Developments in Spinning - the Tribological Approach

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SUMMARY

The maximum production speed in spinning is limited either by engineering considerations or by the yarn itsself. Today technological limits, concerning yarn quality and end breakage rate are the most important factors. One should be aware of the fact, that the tribological most important elements in spinning are identical with the most crucial ones when optimizing this processes.
There will be a quiet revolution in the productivity of synthetic fibres like PES, PAN, PP and even wool. The same spinning speeds will be reached as in cotton spinning today. This will be possible through surface and material engineering, where the tribological interactions between the fibre and surfaces of contacting textile machine components are considered.

1 INTRODUCTION

Tribology is the science and technology of interacting surfaces in relative motion and related subjects and practices. It comprises friction, wear and lubrication.
In textile technology these problems often affect the quality of the textile, and the productivity of textile machinery. Those surfaces standing in contact with each other and their acceptable load with respect to wear must allow for maximum spinning, weaving and knitting speeds.
In this article the author will focus on ring and rotor spinning. Each part of these machines, which in both technologies are in contact with fibres or yarn can be defined as an open tribosystem. As such they are determined by a permanent material flow in and out of the surface. (There is only one exception in those machine elements and that is the ring/traveller system which as a closed tribosystem is determined mainly by energy transfer and movement.)

The quality of textiles comes first in the engineering requirements of textile machinery. The rising spiral of quality and performance requires an increasingly detailed knowledge of the actions of textile machinery components on certain fibre- and yarn-contacting surfaces (hereafter referred to as fibre-contacting surfaces). This is in order to guarantee the trouble-free production time demanded and to allow high-quality criteria for textiles. In textile technology, there is a permanent fight to reduce any possible damages to textiles (in fibres, yarn and sheets) despite increases in productivity.

Any damage is of tribological nature. The load, which acts on the fibre or surface in the process, can lead, with natural and man-made fibres, to transformations. This pre-damage makes control difficult, as it gives rise to problems in the subsequent processes through dust, fibre fly, different dying characteristics and so on. As a consequence, the textile produced is decisevely reduced in value (Figure 1).

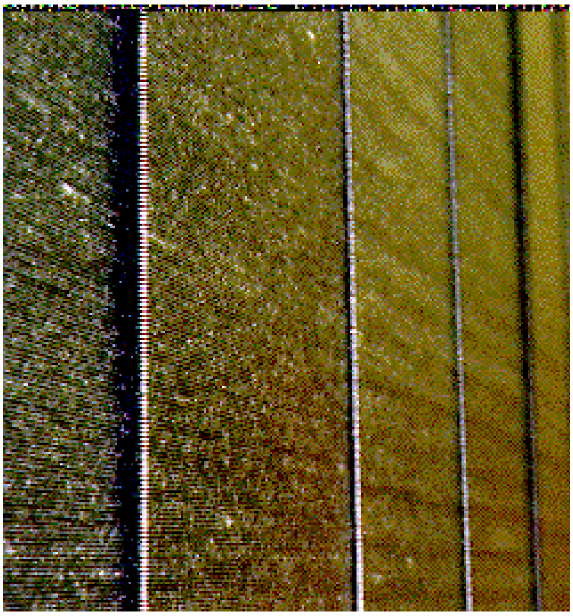

Figure 1: Yarn boards showing smooth and even yarn (left) compared to periodic stripes due to tribological interaction (right).

2 THE PROBLEM

Manufacturing textiles puts extreme pressures on process stability, the quality consistency of textiles and the life span of machine components. With operating times gradually reaching the maximum numbers of hours available in a year, a high level of long-term consistency in all three factors is expected. In spinning practice, there are constant attempts to work against the gradual deterioration of these points. Process stability is influenced mainly by unsteady yarn tension.
A consistent quality can only be guaranteed through the stabilisation of the relevant parameters. Both criteria must assume primarily defined and temporal constant friction between textile and contacting machine element.

In the case of textiles, production deals with isolating soft solids which have a dynamically changing and loose structure, with an ability to manipulate surface characteristics in a wides variety of ways through the textile process. The typical (open) tribosystem that is found on a textile production line consists of the basic body (the textile), the opposite body, 100 to 1000 times harder then the textile, and the body between these.
The opposite body is the fibre contacting surface; its usual function is to separate or guide fibre flow or it serves as a twist insertion. The body found in between is composed of fibres, rub-off polymers, wax, finish and other environmentals (Figure 2).

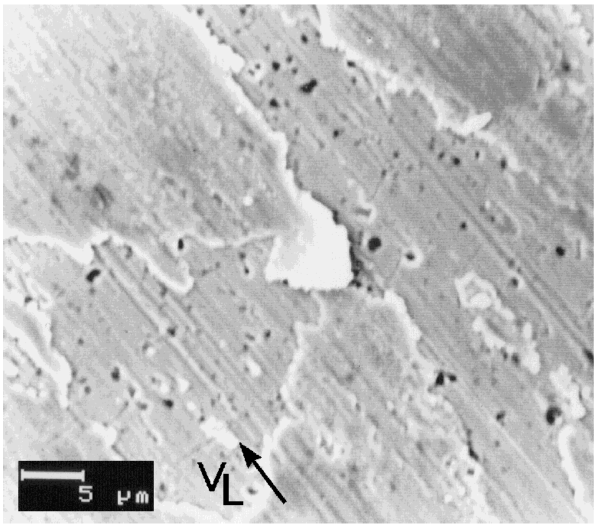

Figure 2: Debris of polymer and oligomer an textile machinery component.

Generally, textiles change their tribological properties with humidity and process speed in relation to the stress present. An occurence of triboelectricity for instance, causes a fluctuating electric charge in the textile, which can lead to a temporary spreading of the fibres - loosening as well as migration. Through this, the friction coefficient of the textile surface is changed at the subsequent fibre guides, which then leads to permanent, oscillating changes of hairiness and dying behaviour.

Progressive alteration of fibre contacting surfaces changes process stability as well as the characteristics of the textile product; particularly surface topography (yarn hairiness), mechanical characteristics (handle) and dying behaviour (depth). Visually recognisable differences appear that are conditioned by the material and the process: differences in tone, lustre and structure. These often appears in the last and most expensive step of manufacture, finishing, or in use, and lead to a considerable loss of money as a result of a reduction in quality.

3 REQUIREMENTS IN FIBRE CONTACTING SURFACES

Only optimum treatment during all steps of production leads to an excellent textile product. Through the optimisation of those surfaces in contact with the textile material, further increases in performance and quality are possible. Friction and wear are the determining factors. We are just beginning to understand the mechanisms which, given apparently identical surfaces, lead to different running behaviour, fibre damage and fly emissions. From the continuous effort, to raise productivity without reducing the quality of textile goods, intensified demands on both textile machinery and fibre-contacting surfaces have emerged.

The essential demands on fibre contacting surfaces can be described as follows:

- Constant friction coefficient over an entire service life,
- Defined, indpendent friction coefficient despite processing different fibres (cotton, viscose, polyesters, wool, and so on),
- Constant friction coefficient despite different twist indices,
- Lowest possible wear,
- Abbility to draw off electrostatic charge,
- High heat conductivity and
- No damage to textile goods.

To be able to fulfil these criteria, the topography of the contacting surfaces must be given maximum attention. Future developments in textile-machinery components might be to surfaces, whose wear profile guarantees a constant surface topography and, therefore, eliminates any running-in behaviour.

4 SPINNING

In the spinning mill the stress on fibre and yarn with respect to the amount of end breakages accepted determines productivity. Each increase in the productivity of an existing frame inevitably means an increase in the relative velocity between fibres or yarn and contacting surface in relation to the guiding or twist-insertion elements. This usually leads to a more than proportional increase in the yarn tension, bringing with it an increased rate of end breakage, fibre damage and load of the contacting surface - and the wear increases (Figure 3).

More than 45 % of spun staple fibres are man-made - mainly polyesters, acrylics and polyamides. The fact is, that these man-made fibres can only be spun with a drastically reduced output - only 70 % to 75 % of that possible with cotton - although their mechanical characteristics are often classes better than those of cotton. The reason for this is thermomechanical damage to fibres occuring because of friction. In the 1980s, through the optimisation of spinning geometry and the logistical framework, a remarkable increase in the productivity of a ring spinning frame became possible. This concerned, almost without exception, the spinning of cotton.

With regard to the spinning of man-made fibres, as well as wool, hardly any increase in productivity was achieved. In 1999, the ring spinning of polyester was still carried out with the same level of traveller velocities as 20 years ago. The cotton fibre managed to cope with the increased tribological load brought by engineering improvements to the spinning machines; the thermally sensitive fibres, could not follow suit (Table 1).

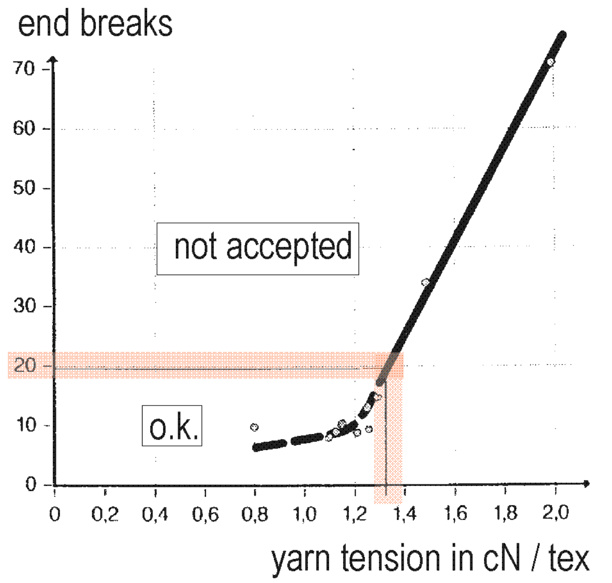

Figure 3: Relation between yarn tension and end breaks.

Table 1: The three historical steps of developments in spinning

Step	Problem	Solved with	Year
First	What kind of spinning technology will survive?	Ring, rotor, airjet	1975-1990 √
Second	How can spinning geometry, kinematics and dynamics be optimised?	Increasing precision, engineering, miniaturisation	1985-1995 √
Third	How can thermodynamics, wear and friction be optimised?	Surface engineering, tribology	1995-?

Until now, for critical applications, lubricated systems were inserted to reduce friction (for example ring/traveller - systems with longstaple spinning, balloon control rings with folding glass fibre). Beside the unwholesome danger of aerosols, staining of the yarn can occur. In addition ensuring constant friction, through proportionate lubrication at each spindle within a spinning machine, is a problem.

Increasing performance on the one hand, and the spinning of crude yarns on the other, increases the throughput of fibre materials and yarns on the spinning machine. Mineral dust, abrasive TiO_2 and the fibre substance itself give the contacting machine elements a hard time (Table 2).

Table 2: Crucial fibre/machine surface-contacting components in ring spinning

Component	Problems with increasing productivity	Possible future solutions
Drafting	- Wear of apron and front roller with increasing load, especially when soft surfaces are used - Electrostatic load of apron	- Lower twist in flyer strand - Aprons with laser structured surface for example to manipulate hairiness - Conducting aprons with low ash content
Yarn lappet guide	- Depending on spinning geometry and surface quality up to 10 - 20 % twist reduction at spinning delta - Abrasive fibres cut into metal surface - Jumping of yarn causes transversal waves which superimpose to high frequency yarn tension peaks	- Low friction surfaces for low speed yarn (axial) - Low wear surfaces - Re-engineered pigtail design
Balloon control ring	- Depending on spinning geometry and surface quality up to 20 - 30 % twist reduction at spinning delta - Thermomechanical damage of fibres and yarn surface - Exponential increase of high frequency yarn tension peaks due to gap at thread opening - Wear of metal surface through abrasive yarns	- Low friction coatings for high speed yarn (tangential) - Redesigned balloon control ring - Wear resistant and corrosion resistant surface coating
Ring/traveller-system	- Wear of traveller increases yarn hairiness and neps - High friction between yarn and traveller decreases stability of balloon	- Long-life traveller with extremely hard ceramic coatings (already available) - Low friction surface for yarn - Optimised geometry of traveller

In OE-rotor spinning of man-made fibres, sticky deposits or powder collecting on the inner parts of the rotor box cause instability in spinning, dull fibres have a severe abrasive effect (TiO_2), with the danger that all thread guiding parts may be damaged in a very short time. The service life of a nozzle in OE-rotor spinning can in particular cases total a few months or only weeks. Steel opening rollers used for man-made fibres have a service life of approximately 800 kg fibre throughput, before they need to be replaced. That is 5 weeks for a yarn count 83 tex (Nm 12) or 22 weeks for 30 tex (Nm 34) with 80 000 rpm rotor speed; with 20 % incease of speed, service life decreases at least 20 % (Table 3)

5 SURFACE ENGINEERING

Understanding of tribological processes between yarns and metallic or ceramic surfaces is still limited. The question of the optimum physical characteristics of a material for a machine element that is in contact with fibres, as well as its morphological requirements, has not been answered comprehensively until now. The profile of requirements for a surface cannot be described through roughness values like Ra, Rz and Rt. Yarn as a cause of wear has simply not yet been considered constructively.

Surfaces that minimize damage to the yarn are beeing sought. These surfaces, however, will have different specifications, depending on their tribological load. Active surfaces, which transmit power such as twist-insertion elements, should master the axially, radially and tangentially different fibre flow (twist, translation and oscillation) just as well as passive surfaces, which serve only as fibre guide. If it is possible to manufacture successfully surfaces, that last and reduce friction, it will be possible to increase productivity with passive surfaces. In the case of active surfaces, modifications in mechanical engineering will proceed, consequently increasing productivity.

Within textile technology the employment of passive fibre-contacting surfaces cannot be overlooked. This becomes necessary because of engineering as well as textile technological pressures. In theory each elimination of a fibre contacting surface reduces the tribological load on the fibre, however requirements placed on the surfaces of the remaining elements are increased.

In modern spinning mills, under good conditions, a net efficiency of more than 90 % per each machine is reached. The net efficiency a year is, however, considerably lower. This goes back to the maintenance and reconditioning (repair) time necessary. An important part of the downtime and costs of a spinning machine go back to the changing of parts that are subject to wear and tear.

At present the specifications of fibre-contacting materials with regard to their surface topography, geometry and their physical characteristics can be judged only by a few experts. In the case of ceramics certain requirements on the heat extension coefficient, minimum break stress, young modulus and heat conductivity must be fulfilled. For coatings, there is an important role for adhesion and hardness. No tribologically decisive parameters, however, have yet been determined. These parameters are not material but system parameters and are dependent on the process itself.
Traditionally, with regard to wear, advanced ceramics (structural ceramics) have displayed high tolerance to oxidation and corrosion but have not offered the satisfactorily low damage to fibres or low friction, that steel surfaces have been able to achieve. With increasing research success the limitation of the ceramics are however overcome. Naturally the chemical composition owes as much to the atomic interactions with metals as with advanced ceramics. By manipulating the size of polyceramic particles, their boundary layer and atomic configuration in combination with further modifications are possible including the reversal of the characteristics originally determined through the chemistry. Through the use of additives, the material structure can be increasingly controlled and modified in a variety of ways.

Table 3: Crucial fibre/machine surface contacting elements in rotor spinning

OE- rotor spinning	Problems with increasing productivity	Possible future solutions
Opening roller	- Wear of pins and rigid metal wire clothing	- Homogeneous wire coatings with high elasticity and "rough round" surface - Fully ceramic opening roller with modified tooth shapes - Geometry modifications
Rotor	- Wear of collecting groove and slide wall (especially at hight of feed tube outlet) - Undefined friction depending on fibre type makes different rotors necessary	- Modified coatings with low wear and ability to reach the groove properly. - Fully ceramic rotor with defined surface topography
Nozzle	- Wear of grooves and surface - Unidirectional friction coefficient in radial and axial direction	- Fully ceramic nozzles also for thermosensitive fibres through defined surface topography and optimized shape

6 OUTLOOK

The need to understand fully the tribological response of surfaces is becoming more and more urgent for the
textile machinery industry. In the topographies of surfaces, their structure and their texture lies a hidden, untapped, potential. This may provide a satisfactory increase in productivity for mills, if it is successful in reproducing and manufacturing functionally optimal surfaces. The newest developments in friction and wear on microscales have been found to be generally smaller compared to those of macroscales. This might help to develop surfaces with either ultra low friction or stable and defined friction and in all cases low wear.

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