direction Y. This time another window must be opened on the stored surface picture of the yarn inside of the contours (*Fig. 7*). The program is able to determine the twist angle valid in this window.

The software examines the changes of the gray level in the vicinity of every pixel. The base of this examination is a given threshold. If the absolute value of the gradient (g) in the vicinity of the given pixel exceeds the threshold limit (g_0) we consider the point to be dominant that is to be suspected of being an edge point:

$$g = [g_x^2 + g_y^2]^{\frac{1}{2}} > g_0 , \tag{1}$$

where g_x and g_y are the components of the gradient vector. The direction angle γ of the gradient vector is determined for all the dominant pixels (n) in the given window:

$$\gamma_i = \arctan \frac{g_{yi}}{g_{xi}} , \quad i = 1, \dots , n . \tag{2}$$

From this we get the surface twist angle α_i with $-90°$ rotation:

$$\alpha_i = \gamma_i - 90° , \quad i = 1, \dots , n . \tag{3}$$

In the *Fig. 7* the directions of the gradient vector and the fibres are marked with g and f.

The determination of the gradient is skew for the point examining that is why a number of symmetrical convolution filters were worked out to indicate points to be edge-suspect [5, 6]. So the gradient components g_x, g_y can be estimated by the weighted average of the intensity changes in the vicinity of the given point. For example in the *Fig. 7* the so-called Soebel's operator is used for emphasizing the edges in directions X and Y, where S_x and S_y are the component matrices (here 3×3) for estimating the gradient components g_x and g_y (see the TOOLS menu) [5, 6].

The program uses the so-called top hat filter for indicating points to be edge-suspect. Essentially this is a convolution filter estimating a two-dimensional Laplace's operator [5, 6]. The calculation of the filter elements is performed with the help of the kernel function as follows:

$$T(i,j) = 1 - b \frac{i^2 + j^2}{\sigma^2} \exp \left(-\frac{i^2 + j^2}{2\sigma^2} \right)$$
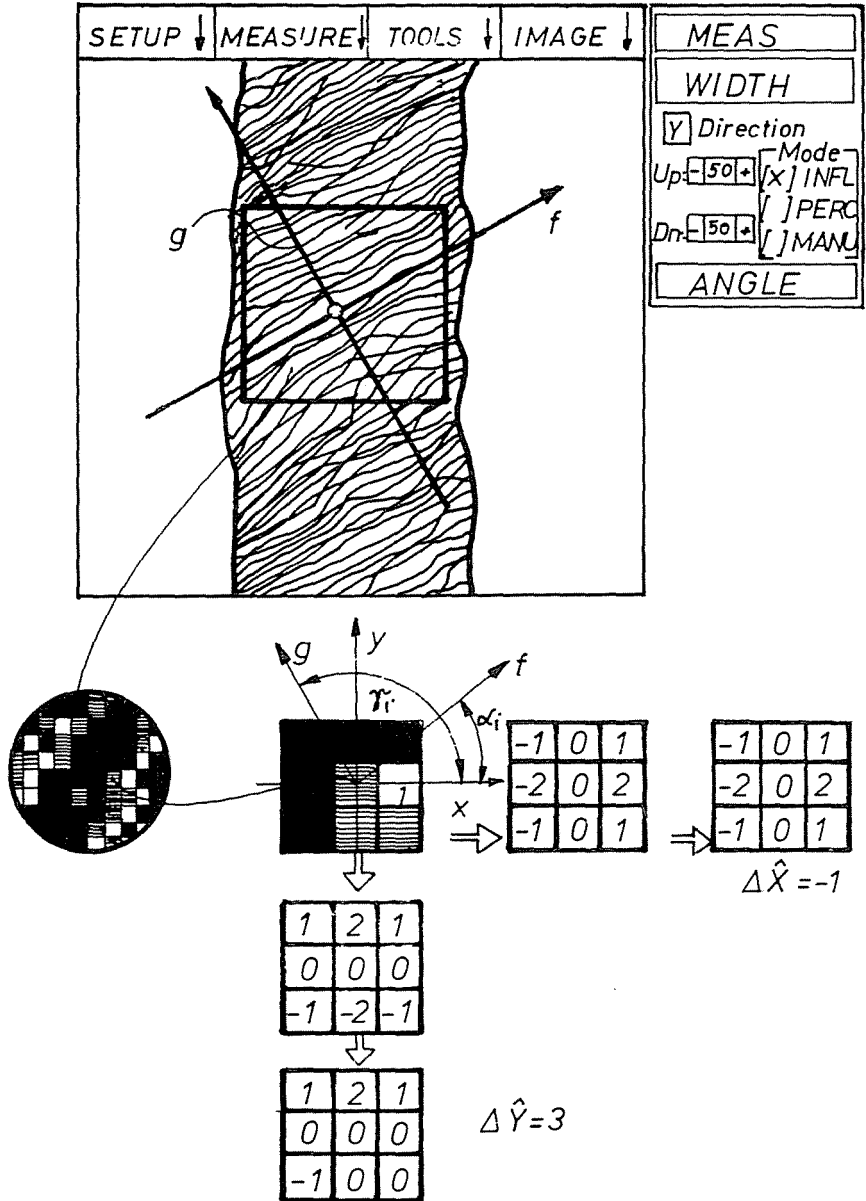
$$-\frac{N}{2} \leq i, j \leq \frac{N}{2} \tag{4}$$

Fig. 7. Determining the local gradient value (g) and angle (γ) and the fibre angle (α). Illustration of the estimation in the 3×3 vicinity of a dominant pixel

and the equation of the convolution filtering is:

$$q'(i,j) = q(i,j) * T(i,j) \tag{5}$$

where i and j are the running indices of the pixels and N is the dimensions of the convolution matrix; q and q' are the original and the transformed gray levels at the pixel (i,j); '$*$' is the sign of the convolution multiplication. The value of b must be chosen so that the sum of the matrix elements is zero. The one-variable shape of the expression (4) shows *Fig. 8*. With the change of σ the half-value width of the function can be set. On calculating the convolution edges and parts will be detected the dimensions of which correlate to the half-value width and the other will be filtered out.
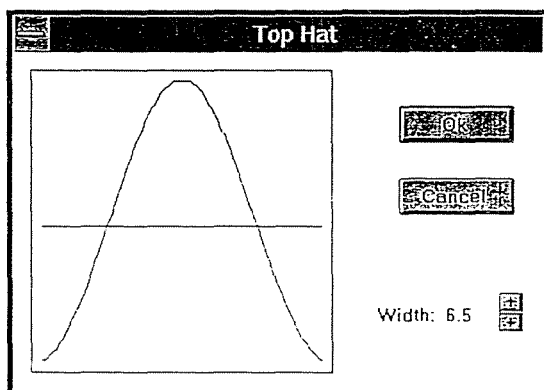

Fig. 8. Function form of a one-variable 'top hat' filter

In basic mode the program uses 5×5 dimension filter. In the TOOLS menu the user can define maximum 15×15 dimension filters of other type (User defined filter). The determination b and σ as well as the symmetrizing of the top hat filter happen automatically. The threshold g_0 mentioned above can be set as filter constant.

The diagram a in *Fig. 9* shows the frequency histogram of the gradient angle of three special groups of fibres arranged at about 60° angles to each other to test the measuring method. The determination of the gradient angles takes place in 5×5 vicinities, so the resolution in certain directions is higher than in the other ones therefore the frequency of certain angles
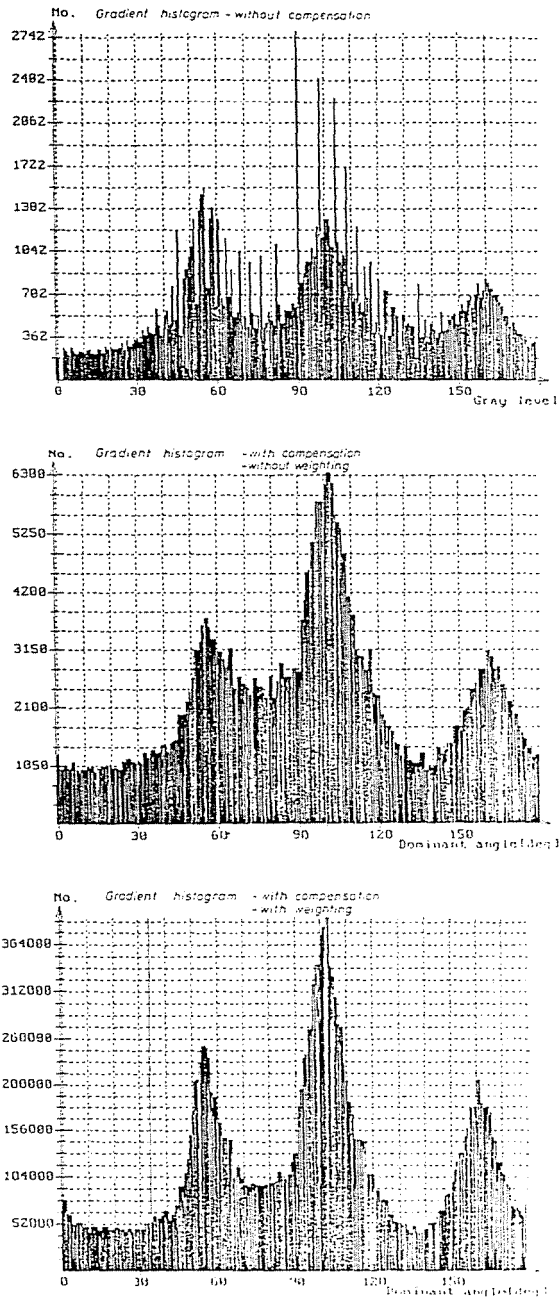
Fig. 9. The effect of the compensation and the weighting on the form of the gradient histogram of three fibre bundles arranged at about 60° angles to each other

is also greater because of the quantization. To compensate the error of the angle digitizing the program corrects the histogram of the primary gradient angles with the probability of the quantized angles. It can be seen in the diagram b that the compensation emphasizes the significance that is dominant for angles while the 3-point median filtering performed at the same time equalizes the needle-like impulses (Setting Show histogram ON). At the setting 'Show histogram OFF' (see FIBER menu) the gradient histogram will be weighted with the absolute value of the local gradient. Consequently, the sharper a part of the image or an edge the greater its weight is. The effect of emphasizing is well illustrated with the diagram c in *Fig 9*.

At last the program calculates moving average (in basic mode from 5 points) going along the histogram and that angle value is considered to be dominant gradient angle (α_D) at which the moving average has the maximum value. The program gives this value as the result of the measurement that is the local twist angle and shows it at the same time in the given window.

In the STATISTICS menu there is a possibility to determine the second and/or the third dominant peaks and the suitable second (α_S) and third (α_T) dominant gradient angles (*Fig. 10*). With a decomposition procedure the program determines three Gaussian density functions as the weigthed sum of them fitting to the gradient histogram $h(\alpha)$ best of all:

$$h(\alpha) \approx p_1\varphi_1(\alpha; \alpha_1, \sigma_1) + p_2\varphi_2(\alpha; \alpha_2, \sigma_2) + p_3\varphi_3(\alpha; \alpha_3, \sigma_3) , \qquad (6)$$

$$0 \leq p_1, p_2, p_3 \leq 1 , \quad p_1 + p_2 + p_3 = 1 ,$$

where φ_i ($i = 1, 2, 3$) are the Gaussian density functions with α_i 'expected value' and σ_i 'standard deviation'. Knowing them we get:

$$\begin{aligned} \alpha_D &= \alpha_1 , \\ \alpha_S &= \max(\alpha_2, \alpha_3) , \\ \alpha_T &= \min(\alpha_2, \alpha_3) . \end{aligned} \qquad (7)$$

6. Measurement on Yarns

To demonstrate the applicability of the system in testing textile yarns the following figures show some results of measurements performed with the system.

Some graphic results obtained by testing two kinds of polyester rayon yarn can be seen in *Fig. 11*. The PES1 Rayon (on the left in the Figure) is a 15 tex filament yarn protected with a small twist of about 30 tpm. The
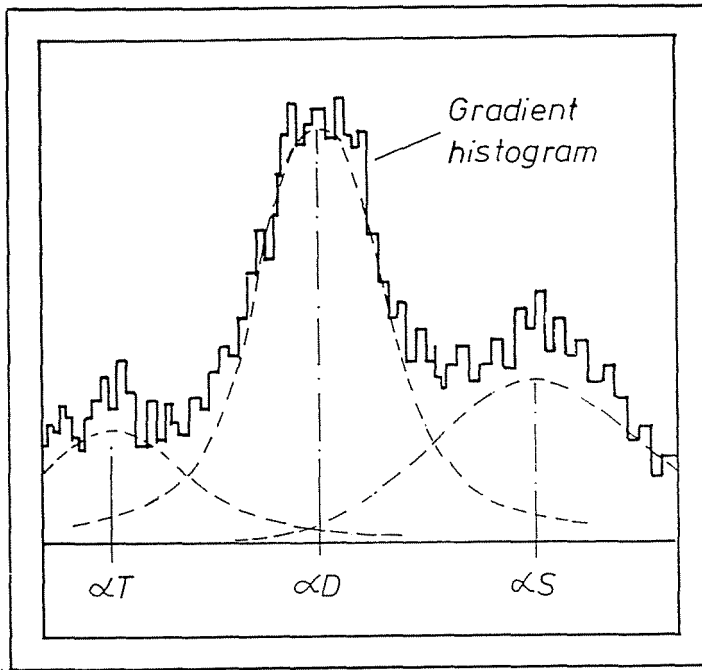
αD = Dominant angle

αS = Second dominant angle

αT = Third dominant angle

Fig. 10. Identification of the first three dominant peaks and twist angles of the gradient histogram with decomposition

PES2 Rayon (on the right in the Figure) is a 7 tex filament yarn glued together periodically for protection. The gray level histograms on the top and the gradient histograms on the bottom are results of single measurements, but the average profile histograms in the middle were calculated from 10 measurements performed on the same specimens. The gray level histograms on the two sides demonstrate well the structures with different looseness or extensiveness. On the other hand, the average profile histograms illustrate also well the smoothing effect of averaging several contour profile histograms. The local and the average diameter of yarn are denoted by the contour widths W and W_a.

In the next test a 16.7 tex ring-spun yarn specimen was twisted under the microscope and the CCD camera with the help of a small appliance and
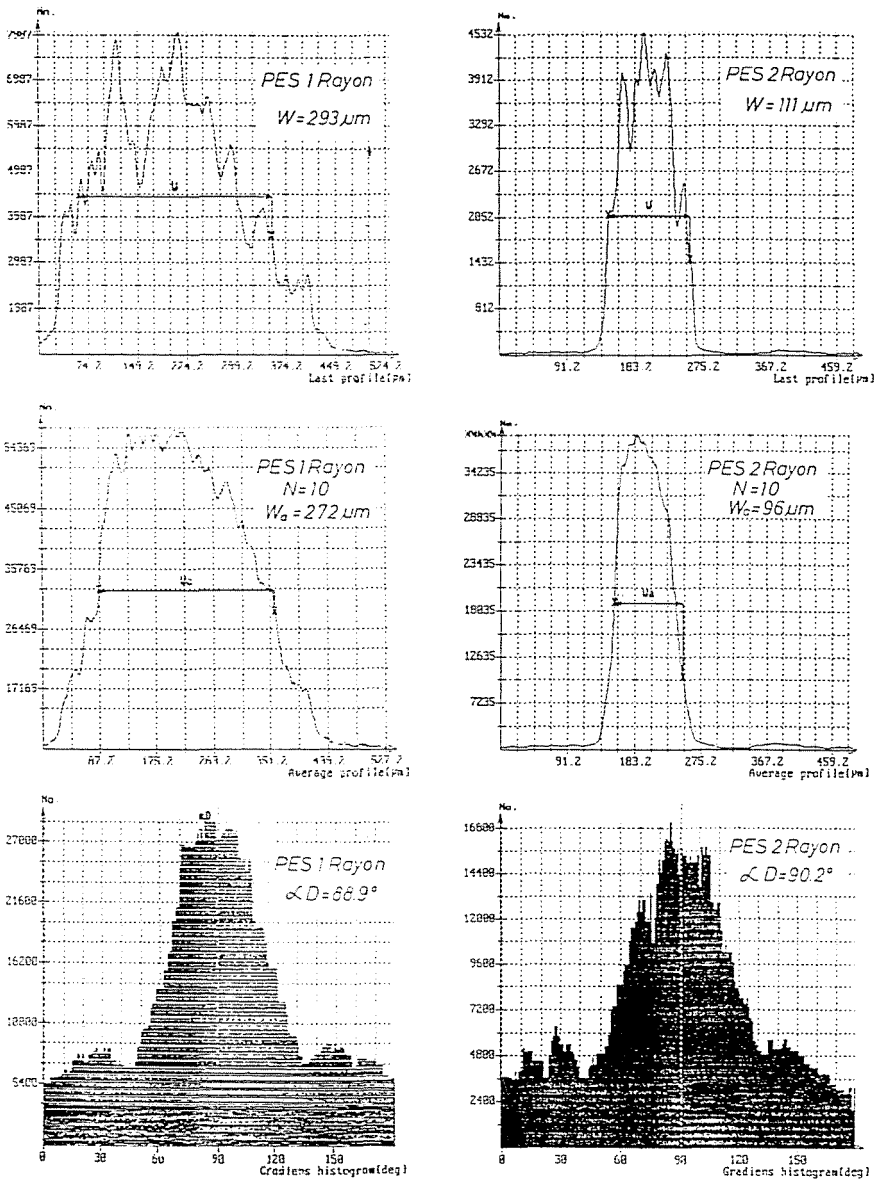
Fig. 11. Gray level profile, average gray level profile and gradient histograms determined at testing the PES1 and PES2 polyester rayon yarns
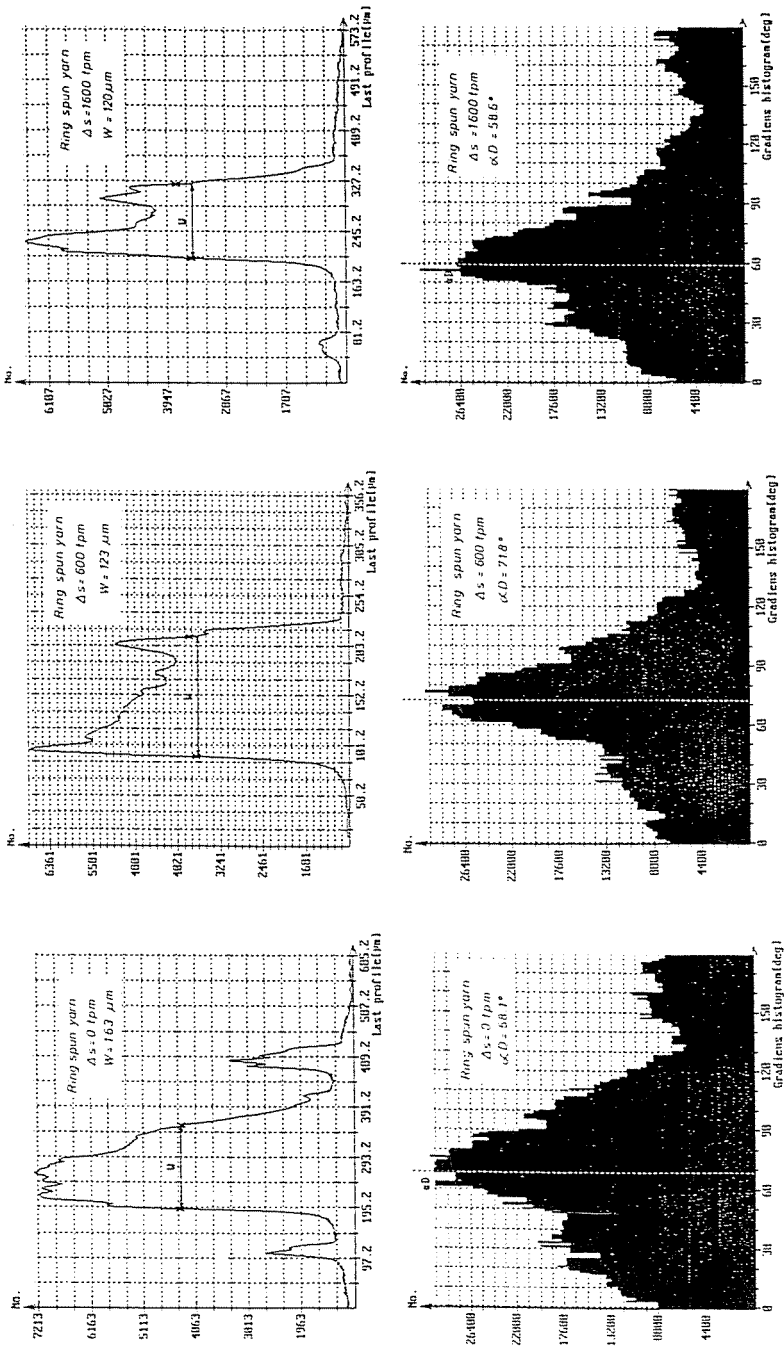
Fig. 12. Gray level profile and gradient histograms measured on ring-spun yarn at different twist values
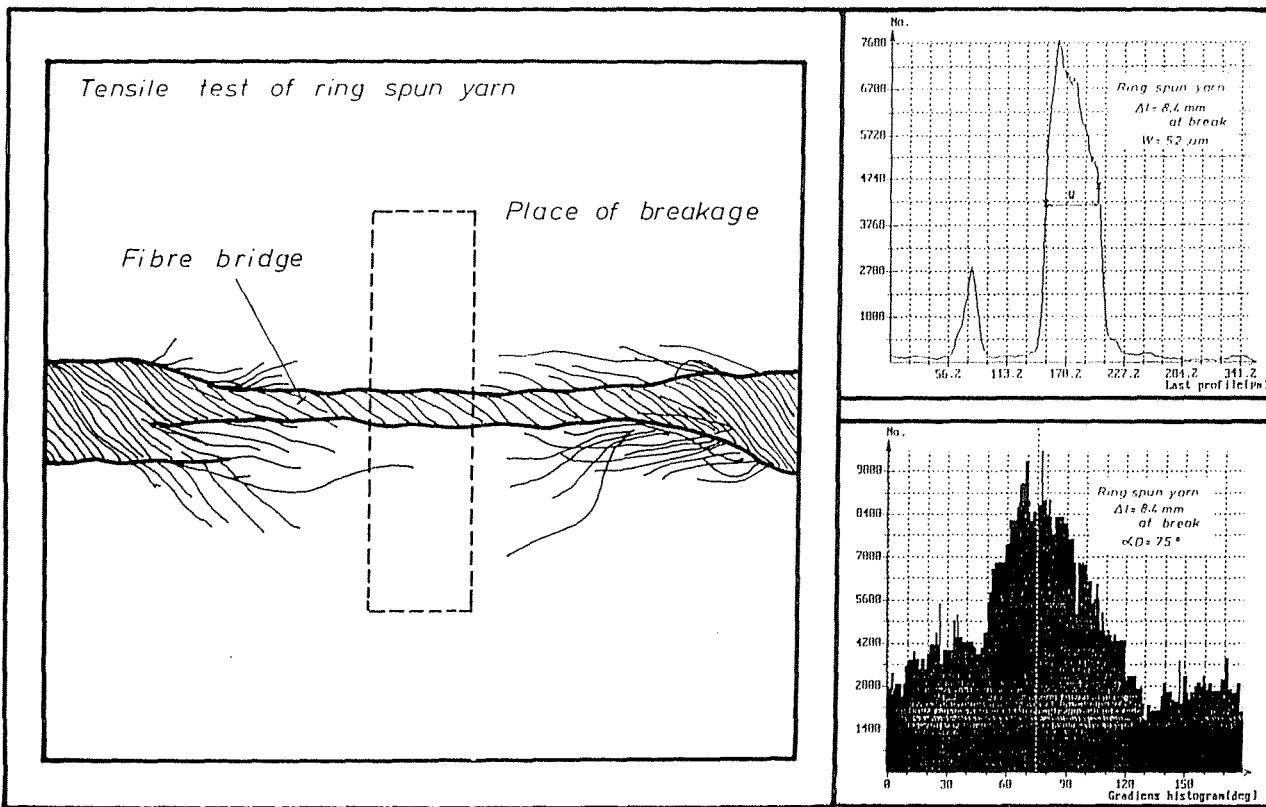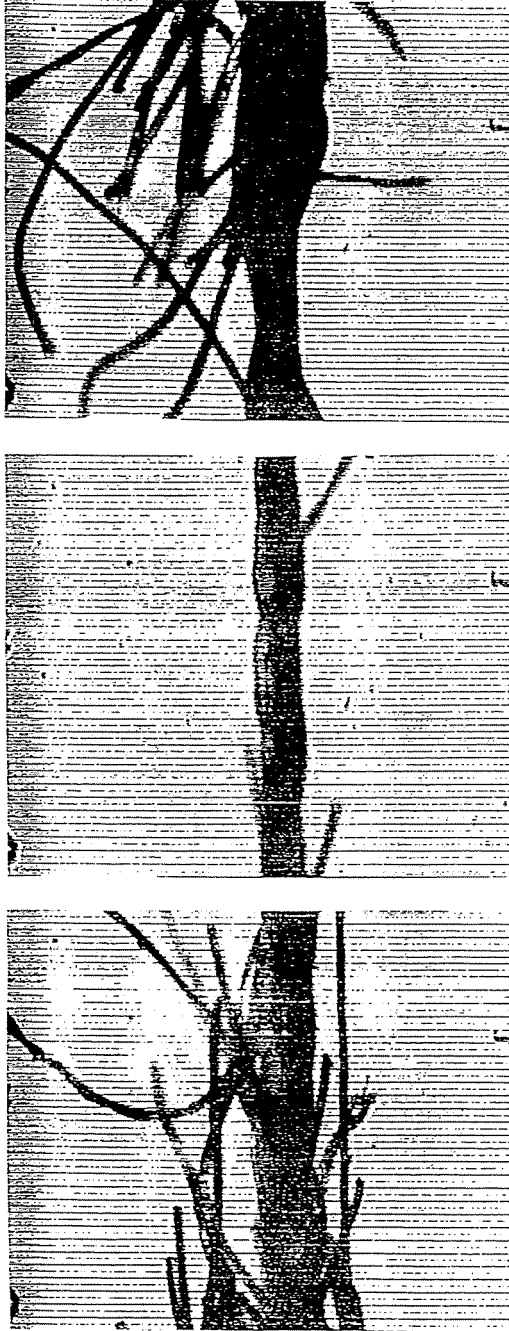
Fig. 13. The sketch of a breakage of the ring-spun yarn and the gray level profile and the gradient histograms measured on the fibre bridge in the window marked

Tensile test of ring spun yarn

Place of breakage

Fig. 14. The picture of the breakage place taken on the ring-spun yarn at tensile test

images were grabbed and evaluated at different twist values. *Fig. 12* shows the gray level histograms on the top and the gradient histograms on the bottom. The diagrams on the left refer to an original yarn segment with some fibres standing out of the surface. The diagrams in the middle and on the right were made after 600 and 1600 turns per meter. It can be seen well how the contour width decreases and the dominant fibre orientation that is the twist angle on the surface changes with increasing of the twist. It is also visible that at the first twist increase mainly the diameter decreases and the twist angle is about unchanged or it can locally fluctuate inside a little deviation. However, after the second twist increase the diameter of the already almost solid yarn body decreases just a bit but the twist angle changes more significantly.

The next two figures show some results of a tensile test performed on the ring-spun yarn mentioned above with a special appliance under the microscope. In this case the yarn specimen did not break totally but a small fibre bridge remained at the place of the breakage. *Fig. 13* shows the sketch of this fibre bridge, the measuring window used as well as the profile and gradient histograms. From the results it turned out that instead of the original twist value of 467 tpm a high twist value of 1640 tpm accumulated in the fibre bridge. *Fig. 14* shows the picture of the place of the breakage composed from three printed copies. In the middle the fibre bridge can be seen and it is well visible that the breakage is asymmetric.

Conclusion

It can be seen from our measurements that the image processing system developed for measuring the diameter of yarns and fibres and the surface twist angle of yarns can be well used for a number of purposes in testing textile materials and provides a possibility for doing exact and quick measurements.

Acknowledgement

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