Microoptical sensor for online characterization of textile fibers

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Introduction

Modern textile industry has an increasing demand on artificial high-performance fibers. A lot of technical applications require precise and constant properties of the filaments which therefore have to be already controlled during the spinning process. This can be done by measuring either mechanical or optical fiber parameters. However, measuring the optical properties is often better suited than measuring the mechanical ones. Using optical methods the measurement speed may be higher and a contactless sensor system is obtained.
In general, there are two parameters giving a representative overview of the fiber properties being the fiber diameter and the optical birefringence. From both parameters the degree of polymer-chain orientation in the fiber and therefore the state of its racking can be estimated. This property is important for the mechanical behavior of the fiber in later applications. Within the framework of the project "Sentex" the IOF developed in cooperation with the Thüringisches Institut für Textil- und Kunststoff-Forschung, different small companies and an Institute of Friedrich-Schiller-University Jena a microoptical sensor for the online measurement of the fiber-parameters mentioned above.

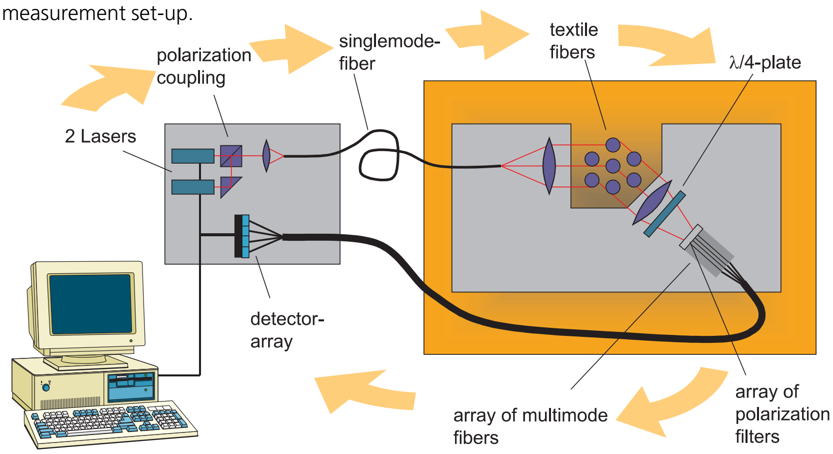

Fig. 1:
Sketch of the measurement set-up.

Realization of the sensor

In order to qualify the sensor for application in a common spinning machine, special demands for the geometrical extension of the detector housing, the measurement speed and the operation temperature and humidity has to be fulfilled. The extension of the available measurement volume in some spinning machines is limited to about 6 mm in direction of the fiber movement.
In the environment of the sensor a temperature up to 80°C and a relative humidity of nearly 100% may occur depending on the particular spinning process. During the online characterization of the fibers up to 8000 meter fiber per minute pass the measurement set-up. In order to realize a measurement in such an environment the microoptical sensor system has been split into one part containing the light sources, detectors, and electronics and a second part for the measurement line containing only microoptical components such as lenses for beam shaping, filters and waveplates. The connection between the two parts is established by single- and multimode optical fibers for illumination and detection, respectively.
The estimation of the birefringence is done by the so called Senarmont-method /1/. For this method the fiber is illuminated with linearly polarized light, tilted by 45° with respect to the fiber axis. The direction of the mechanical stress during the racking of the fiber is along the fiber axis which is therefore identical with the birefringence axis. The light transmitted through the fiber is elliptically polarized because of the different refractive indices for the field components parallel and orthogonal to the fiber axis. A quarter-wave-plate oriented by 45° with respect to the fiber axis transforms the polarization state of the transmitted light into a linear one whose polarization direc-

tion is a measure for the strength of birefringence in the textile fiber. As a result the estimation of birefringence is reduced to a measurement of the orientation of linearly polarized light. However, there is an uncertainty of N × λ (with *N* being an integer number) for the measured birefringence if the path difference for the two orthogonal polarization directions parallel and orthogonal to the textile fiber axis is larger than λ. By using two illumination wavelengths λ_1 and λ_2 being not too different, the range of a reliable birefringence detection can be extended to path differences up to $\lambda_1^2/(\lambda_2-\lambda_1)$.
In order to have a compact detector set-up without moving parts, the polarization direction of the transmitted light is measured with an array of polarization filters lithographically realized as so-called wire-grid polarizers. These filters consist of metallic grids having a grating period smaller than the wavelength of the used light oriented under 3 directions (0°, 60° and 120°) with respect to the axis of the textile fiber. For the present case the grating period is 300 nm and the area of each filter is 300 µm x 300 µm. The filter array is mounted to the facet of an array of multimode fibers which guide the transmitted light to photodiodes. A sketch of the measurement set-up is shown in Figure 1. Two laser diodes at λ_1= 630 nm and λ_2= 650 nm are coupled into a polarization maintaining single mode fiber and at the fiber output two cylindrical lenses are used for optimal shaping the beam for illumination of the textile fibers. In order to separate the light transmitted through the textile fibers from the light passing by these fibers the optical axis of the polarization detection is arranged under an angle of 45° with respect to the direction of the collimated illumination beam.
A collecting lens directs the light onto the filter array and the multimode fibers. The measurement at the different wavelengths is performed in succession and controlled by computer which also calculates the path difference from the detected signals. Photographs of the detector stage and the measurement plate are shown in Figure 2. The thickness of the plate is 6mm including the cover.
Furthermore, a detection system for the measurement of the fiber diameter based upon a modified spectrum analyzer is implemented into the measurement plate. This system has been developed by the project partner ETA-Optik. From both measurement results, the birefringence and the diameter, the state of racking of the textile fiber can be estimated.
In conclusion the developed sensor system can be easily inserted into common spinning machines for characterization of textile fiber properties during the spinning process. The measurement method gives correct results for the strength of birefringence also if the path difference between orthogonal polarization components is larger than one wavelength. The construction of the system fulfills the tight space requirements in the spinning machines.

Acknowledgement

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References

/1/ S. Kaufmann, E.-B. Kley, „Zur Eindeutigkeit und Miniaturisierung des Senarmont-Verfahrens bei online Messungen," DGaO Jahrestagung, Kloster Banz, 21.–24. Mai 1997

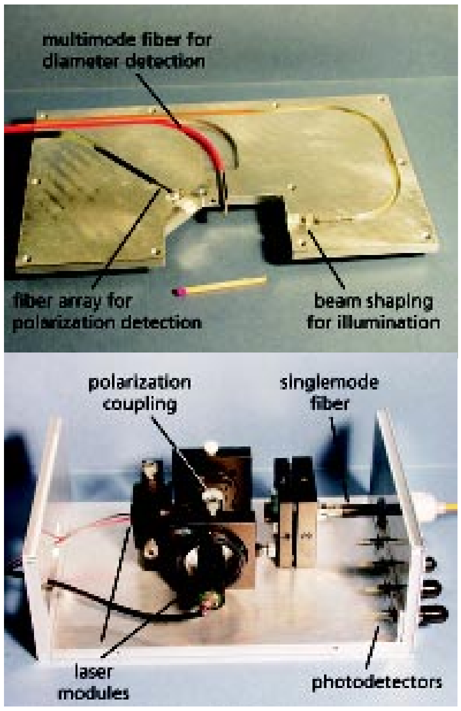

Fig. 2:
Microoptical sensor system with source and detector stage and measurement plate (covers removed, detector stage without electronics).