VLÁKNA a TEXTIL

2

Ročník 7.
2000

ISSN 1335-0617

Indexed in:

Chemical Abstracts,

World Textile Abstracts

EMBASE

Elsevier Biobase

Elsevier GeoAbstracts

TECHNICKÁ UNIVERZITA LIBEREC • FAKULTA TEXTILNÍ •

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FACULTY OF TEXTILE ENGINEERING, TECHNICAL UNIVERSITY OF LIBEREC

Radko Kovář, Dean of the faculty

HISTORY

Textile products are very old. Nobody knows exactly how old, the oldest till now discovered prints of woven fabrics are old about 27 thousand years. The faculty of textile engineering is much younger and her age is known exactly. This issue is devoted to her 40^{th} anniversary what means, that this lady is in the best age. Let us discuss in brief her history, the present and perspectives.

Our Technical university was at the beginning in 1953 named "College of Mechanical Engineering" with one faculty only. Liberec, the town of developed industry, with beautiful surroundings, living culture, pure 100 km from Prague and yet very near to Poland and Germany, was without fail worth of its higher education institution. The region was exuberant with textile industry, research and textile machines producers. No wonder that the department of textile machines and technology was founded and that it became incubator of textile specialists. As it was not sufficient, the Faculty of textile engineering was established in 1960. From today view it seems strange but the situation used to be like this – the main document that enables our faculty origin was "Resolution of central committee of the Communist party of Czechoslovakia", the body of extreme power in the country. The name of institution was changed on "College of mechanical and textile engineering" and in the same year the group of about 100 young people (including author of this paper) started to study new and just being developed study program.

The first dean and one of the originators of the faculty was Prof. Ing. Jaroslav Simon, who leads the faculty for the longest period till 1972. His successor was Prof. Ing. dr. techn. Radko Krčma, DrSc. (1973–1979), next Prof. Ing. Jáchym Novák, CSc. (1980–1982). When it became known among the "nomenclature staff" that his daughter lives in the USA he was replaced by Doc. Ing. Vladimír Moravec, CSc. (1983–1986). Then once more became a dean Prof. Ing. Jáchym Novák, CSc. (1987–1989) when somebody found out that daughter in the USA is not so fatal mistake. After November 1989 our students agreed with only two people to stay in their high academic position (rector, vice rector, dean and vice-dean). One of them was Prof. Ing. Jaroslav Nosek, CSc., faculty dean in 1990. Next deans were in accordance with the new regulations (Higher Education Law) elected by academic senate. First was Doc. Ing. Otakar Kunz, CSc. (1991–1993), second Prof, Ing. Jiří Militký, CSc., who served two periods (what is maximum allowed by law, 1994–1999), third is Prof. Ing. Radko Kovář, CSc. (from 2000).

One of the best known persons of the faculty was Academic Jovan Čirlič. Twice he was the rector (1966–1969 and 1972–1984) but never dean. He was famous with the number of degrees and state distinctions, unfortunately this number was not accompanied by adequate number of scientific works and publications.

MILESTONES

Let us remind the main points in the life of the faculty.

M1. Establishing of the faculty (1960).

Every beginning is difficult. First study programmes ware created short while before courses start, at the end of summer holidays we did not know which subjects we shall study next week. First programmes copied these of faculty of mechanical engineering, some lectures ware commonly red. Initial four years of the studies were united, we were separated only in the last (fifth) year. Next specialisation was possible: spinning, weaving, knitting, textile finishing and clothing. How the specialisation and next employer was determined? It was simple. 41 graduates received from government 41 so called "placing billets" and the choice was over, job selection was done by central organs.

Science and research are the basic activities of any university. What was the situation in the initial years of our faculty life? Simply something schizophrenic. Government and communist party ordered to each teacher 500 hours of the science a year. First two professors of the faculty, Jaroslav Simon a František Pompe, have not reached any scientific degree in all their life. Nevertheless some enthusiasts searched into textile problems, carried out some research and development, whereas some others more or less successfully pretended these activities and put them into statements. Nevertheless textile science started to take root in Liberec.

M2. Normalisation (1969–1989).

The first real, deep and long crises started in 1969, short after Warsaw pact invasion. Not crises in conception of official documents of Communist party, but crisis of morality, of truth, personal crisis. The substantial part of the best teachers had to leave the university and the most of them was not allowed to be employed in any qualified occupation. For example Prof. Ing. Zdeněk Kovář, CSc., rector of the university from 1991 to 1996, could not go on teaching and his job for about ten years was: lorry driver. There were tens of the fates like this. It was almost miracle that the faculty managed to live somehow even in this period and quality of teaching and research was not as bed as the conditions.

In the years of deep normalisation (1969-1971) the situation on our university was may be yet worse then in other institutions. Some not too able persons and careerists felt and used their chance. Good luck was that for some others the job of university teacher was as well a hobby and that they did not allowed complete faculty destruction.

Typical evidence of moral degeneration is, for example, the fact, that the great majoity of educated people as flock of sheep signed the protest against the document they was not allowed to read. Of course it was well known "Chart 77".

M3. Reorganisation (from 1960, never ending activity).

To put reorganisation anywhere on the time axis is impossible as the process of changes cannot be interrupted. It is in the Czech nature to love change, especially if this change is not too deep and if it is realised by another people. The most of our changes was reorganisation of department structure and study programmes. The only real great change was enabled by our "velvet revolution", which brought to the faculty autonomy till this time unknown.

M4. Liberalisation (from November 1989).

An attempt to set a past wrong doings right was great, the success was only partial. Some of the "punished without trial" teachers came back, they can quickly get the degrees they were worth of, but for some of them 20 lost years was too much to start again.

One of the students revolutionary demands was return to 5 years M. Sc. study courses. It was not problem for university management to meet this demand, because previous shortening of the studies was against their opinion and against healthy reason as well.

After our revolution the students woke up and started to be very active, they were even able to fight for their opinion. Some two or three years later they fall again into deep sleeping and started to deal only with studies and their other usual daily problems. From some point of view it is natural, but the share of social activities of our students should be higher.

Faculty management and all the teachers were aware of possible problems, connected with losing of the eastern marked and with far east countries competition in the textile branch. The impact on our textile and clothing companies was really great. The response of our faculty was large diversification of the study programmes. Some till this time quite new bachelors programmes was created, form example Textile and fashion design and Textile marketing. In M. Sc. programmes the stress was put on advanced technologies, very perspective technical textiles, knowledge about the structure and properties of textiles etc.

PROBLEMS (contemporary and eternal)

P1. Money.

The majority of problems is based on economy. The occupation of university teacher is not too attractive, good graduates can easily find much better paid job. To save up money for little house or flat from teacher's income is mere vision and not each young girl or boy have to their disposal rich parents.

Labs equipment is rather better then ten years ago but still far from being the best. Our government is giving to university smaller part of smaller state budget that it is usual in advanced countries. The situation was acceptable till 1996, when came restrictions connected with the problems of our economy caused by bad governing of our country.

We probably did not fully realised that the way to prosperity leads only through education. Saving on education means to borrow money from the next generations. As well an approach to other financial resources is limited. For example GAČR (Grant agency of Czech Republic) has not textile in the list of branches, other agencies has wide range of different priorities but not textile etc. Sometimes it is possible to listen to opinion that there in nothing like textile science. The true is, that the exact description of very complicated textile processes and textile structures is as well very complicated and this is why the textile science is comparatively young.

P2. All other problems can be transferred on P1.

Not all graduates from our faculty work in the textile branch. From one point of view we can be proud of their ability to be successful at a very wide range of professions, from another we feel pity that some share of knowledge is not used. On our faculty there is approx. 75% girl students. That is no wander that they have for their further life other priorities then is branch of the study. Nevertheless education with large adaptability of graduates is modern and probably the only way to the future. Development of sciences and technologies is too quick and human life too long, re-qualification will be necessary.

One of the problems is dislike of many graduates to work as industrial managers. In the both social formations (socialist and capitalist) majority of students prefer peaceful and tranquil occupation.

ACHIEVEMENTS

It is not popular to praise ourselves and it is not good strategy to undervalue our home institution. This paragraph should therefor mainly to state the objective facts.

Faculty of textile engineering has succeeded in her main goal to educate experts of both M. Sc. and Ph. D. level for textile industry, research institution, technical secondary schools etc. on the territory if Czech and Slovak republics. Many of graduates comes from another counties, which were chosen with respect to current political situation. It was for example Korea, Vietnam, Mongolia, Cuba, some of Africa countries and of course other European socialist countries.

Many of our graduates took the possibility to reach simultaneously technical and pedagogical education (now on our Faculty of Education), in last almost ten years they can receive with technical M. Sc. (Ing.) diploma as well bachelor diploma in economics thanks to a special courses provided by our Faculty of Economy.

All her life faculty used to co-operate with textile faculties abroad. Of course, after 1989 there was a rapid movement to the west Europe, USA etc. After opening of the frontiers we started to travel and became known even behind the border of former RVHP. Soon we received accreditation of M.Sc. courses by The Textile Institute Manchester, world wide association of textile producers, universities and other institutions. Now we have full accreditation of all graduate courses. We belong as well among faculties, accredited by FEANI (European Association of Engineering Universities) and each our graduate with some praxes can receive degree of Euro-Ing, valid in all EU states. We are as well active member of AUTEX (Association of Textile Universities in Europe), Textile Academy etc.

Faculty organises each 2 or 3 years world wide conference "Textile Science", this year forth one. From the very beginning (1991) the participants from all over the world are coming to Liberec to transfer the latest knowledge.

Faculty appreciates the best specialists in the textile branch as well by awarding them the degree of "dr. honoris causa". This year it will be Prof. S. Batra (USA), Prof. A. Hamza (Egypt) and Prof. J. Kurz (BRD).

MAIN GOALS

In brief: how we see the future? As the behaviour of the faculty has been since 1989 rational, no other revolution is necessary. The only one exception may be connected with preparation of our admission to European Union. It is probably necessary change on the serial system of bachelor ® master courses. The faculty is well prepared for it. Our M. Sc. courses are divided into two parts. First (base studies) can be transferred to bachelor studies, second (branch studies) will provide M. Sc. degree. As well we have some experience with credit system.

It will be necessary to improve efficiency of our studies and to enlarge the space for scientific and other creative work of our teachers. Possible way can be reduction and more effective forms of the direct teaching hours with stress being put on self education, larger students projects, greater participation of students on departments activities etc. Reduction of number of subjects would be useful as well.

We hope that after bad years of our economy we can wait a better period and that it will become realistic vision to employ the best of the best as an university teachers. We hope that one of our future governments will have development of education as real priority, not only as a part of the program before elections. We hope that each citizen of Czech Republic will have the real right to be enrolled into university he has chosen and to prove if he/she is able to complete the studies.

What is the challenge of modern university, what change of its students should happen during studies? Surely not to change them into walking (or car driving) encyclopaedias. The amount of human knowledge increases quicker than the brain capacity. In addition to it the modern information technologies are able to connect everybody with the resource of information at any place and any time. The matter is to develop ability to use information, to become creative, to understand problems and context, to be able to communicate, to have opinion etc. We are still far from this vision. It is good luck for diligent people, we have enough to do in the next years.

Survey of the degrees, given by the Faculty of textile engineering:

Faculty keeps the rights (accreditation) to confer all main academic degrees, such as bachelor (Bc., equivalent of B. Cs.), engineer (Ing. or M. Sc.), doctor (dr. or Ph. D., previous equivalent C. Sc.) and can administrate appointing of associated (Czech abbreviation Doc.) or full professors (Prof.).

DYNAMIC ANALYSIS OF RING SPINNING: A BRIEF REVIEW[1]

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Dedication: This paper is dedicated to Professors Stanley Backer (MIT), Edward R. Schwarz (MIT), Frederick F. Ling (RPI), Edward A. Fox (RPI) and Mishu I. Zeidman (Israel Fiber Institute) who influenced and shaped my (SKB) analytical faculties and the ability to choose doable, yet meaningful problems.

INTRODUCTION

The ring spinning process has been and remains a critical final step in the formation of yarns from staple fibers. The world wide use of ring spindles is illustrated in Table 1. In 1881 [1], roughly 50 years after its invention by John Thorpe [2], ring spinning may perhaps be the first textile process to have attracted analytical attention by physicists and engineers of the day. Since then the need for analysis has been motivated by the recognition, among other things, that: 1. Spinning tension is critical to "fiber migration" during twist insertion, for it develops structure responsible for consequent yarn tensile strength. 2. Until the yarn is wound onto the bobbin, spinning tension must not exceed the local yarn strength. 3. Power consumption by the machine need be optimized to make the process commercially viable. Etc.

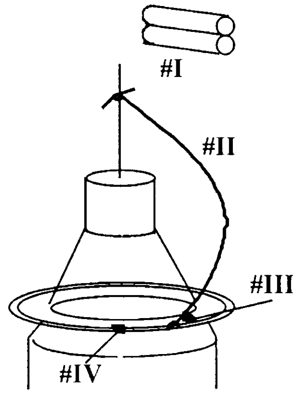

Fig 1. Figure of a ring spindle without balloon control ring. Four distinct segments: (1) The yarn from roller nip to guide eye, (2) The yarn between guide eye and the traveler, (3) The yarn through the traveler, (4) The yarn between the traveler and the package. The balloon in region II is a response to rotation of the package

This paper attempts to review some of the key analyses since 1881 and discusses some of the more recent results and their implications in the context of the process visualized in the Figure 1.

REVIEW

The published work in this area can be divided into three distinct epochs:

Epoch 1 (1880–1950)

Much of what we know about the work done during this period comes from the excellent review by Professor E. Honegger (ETH, Zurich, Switzerland) and Mr. A. Fehr (Brown-Boveri & Co., Baden, Switzerland) [3]. According to them, Luedicke, A., [1] in his quest to understand the process recognized the importance of the coefficient of friction, $m_{R\text{-}T}$, between the ring and the traveler. His measurements suggested a relationship of the form: $m_{R\text{-}T}$ = 0.65 –

Table 1. WORLD SPINNING QUIPMENT (x1000)

	Installed 1997			Cumulative Shipments (10 years)			Shipments		
	Short	Long	Rotor	Short	Long	Rotor	Short	Long	Rotor
AFRICA	7765	240	190	916.14	128.38	70.61	40.03	3.53	4
AMERICA NORTH	9416	913	1082	1656.4	167.34	817	272	29	52
AMERICA SOUTH	10780	696	400.5	1438.9	100.9	198.8	106	1.15	19.58
ASIA & OCEANA	116681	7415	2151.8	22946	1759	753.7	1403.3	38.27	36.55
EUROPE – EAST	10603	1467	2876.6	1899	543.96	981.1	25.30	6.68	10.4
EUROPE – WEST	6256	5010	563.9	2527	932.8	369.9	161.21	64.46	36.9
EUROPE – OTHERS	5382	743	388	2658.3	296.7	371.7	343.98	16.18	24.05
WORLD	166883	16484	7653.8	34497	3942.5	3587.65	2351.88	159.4	182.51

Source: ITMF (1998) Some numbers have been rounded off.

0.00005n, where n is the traveler rotational speed, 5,000–8, 000 rpm in those days. A few years later, Escher [4] "made an attempt to develop a comprehensive, mathematical theory of ring spinning, neglecting only the air resistance ...[3]" "... calculation of the shape of the balloon led to an elliptic integral which remained unsolved [3]." In addition [3], Escher determined experimentally that tension in the yarn at the bottom of the balloon is about half the thread tension between traveler and the bobbin. This accounted for the influence of friction between yarn and traveler.

Honegger and Fehr [3] reported observations made by Brown-Boveri & Co. (precursor of the modern ABB, Inc.) engineers during 1907/1908. Using ex-

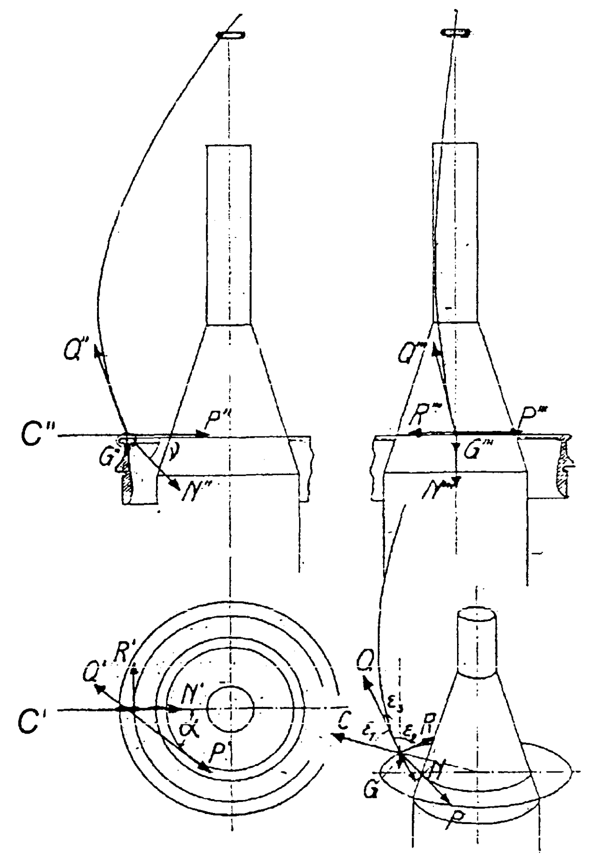

Fig. 2. Figure showing force analysis from Honegger and Fehr [3]

act photographic shape of the balloon, mass linear density of the thread, its rotational speed and "radial load due to centrifugal forces" acting on the balloon was calculated. Yarn tension (distribution) in the balloon was then calculated using graphical methods. The results showed that the smallest thread tension was associated with the largest diameter of the balloon. The higher spinning tension resulted in contraction of the balloon to nearly a cone. Also, the highest spinning tension occurred at the upper part of the ring rail traverse when winding onto the smallest bobbin diameter.

"In order to avoid the variation of the thread tension, Brown-Boveri successfully introduced spinning frame motors of which the speed was varied automatically. The ring spinning drive had been proposed earlier but the mechanical laws governing the process were made clear only by the experiments mentioned above." The claimed advantages were: "the thread is spun under constant tension and becomes more uniform, ... the output ... is increased by 10 to 15 per cent."

In 1910, Lindner [5] solved the "differential equation of the balloon" by assuming that mass of the yarn in the balloon is proportional to balloon height instead of balloon length (dz = ds). The consequent error was negligible because the balloons due to spindle rotational speeds of those days were slender. As a result the balloon assumed a sine function shape with maximum radius as amplitude.

Twenty three years later, Meister in 1933 [6], using dynamometer spindle measurements, concluded that "thread tension varied during each cycle of the ring rail movement in the ratio of 1 : 2; with progressive filling of the bobbin, i. e. decreasing length of the balloon, the lower thread tension decreases while the higher thread tension increase." For the thread tensions before, Q, and after, P, the traveler, he derived the empirical relationship:

$$P = Q(2.3 - 1.5 \sin.a) \quad \text{(see Fig. 2)}$$

He further observed that "absolute value of the thread tension" goes up linearly with traveler mass and square of the spindle speed, "in agreement with theory." And, for unlubricated traveler the coefficient of friction $m_{R\text{-}T}$ can be shown to be (and in "good agreement" with the results of Luedicke)

$$m_{R\text{-}T} = 0.8 - 0.003v_T + 0.00025\, v_T^2,$$

where v_T is traveler linear speed (m/sec).

The measurement of $m_{R\text{-}T}$ seemed to attract attention of others as well. Honegger in 1935 [7], curiously, obtained measured values as 0.091–0.1 while spinning cotton, and as 0.2–0.25 while spinning rayon, at 7,000 rpm spindle speed.

The focus up to this stage was on understanding dynamics of the yarn balloon in the absence of air drag (justifiable at the low spindle speeds of the day), establishing a relationship between thread tension before and after the traveler, and measurement of the ring to traveler coefficient of friction. Some key elements, as we shall see, of the ring spinning dynamics were missing.

Epoch 2 (1950–1980)

During 1950s, to improve productivity of the process, machine builders began considering design of machines for larger diameter bobbins, which rekindled an interest in theory of ring spinning.

On the academic end, in early 1950s, Hannah [8, 9] developed analyses for cap spinning, related to ring spinning in many of its features. She assumed uniform, flexible yarn and accounted for centripetal acceleration and air drag (simplified). Further, assuming slender balloons ($dz \sim ds$) she obtained the following balloon Equations of Motion (EoM):

$$-mw^2x = \frac{d}{dz}\left(T\frac{dx}{ds}\right) + Pw^2ry,$$
$$-mw^2y = \frac{d}{dz}\left(T\frac{dy}{ds}\right) + Pw^2rx, \text{and}$$
$$0 = \frac{d}{dz}\left(T\frac{dz}{ds}\right),$$

where m is mass linear density, r local radius of the balloon with x, y coordinates, w angular velocity of the balloon and P is the air drag coefficient. How she solves these equations and the boundary conditions used is difficult to determine from her papers.

In 1953, Crank [10] tried to formulate the same problem for cap/ring spinning. He assumed flexible, uniform yarns and included air drag, centripetal, Coriolis and gravitational accelerations. The air drag coefficient was assumed independent of radius of the balloon and the air drag force was assumed proportional to square of circumferential velocity. The quasi-stationary case EoM were:

Error! + **Error!** + $2mwv$**Error!** + $mw^2x = 0$
Error! + **Error!** + $2mwv$**Error!** + $mw^2y = 0$
Error! + $mg = 0$
$T_1 = T - mv^2$,

where v is the winding speed of the yarn and f relates to air drag but was left undefined; neither were the boundary conditions stated. Using a „Differential Analyzer," he showed that for assumed values of spinning tension at the guide eye, shape of the balloons for cap spinning can be calculated, and for low values of spinning tension it is possible to get collapsed balloons which would lick the cap; he also showed that presence of air drag makes the yarn path in the balloon bend out of plane. It is unclear how he used the inextensibility condition. For the case of ring spinning he seems to be the first to develop correct EoM of traveler, although he did not use them to solve the problem in any way. He did recognize its importance in determining the correct balloon shape for specified spinning tension.

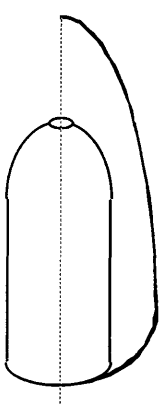

Fig. 3. Cap Spinning

About the same time Mack [11] published a similar formulation of the EoM of the balloon excluding Coriolis and gravitational acceleration. He introduced the inextensibility condition (**Error!**)^2+(**Error!**)^2+ (**Error!**)^2 = 1 and introduced the scaling length, $t = (T_0/w^2m)^{1/2}$ for non-dimensionalization of the equations. While he suggested the use of Runge-Kutta method to solve the differential equations, he neither formulated any boundary conditions nor obtained any solutions. Mack and Smart [12] made some useful measurements of the air drag force on yarn held across a moving air stream and compared them to what would be obtained from the empirical formulations for smooth cylinders found in the fluid mechanics textbooks. Mack's [13] later attempt at the problem did not provide any additional useful insights.

On the industrial end, larger diameter and taller bobbins meant "long lift spinning." This generated considerable interest in understanding the theory of ring spinning even among machine designers. In this milieu, Grishin, an émigré to the US from Russia, made a big impact through the publication of a five part series [14–18] that looked at the problem seemingly comprehensively. He formulated EoM of the balloon including air drag, Coriolis acceleration and the centripetal acceleration. He also suggested a connection between forces acting on the traveler, shape of the balloon and tension in the yarn. And finally, he appears to be the first to deal with analysis of the collapsing balloon.

Further, Grishin [16] devoted part of his attention to the problem of controlled balloon. He realized that the mathematical treatment for controlled balloon is more difficult than that for free balloon. He tried to expand his semi-empirical method for free balloon introduced in his previous papers [14, 15] to deal with the problem of controlled balloon by additional simplifications and modifications; he basically treated balloon segments separated by control ring(s) as individual and independent free balloons. The calculated results so obtained were not consistent with his experimental observations. His experimental results in general were consistent with what were independently reported in Bracewell and Greenhalgh's experiments [19].

Grishin in his analysis used unorthodox methods sometimes mysterious and difficult to follow. He used what might be called "engineering approximation" approach of the time, using Lindner's solution for zero air drag case as the fundamental frame of reference for his solution. The strength of his contributions lay in the fact that he offered many "approximate" but simple formulas to calculate parameters useful to machine designers. His formulation of air drag force, traveler dynamics, effect of balloon control rings were at least somewhat questionable, if not wrong. The principal value of his contribution lies in bringing together all physical effects into consideration

The interest in analysis of the ring spinning problem was not limited to U.K. and U.S.A. alone. Capello, in 1958 [20, 21] published the Italian perspective. He obtained shapes of the balloons for different yarns and spinning conditions through an ingenious experimental procedure using two cameras viewing the balloon at right angle relative to each other. His stroboscopic images were excellent. Unfortunately, he limited himself to very slow spindle speed (less than 9,000 rpm). The logic of his analysis of the images and his subsequent simplified equations for shape of the balloon [21] are difficult to understand in terms of physical nature of the problem. He seems to suggest, it is possible to calculate air drag force at every point of the yarn from the two projection images of the balloon, for the specific yarn and machine parameters; the process is somewhat unclear. His results suggest that air drag force is proportional to yarn diameter (average) and square of velocity of the element in the balloon. His equations of motion to determine shape of the balloon [21] are given without adequate justification.

To obtain shape of the balloon, including the effect of air drag, Capello first obtains shape of the balloon without the influence of air drag but assuming the balloon to be slender (Lindner's sinusoidal solution). This shape is then used to calculate the circumferential velocity of the yarn elements, assuming the velocity square law and that the air drag acts in the circumferential plane. This leads to trigonometric expressions for distorted shape of the balloon (due to air drag) linearly superposed over the sinusoidal solution. The solution contains constants of integration to be determined through the use of "boundary conditions." The boundary conditions are not specified. Finally, it must be pointed out that shape of the balloon is dependent on the spinning tension assumed known. Capello sees no role for traveler dynamics in the analysis to determine shape of the balloon.

Working in parallel with Capello, De Barr, published several papers [22–24] which might be described as "descriptive account of yarn tensions and balloon shapes in ring spinning." Sadly though, he promoted the view that spinning yarn balloon is minor modification of a circularly polarized vibrating string unaffected by air drag and Coriolis acceleration [22]. This view, also shared by a few others, was most unfortunate and resulted from their inability to integrate properly the role of the traveler and that of the air drag. De Barr uses the EoM of the traveler, developed by Honegger and Fehr [3] to make estimates of the influence of yarn and process parameters, such as frictional coefficients between yarn-and-traveler as well as traveler-and-ring, bobbin radius, etc., on spinning tension. De Barr also used some results derived by Mack [11] to study the influence of air drag on the spinning balloon. To justify his approach, De Barr stated [22]: "A complete treatment of the problem is necessarily complicated and involves much mathematical ingenuity. In consequence, although fairly complete theoretical accounts of most aspects of the problem are now available, their completeness makes it difficult to form a satisfactory picture of the mechanisms involved." As a result, despite the asserted completeness, he comes up with "rules of thumb" only. For example [22]: "it is also evident that the rate of increase of tension as a (angle between ring radius at traveler location and tangent connecting wind-on point to the traveler) decreases below, say 40, increases rapidly as the coefficient of friction between traveler and the ring increases." "... with the larger values of *m*, the tension passes through a minimum as a increases" from its value at winding on empty to full bobbin. "Thus the minimum tension may be obtained when winding on to a diameter" less than that of the full bobbin.

The formulae he developed, or borrowed, do not seem to yield a prediction of spinning tension during bobbin formation for a given set of yarn and operating parameters. They do in some cases, however, lend credence to the observed variations of spinning tension or balloon shapes. His approach is similar to that of Grishin; he too makes the problem linear through numerous plausible simplifications and assumes either the spinning tension or the balloon shape to be known in order to predict the other through superposition of separate effects.

The parallel activity in Japan is represented by an excellent experimental study by Musha [25] who concluded that:

"(1) The variable speed drive of spindles is useful for reducing the tension variation for chases in which the winding angle varies during the vertical motion of the ring rail. It is possible to keep tension uniform if the speed of the spindle is properly adjusted with consideration given to the balloon height and the winding angle, and if the balloon control ring is fixed.

(2) The smaller the winding angle, the larger the spinning tension. A winding angle smaller than 23 degrees is undesirable.

(3) Use of antinode ring reduces the spinning tension level by an average of 15% and the variation in the spinning tension by 50%. The position of the control ring should be at 40–50% from the bottom of the balloon. A control ring of equal radius with the spinning ring can be used with satisfactory results.

(4) The variation in spinning tension can be reduced by proper vertical motion."

Note that these experiments were carried out using spindle speeds less than 9,000 rpm.

During 1970s, Migushov published a series of papers, some translated into English [26, 27] others in Russian [28–30], attempting to understand the ring spinning problem analytically as well as experimentally. He acknowledged only the previous work of Mack and Smart [12] conveying thereby his "independent" approach. His first analytical treatment deals with equilibrium of the quasi-stationary balloon including the effect of air drag, gravitational and Coriolis accelerations; the formulation is rigorous and elegant [26]. Both air drag along and across the yarn are considered. The equations of motion appear to have been formulated in a moving cylindrical polar coordinate system. Migushov uses $T_1=T - mu^2$ (m = m, u = v) as the general tension parameter, reminiscent of Crank [10]. Very ingeniously, he is able to partially integrate the equations to show that tension distribution along the balloon can be predicted, provided shape of the balloon, spinning tension and coefficient of air drag along the yarn are known. The results suggest that tension distribution in the balloon is directly affected by the coefficient of air drag, along the yarn path, and only indirectly, through the balloon shape, by the coefficient of air drag across the yarn; the influence of the weight of the yarn on its tension is negligibly small. Then he claims his equations are suitable for solving a variety of practical problems in textile technology, even though he does not give solution for the shape of the balloon.

In his follow up attempt, Migushov [27] makes an effort to solve the EoM derived in his previous paper [26] by neglecting air drag and gravity but including the effect of Coriolis acceleration. The closed form solutions obtained show that shape of the balloon can be determined, with the help of the inextensibility condition, provided spinning tension and balloon angle to the axis at the guide eye are known. Similarly, if shape of the balloon is known the tension distribution in the balloon can be predicted in terms of spinning tension and shape related parameters. Far more intriguing, though, Migushov shows that Coriolis acceleration tends to distort the balloon out of plane into a spiral and the degree of distortion is directly proportional to product of the yarn rotational speed and its speed of throughput. This is the first time, and perhaps, the only time the effect of Coriolis acceleration has been elucidated thus.

Migushov's later publications [28-30], formulate the EoM of a ballooning yarn in balloon twisting or axial unwinding from packages where non-steady state dominates the phenomenon and includes the effect of air drag and Coriolis acceleration. To the best of reviewers' ability, it does appear that in its application to ring spinning traveler dynamics is not brought into consideration at all and the method still remains semi-empirical-semi-analytical. The contribution of these papers is best summed up by the "abstracts" given in the World Textile Abstracts: "A mathematical analysis is given."(1975/9465), or "A mathematical analysis is presented. Equations are derived which make it possible to determine the parameters corresponding to changes in the balloon ratio."(1976/1960)

Thus Migushov, too, falls into the same conceptual trap as did all previous investigators: namely, you can calculate shape of the balloon and tension distribution in the yarn for a specific set of operating conditions without paying attention to dynamic equilibrium of the traveler. In this framework, if shape of the balloon is "measured" experimentally, the tension distribution can be predicted, or vice-versa. The argument is perfectly valid, because either of the two experimental measurements automatically takes the traveler dynamic equilibrium into account and the latter is controlled by mass of the traveler selected, coefficient of friction between yarn and traveler and coefficient of friction between traveler and ring. Thus even if such a semi-empirical-semi-theoretical approach is practically useful, the physics of this dynamic remains to be fully understood.

Epoch 3 (1980–??)

Before 1980's, the solution of the EoM of the ring spinning balloon was often looked at as an initial value problem independent of the dynamic equilibrium of the traveler. Those few who recognized their interdependence were unable to do much about it. Lisini , Nerli and Rissone [31] resurrected the idea of interdependence in the context of two-for-one twisting, and proposed a rudimentary methodology to solve the two point boundary value problem using "finite segment" (equivalent to finite difference or one dimensional finite element) approach.

Nerli [32, 33] used this methodology in the context of ring spinning; the procedure consisted of dividing the length of yarn in the balloon into small segments of equal length joined by completely flexible nodes. The forces acting on a segment length are then concentrated on the subsequent node. The direction of the segment is determined by the need to equilibrate the forces. The forces considered are those due to differential tension at two ends of the segment, air drag forces across and along the segment, dynamic force due to Coriolis acceleration, dynamic force due to centripetal acceleration, and inertial force due to relative motion along the curvature of the balloon. The last one is a bit mysterious.

To start the solution process, the angle of inclination of the balloon at the guide eye is first assumed. To arrive at the ring radius in the final segment, for a given balloon height, the value of angle of inclination at the guide eye is adjusted, iteratively. The next step is to establish the dynamic equilibrium of the traveler by using the direction and magnitude of the tension in the balloon at the ring. This equation of

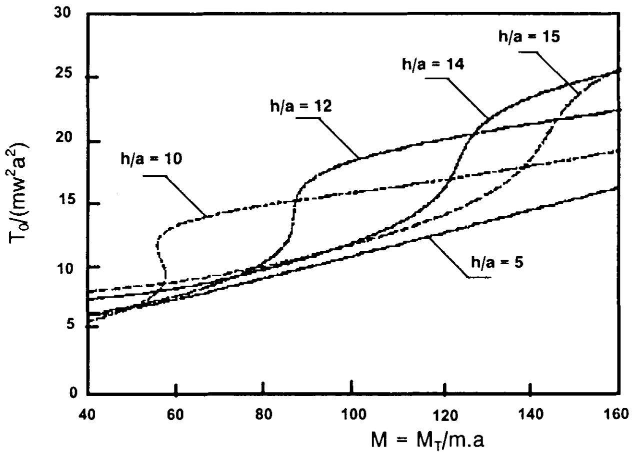

Fig. 4. Tension variations for changing traveler mass and balloon heights. [37]

equilibrium is used to predict the required coefficient of friction between the ring and the traveler. If this value is different from the specified "real" value, the whole process is repeated until the specified frictional coefficient is arrived at.

While accuracy and robustness of Nerli's method, in the light of nonlinearity of the problem, is in doubt, it is to Nerli's credit that he recognized the need to satisfy dynamic equilibrium of the traveler to arrive at the correct solution for tension distribution and shape of the balloon.

Unaware of Nerli's work, in 1989 Batra, Ghosh and Zeidman [34, 35] at NCSU developed an integrated approach to solving the two-point boundary value problem (BVP) for the quasi-stationary case of dynamics of ring spinning, numerically. This scheme allowed calculating spinning tension as well as the balloon shape for a specified count, traveler mass, traveler rotational speed, balloon height, coefficient of friction between yarn and traveler, and the coefficient of friction between traveler and the ring. It was possible to show that collapsed balloons were plausible for tall balloons and low traveler mass. It was also possible to show why in practice at the start of the process the base of the bobbins had to be built at spindle speeds lower than that used subsequently.

In 1990, W. Barrie Fraser of the U. Sydney, Australia, began to collaborate with the NCSU group to solve the problem of over-end unwinding from cylindrical packages [36]. In 1993, he looked at the ring spinning problem as well and confirmed the results obtained by Batra, *et al.* [34,35]; his formulation and symbols are briefly described in the Appendix. In addition, Fraser showed that relationship of normalized spinning tension ($T_0/(m\omega^2a^2)$) to normalized traveler mass ($M = m_T/(ma)$) for fixed values of bobbin wind-point radius (b/a), air drag coefficient (p_0), yarn-traveler friction parameter ($\exp(m_Y a)$), traveler-ring friction coefficient (m_T), and balloon height (h/a) exhibited s-shaped regions of the form shown in Fig. 4. Note that the relationship is also dependent of values of h/a and that the s-shaped region gets accentuated at smaller values of the traveler mass. More to the point, for traveler mass values corresponding to the s-shaped regions there exists the possibility of two or three different balloon shapes corresponding to two or three different spinning tensions which sustain them. That is, these shapes and their corresponding tensions could be *meta-stable*.

Fraser further showed that for a fixed traveler mass (M = 150 in non-dimensional terms), the spinning tension nearly doubles, as chase of the bobbin is formed from a full bobbin radius (b/a = 0.9) to empty bobbin radius (b/a = 0.3). And, correspondingly, as the chase height varies from ten ring radii (10a) to eight ring radii (8a), see Fig. 5.

These observations led to the conclusion that, mathematically, a discussion of the behavior of the solutions of ring spinning system must be set in the context of the *bifurcation* theory [38]. According to Golubitsky and Schaeffer [38], "...*bifurcation* theory is the study of equations with multiple solutions. Specifically, by a *bifurcation* we mean a change in the number of solutions of an equation as a parameter varies." Thus to validate the theoretical model using some specially generated experimental data and to derive practically useful information, Batra *et al.* [39] recast the bifurcation problem to seek spinning tension as a function of the other parameters of the problem; That is,

$$T_0 = ma^2w^2\,\mathrm{f}\,(M, h/a, b/a, m_T, m_Y, p_0)$$

Details of the experiments can be found in [39]. Suffice to say, experiments were conducted to measure balloon shapes for a fixed height balloon while building the bobbin chase by chase. For three different traveler mass cases the bifurcation analyses suggested the spinning tension vs. normalized wind radius as shown in Fig. 6. Note that the spinning tension decreases monotonically as the yarn is wound from empty to full bobbin for traveler mass M = 115.5, 105.6. But for M = 87 the spinning tension can assume multiple values (2 or 3) in the wind radius range of 0.64–0.72; beyond 0.72 the tension drops dramatically. Thus, it turns out that in the *b/a* = 0.64–072 range there is inherent instability in the process; the balloon can flip between a "single loop" to collapsed "multiple loop" balloon. In the region beyond 0.72 the multiple loop balloon is stable. This is borne out by experimental data shown in Figures 7. The calculations show the three possible balloon shapes corresponding to three different spinning tension values. The geometry of the multiple loop shape suggests that the collapsed node will hit the empty bobbin. The experimentally measured profile shows that it does. Theoretical calculations have verified several other experimentally measured

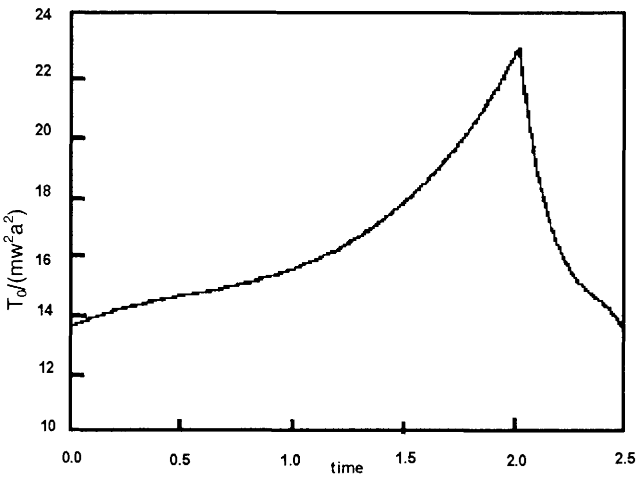

Fig. 5. Typical tension variation during chase formation. [37]

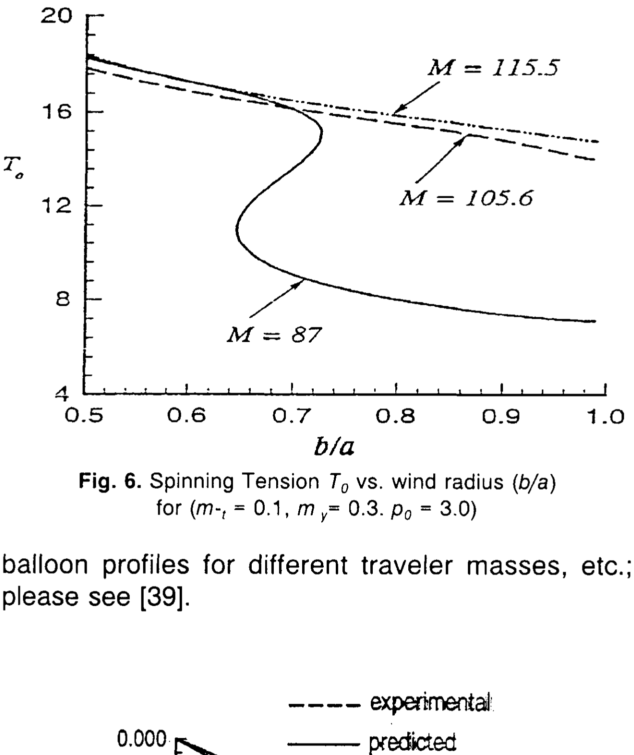

Fig. 6. Spinning Tension T_0 vs. wind radius (b/a) for (m_{-t} = 0.1, m_y= 0.3. p_0 = 3.0)

balloon profiles for different traveler masses, etc.; please see [39].

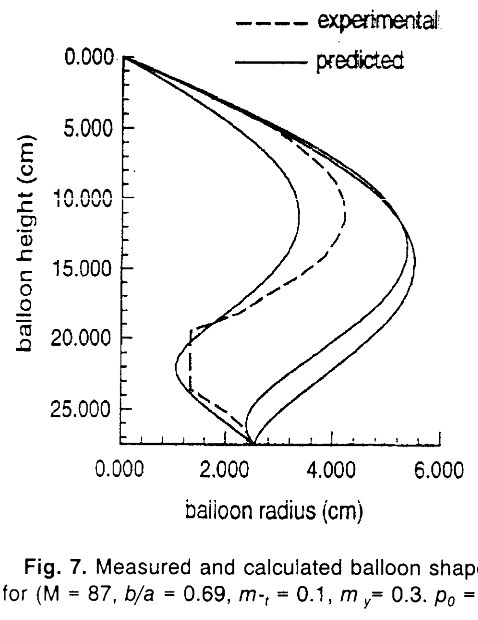

Fig. 7. Measured and calculated balloon shapes for (M = 87, b/a = 0.69, m_{-t} = 0.1, m_y= 0.3. p_0 = 3.0)

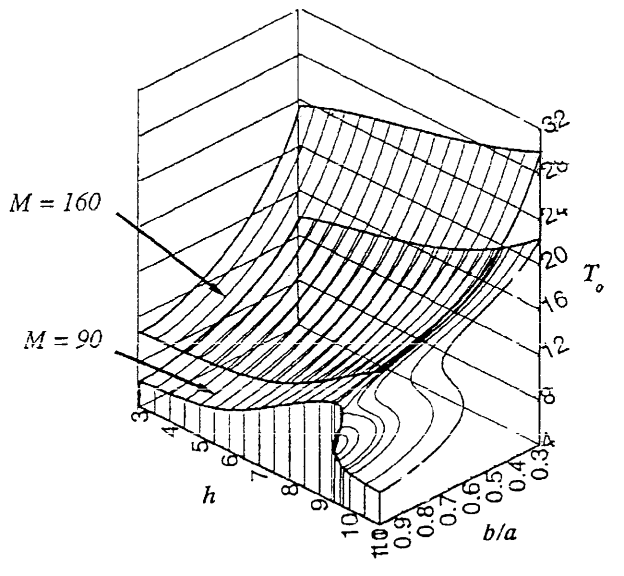

Fig. 8. Bifurcation curves for traveler mass M = 90 and 160 for (m_{-t} = 0.1, m_y= 0.3. p_0 = 3.0)

Extensive analyses have been carried out to produce solutions typified by Figure 9. Here bifurcation curves are shown for different values of balloon heights for two traveler masses M = 90 and 160. For the M = 90 case, the instability seems to exist for balloon heights greater than 9. For M = 160 no instabilities are anticipated in the range calculated.

These procedures have also been used to study the cases of controlled balloons as well, and will be reported elsewhere. Also, our colleagues in Australia have looked at several other issues, such as stability of the balloon in the presence of a slub in the yarn, twist propagation in the yarn, etc. These have been reported in the literature.

Acknowledgements

The authors are grateful for the support provided by the State of North Carolina and the National Textile Center over the years.

REFERENCES

1. Luedicke, A., Ein Studie Heber Ringspindle, *Dingler's Polytechnisches Journal,* 242, 334 (1881).
2. *Encyclopedia Brittanica*, on-line April 24, 2000.
3. Honneger, E. & Fehr, A., Effects of Accessory Influences on Ring Spinning of Cotton and Spun Rayon, *J. Text. Inst.*, 38, P353 (1947).
4. Escher, R. "Theorie der Ringspindel," *Der Civilengenieur*, 29, 448–487 (1883).
5. Lindner, G. "Ballonform, Fadenspannung und Lauferstellung an Ringspinnmachinen," *Leipziger Monatschrift fur Texti-Industrie pp. 213–216 (1910).*
6. Meister, E. "Erforschung des Spinnvorganges durch Messung der Fadenspannung," *VDI Jaournal* (1933).
7. Honneger, E. "Tests on Ring Spinning," *Melliand Textilberichte*, 16, pp. 333–339 (1935).
8. Hannah, M., Applications of a Theory of the Spinning Balloon (I), *J. Text. Inst.* 43, T519, (1952) (cap spinning)

9. Hannah, M., "Applications of a Theory of the Spinning Balloon (II)," *J. Text. Inst.* 46, T1, (1955) (cap spinning)
10. Crank, J., "A theoretical Investigation of Cap and Ring Spinning Systems," *Text. Res. J.* 23, 266 (1953).
11. Mack, C., Theoretical Study of Ring and Cap Spinning Balloon Curves (With and Without Air Drag), *JTI*, 44, T483 (1953).
12. Mack, C. & Smart, E., Measurements of the Air Drag of Textile Threads *J. Text. Inst.* 45, T348 (1954)
13. Mack, C., Theory of the Spinning Balloon, *Quart. J. Mech. of Appl. Math.* XI,Pt.2, 196 (1958)
14. Grishin, P. F., Balloon Control, Part I: General Theory of the Balloon, *Platt's Bull.* 8, 161 (1954)
15. Grishin, P. F., Balloon Control, Part II: General Theory of Yarn Tension, *Platt's Bull.* 8, 178 (1954)
16. Grishin, P. F., Balloon Control, Part III: Control of the Collapsing Balloon, *Platt's Bull.* 8, 240 (1954)
17. Grishin, P. F., Balloon Control, Part IV: Refinements of the Theory, *Platt's Bull.* 8, 333 (1954)
18. Grishin, P. F., Balloon Control, Part V: Application of the Theory, *Platt's Bull.* 8, 346 (1954)
19. Bracewell, G. M. & Greenhalgh, K., Controlled Balloon Spinning, *J. Text. Inst.* 45, T266 (1954)
20. Capello, A., The Spinning Balloon, Part I: An Experimental Determination of the Forces Acting in the Spinning Balloon, *J. Text. Inst.* 49, T566 (1958)
21. Capello, A., The Spinning Balloon, Part II: An approximate Solution of the Equations of the Spinning Balloon through Simplifications Suggested by Experimental Results, *J. Text. Inst.* 49, T579 (1958)
22. De Barr, A. E., A descriptive Account of Yarn Tensions and Balloon Shapes in Ring Spinning, *J. Text. Inst.* 49, T58 (1958)
23. De Barr, A. E., The Role of Air Drag in Ring Spinning, *J. Text. Inst.* 52, T126 (1961)
24. De Barr, A. E. & Catling, H., *The Principles and Theory of Ring Spinning, Manual of Cotton Spinning* (ed. F. Charnley & P. V. Harrison), vol. 5. Manchester and London: Butterworths Press (1965)
25. Musha, Toshimi, Spinning Tebsion on Ring Spinning Frame, *J. Text. Mach. Soc. Japan,* pp. 21-26, December (1957).
26. Migushov, I. I., The Dynamic Equilibrium of a Ballooning Yarn in a Resisting Medium, *Tech. of Text. Industry USSR*, English ed. No.4, 51 (1972)
27. Migushov, I. I., Analytical Solution of the Equilibrium of the Yarn Balloon with External Forces Left Out Of Account, *Tech. of Text. Industry USSR*, English ed. No.5, 38 (1972)
28. Migushov, I. I., Investigating the Non-steady-state Movement of Ballooning Yarn, *Tech. of Text. Industry USSR*, Russian ed. No.3 (106), 42 (1975)
29. Migushov, I. I., Boundary Value Problem of Stable and Quasi-stable Motion of a Ballooning Yarn, *Tech. of Text. Industry USSR*, Russian ed. No.5 (107), 66 (1975)
30. Migushov, I. I., Balloon Ratio and Unity of a Boundary Problem Solution for Steady-state and Quasi-State Motion of a Ballooning Yarn, *Tech. of Text. Industry USSR*, Russian ed. No.6 (108), 31 (1975)
31. Lisini, G. G., Nerli, G. & Rissone, P., Determination of Balloon Surface in Textiie Machines: A Finite Segment Approach, *ASME J. Eng. for Industry*, 103. 424 (1981)
32. Nerli, G. , Mechanical Behavior of Yarn in Certain Textile Manufacture, Part I: Introduction to the Problem and General Calculation Guide-Lines, *Text. Tech.* Dec. 56 (1984)
33. Nerli, G. , Mechanical Behavior of Yarn in Certain Textile Manufacture, Part II: Ring Spinning, *Text. Tech.* Sept. 36 (1985)
34. Batra, S. K., Ghosh, T. K. & Zeidman, M. I., An Integrated Approach to Dynamic Analysis of the Ring Spinning Process, Part I: Without Air Drag and Coriolis Acceleration, *Text. Res. J.* 59, 309 (1989)
35. Batra, S. K. , Ghosh, T. K. & Zeidman, M. I., An Integrated Approach to Dynamic Analysis of the Ring Spinning Process, Part II: With Air Drag, *Text. Res. J.* 59, 416 (1989)
36. Fraser, W. B., T. K. Ghosh, S. K. Batra,, "On Unwinding of Yarn from a Cylindrical Package," Proc. R. Soc. Lond. A 436, 479–498 (1992)
37. Fraser, W. B., On the Theory of Ring Spinning, *Phil. Trans. R. Soc. Lond.* vol 342, pp. 439–468 (1993).
38. Golubitsky, M., Schaeffer, D. G. , *Singularities and Groups in Bifurcation Theory,* Springer-Verlag, New York (1985)
39. Batra, S. K., Ghosh, T. K., Zeng, Q., Robert, K. Q., Fraser, W. B., "An Integrated Approach to Dynamic Analysis of the Ring Spinning Process, Part IV: Inherent Instability of the Free Balloon," *Text. Res. J.*, 65, 7,417–423 (1995).

Appendix (reproduced from [39])

The model assumed that: 1. The effect of gravitational, and Coriolis acceleration as insignificant, 2. The effect of tangential air drag as insignificant, 3. The coefficient of air drag normal to the yarn path was constant throughout the balloon length, 4. The air drag was proportional to square of the normal velocity component.

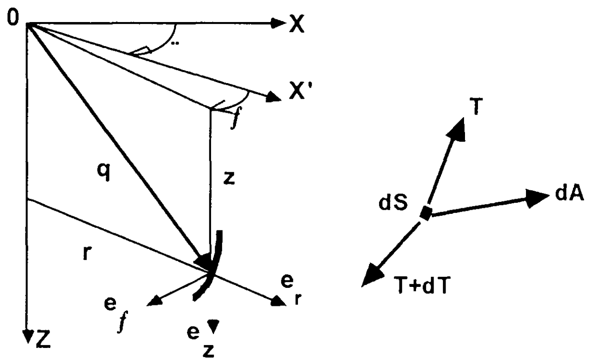

Fig. A 1 Inertial and Moving Reference Frames for Dynamic Analysis of Region II. Reference is made to Figures 1 and A.1, reproduced from Batra *et al*. [34]. In deriving the EoM, by Fraser [37] the following symbols were used: a – traveler-ring radius, b – bobbin wind radius, h – balloon height from guide-eye to ring, r – radius of an arbitrary point on the yarn balloon, z – vertical distance of the arbitrary point on the balloon from the guide eye, m_T – mass of the traveler, m – mass linear density of the formed yarn, m_T – coefficient of friction between traveler and the ring, m_Y – coefficient of friction between yarn and the traveler, a – angle of wrap of yarn around the traveler, s – yarn length of the balloon measured from guide-eye point as the origin, w – angular velocity of the traveler, **v** – linear velocity of the yarn in the balloon along the tangent vector, $\mathbf{v}_n$ – velocity of a yarn element along the normal vector, T – tension in the yarn, D_n – air drag related parameter of yarn in the balloon.

The following non-dimensional parameters are useful in the formulation of the problem:

$$\bar{s} = s/a,\ \bar{r} = r/a,\ \bar{z} = z/a\ \bar{\mathbf{v}} = \mathbf{v}/a,\ \bar{T} = T/(mw^2a^2),$$
$$\bar{\mathbf{R}} = \bar{r}\mathbf{e}_r + \bar{z}\mathbf{k},\ \bar{h} = h/a,\ M = m_T/(ma),\ p_0 = 16D_n(a/m),$$

$\bar{s}_l$ = non-dimensional length of yarn from guide-eye to the traveler.

The relevant non-dimensional differential equations describing the shape of the balloon are

$$\mathbf{k} \times (\mathbf{k} \times \bar{\mathbf{R}}) = \frac{d}{ds}\left(T\frac{d\mathbf{R}}{\mathbf{ds}}\right) + \mathbf{F},$$
$$\bar{\mathbf{F}} = -\frac{p_0}{16} / \bar{\mathbf{v}}_n / \bar{\mathbf{v}}_{n..}$$

The associated boundary conditions are:

$$\bar{r}(0) = 0,\ \bar{z}(0) = 0,\ \theta(0) = 0,\ \bar{z}(\bar{s}_l) = \bar{h},\ \bar{r}(s_l),\ r(s_l) = 1$$

and the EoM of the traveler at $s = s_l$.

THE PRESENT STATE OF DEVELOPMENT OF INTERFEROMETRY OF FIBROUS MATERIALS

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Key Words: Interferometric methods, Two-beam interference, Multiple-beam interference Fizeau interferometer, Pluta microscope, Refractive index, Textile fibres, Opto-mechanical, Opto-thermal properties of fibres, VAWI technique, Optical Fourier Transform.

Abstract: The present work describes the application of interferometric methods to determine the refractive indices and birefringence of textile fibres. It summarizes the different interferometric techniques used in fibre science. Opto-thermal and opto-mechanical properties of fibres are dealt with dynamically by interferometry. The obtained optical properties of fibres throw light upon their structure and other physical properties.

The recent advances in fibre interferometry are dealt with including the application of Optical Fourier Transform (OFT) and improving the accuracy of measurement. Illustrations are given using microinterferograms.

1. Introduction

Natural and synthetic fibres are composed of long chain molecules and have different structural elements. Textile fibres have a wide range of physical properties which are related to their structure. Most textile fibres are anisotropic materials as a result of fibre drawing. Interferometric methods were applied to determine the mean refractive indices and birefringence of these fibres. [1-12] These methods are; two-and multiple-beam interference techniques. Many techniques based on two-beam interference microscopy were used to study the optical properties of fibres. These techniques have many advantages in fibre investigation. Multiple-beam interference systems have the advantages that the fringe patterns are sharp and has a narrow width. So, measurements obtained are more accurate than in the case of two-beam interference.

Plane polarized monochromatic light vibrating parallel and perpendicular to the fibre axis are used to determine the refractive indices of both state of polarization $n^{\parallel}$, $n^{\perp}$, respectively,[12-22] which are used for investigating the molecular alignment with respect to the fibre axis.[13-16,19-22] Measurement of the changes in $n^{\parallel}$, $n^{\perp}$ and birefringence Δn due to mechanical drawing, thermal treatment and exposure to ionizing radiation throw light upon the changes in optical properties of treated textile fibres.

In this paper, a review of the modifications in the methods used to calculate refractive indices, birefringence,[6-8, 23] refractive index profile and material dispersion[9-11,24,25] in the University of Mansoura are dealt with. Moreover, the improvement in the accuracy of the measured optical and structural parameters have been studied.[9-11,26,27] Some instruments have been introduced in the field of fibre investigation [26,27] and also computer programs have been designed for automatic analysis of the microinterferograms.[28,29]

2. Interferometric Methods Applied to Determine the Optical Properties of Fibres

Both two- and multiple-beam interference methods are used extensively in the University of Mansoura to study the optical properties of textile fibres. These methods can be summarized as follows:

a) Two-beam microinterferometry

i) Pluta polarizing interference microscope[4,30]

It is a double refracting interference microscope with variable amounts and direction of wave front shear. It is capable of giving either the uniform or fringe interference fields with continuously variable amounts and direction of lateral image duplication. It can be used for both qualitative and quantitative examinations.

ii) Variable wavelength interference system (VAWI)

Pluta[31-33] presented this interferometric method which is based on the change in the interfringe spacing with wavelength. A continuous white light source (Halogen lamb) with continuous interference wedge filter are used to obtain a coincidence and anti-coincidence positions of the fringe shift inside the fibre with the air fringes. Pluta[28] automated his microscope to be suitable for variable wavelength automatic measurements. Figure (1) shows a schematic diagram of automatic VAWI Pluta interference microscope.[24, 28]

iii) Michelson interferometer

The Michelson interferometer is adjusted to obtain a

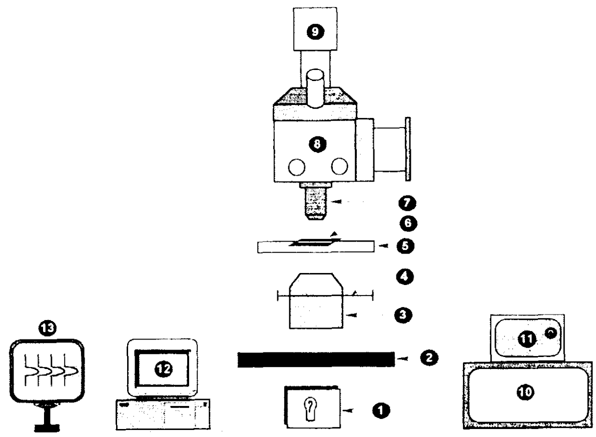


Fig.1 Schematic diagram of Automatic (VAWI) Pluta Microscope (From Ref. No. 28,24), where; 1-Halogen lamp(12V/l00W), 2-Continous interference filter, 3-Condenser, 4-Slit diaphragm knobs, 5-Microscope stage, 6-Sample (fibre), 7-Wollaston Objective lens, 8-Wollaston prism head, 9-CCD camera, 10-Stepper motor controller, 11-Halogen lamp Power supply, 12-PC computer and software display monitor, 13-Image display monitor.

straight parallel line fringes.[34] The examined fibre sample was mounted vertically in a cell containing a matching oil. An identical cell contains the same liquid was introduced in the other path ray. The produced interference pattern has been analyzed to obtain the refractive index profile of the fibre.

b) Multiple-beam microinterferometry.

i) Multiple-beam Fizeau Fringes in transmission and at reflection

Multiple-beam Interferometric methods were applied for the measurement of optical properties of fibrous materials.[1,3,5,12,35] The microinterferograms produced from these methods give valuable information about the optical properties of each point along the fibre radius.[9–11] Figure (2) shows; a) schematic diagram of the set-up of multiple-beam Fizeau system [5] and b) the produced microinterferogram at reflection crossing a Dralon fibre.[19]

ii) Fringes of Equal chromatic Order (FECO)

When a monochromatic light source is replaced by a (pointolite) white light source and adjusting the edge of the interference wedge to be parallel to the slit of the spectrograph, the white light fringes of equal chromatic order are obtained. As these fringes cross the fibre,

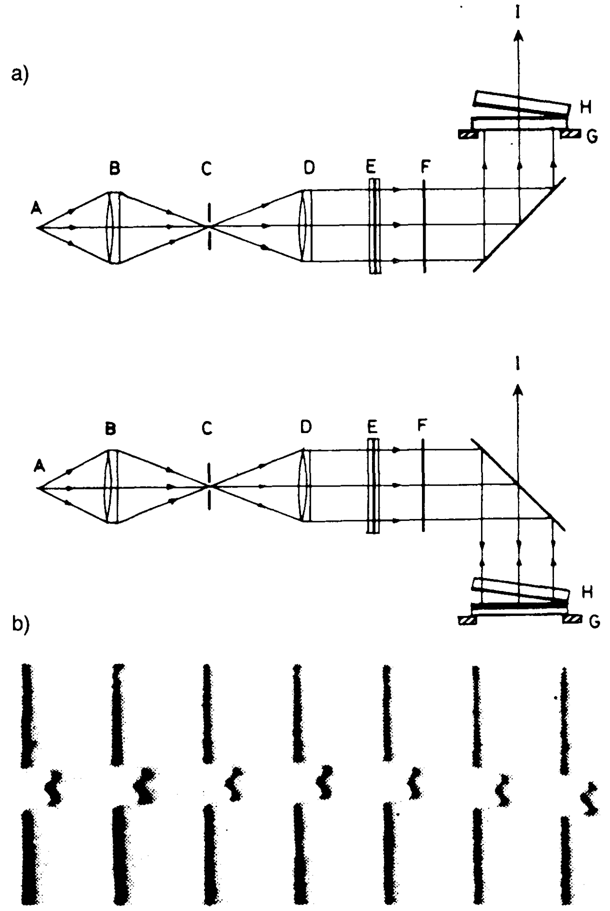


Fig. 2 a) The arrangement for producing multiple-beam Fizeau fringes in transmission (i) and at reflection (ii), respectively, (From Ref. No. 5). b) Multiple-beam Fizeau fringes at reflection crossing a Dralon fibre (From Ref. No. 19).

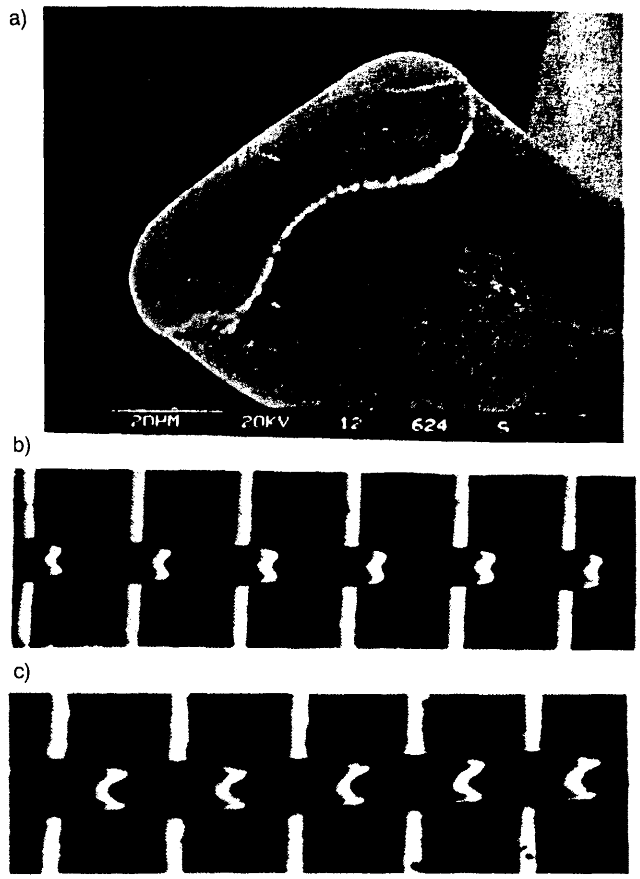


Fig. 3 a) Scanning electron micrograph of a transverse sectional view of a Dralon fibre and Multiple-beam Fizeau fringes in transmission crossing; b) unirradiated fibre, and c) a fibre irradiated with a dose = 28.896 Mrad (From Ref. No. 19).

their shift varies with the wavelength of light and with the direction of light vibration. [3,12]

Most of the above techniques are used frequently in the University of Mansoura. Recently, systems based on these interferometers attached to computers are used to study the optical properties of fibres. Many other interferometers are used in fibre science of which the following are examples:

i) Dyson[36,37] interference microscope.

It is a two-beam interference microscope in which a direct and a comparison ray pass through the sample.

ii) The Baker interference microscope

It was developed in 1950, it is a double refracting interference microscope. Heyn[38] discussed the use of this microscope in the study of textile fibres.

iii) Zeiss-Linnik interference microscope

It is a modified Michelson interferometer used to study the microtopography of surfaces.

iv) Nomarski systems

It is a modified Wollaston prism used to split the beam. Its principles are widely used in different devices and microscopes.

3. Textile Fibres Investigation

a) Refractive index and Birefringence measurement for fibres having regular and irregular cross-sectional shapes;

Microinterferometric methods were applied for the measurement of refractive indices and birefringence of textile fibres with regular and irregular cross-sectional shape.[1,2,4,5,9–12] Hamza [23] presented a method using the interference and scanning electron microscopy to measure the mean refractive indices and birefringence of fibres having irregular transverse sections. This method is used to solve the problem of optical properties measurement of natural and synthetic fibres having irregular cross-sectional shape.

Figure (3) shows, a) scanning electron micrograph of a transverse-sectional view of a Dralon fibre, b) Multiple-beam Fizeau fringes in transmission for unirradiated Dralon fibre, c) γ-irradiated Dralon fibre with a dose = 28.896 Mrad (cf. Hamza and Mabrouk 1988). [19]

b) Structural anisotropy using optical methods;

i) Determination of the polarizability per unit volume (φ)

Two- and multiple-beam interference methods were applied to measure some structural parameters of textile fibres, one of these parameters is the polarizability per unit volume φ.[20–22,39]

$$\varphi^{\parallel} = \frac{4}{3}\pi N\alpha^{\parallel} = \frac{n_{\parallel}^2 - 1}{n_{\parallel}^2 + 1} \tag{1}$$

A similar equation for $\varphi^{\perp}$ can be written. When using light vibrating parallel and perpendicular to the fibre axis, respectively, $\varphi^{\parallel}$ and $\varphi^{\perp}$ are the electric polarizabiliteis per unit volume, $\alpha^{\parallel}$ and $\alpha^{\perp}$ are the polarizabilities of one molecule, N is the number of molecules per unit volume and $n^{\parallel}$ and $n^{\perp}$ are the fibre refractive indices for parallel and perpendicular light state of polarization .

ii) Determination of the optical orientation function $<P_2(\theta)>$

The value of the optical orientation function $<P_2(\theta)>$ can be determined approximately[13] using the following equation;

$$< P_2(\theta) > = \frac{\Delta n}{\Delta n_{max}} = f_{\Delta} \tag{2}$$

Where Δn is the measured birefringence and Δn_{max} is the maximum value of birefringence for fully oriented fibre. de Varies[14] gives an accurate value of $<P_2(\theta)>$ in terms of f_{Δ} ($f_{\Delta} = \Delta n/\Delta n_{max}$) for $0 < \Delta n < 0.8$ as;

$$<P_2(\theta)> = (1 + a)f_{\Delta} - af_{\Delta}^2 \tag{3}$$

where $$(1+a) = \frac{2n_1^2 n_2^2}{n_v^3(n_1+n_2)}$$

n_1 and n_2 are the principle refractive indices for fully oriented fibre, n_v is the virtual refractive index replaces the mean refractive index $\bar{n}$.

iii) Determination of n_1 and n_2

The principle refractive indices for fully oriented fibre[14] were obtained by extrapolation of $n^{\parallel}$, $n^{\perp}$ measured at different values of Δn using the same monochromatic light. The values of n_1 and n_2 are the values corresponding to the value of Δn_{max}.[21] Figure (4) shows the mean refractive indices $n^{\parallel}$, $n^{\perp}$ plotted against Δn to calculate n_1 and n_2 (cf. Ref. 21).

iv) Determination of $\Delta\alpha/3\alpha_0$

The value $\Delta\alpha/3\alpha_0 = 1/2(3\cos^2\theta_m - 1)$ is constant for a given polymeric fibre. It depends only on the molecular structure of the polymer and determined by the angle θ_m which is the angle between the dipole moment and the chain axis.[15,16,20,40–42]

The following equation is used to calculate $\Delta\alpha/3\alpha_0$;

$$(\varphi^{\parallel} - \varphi^{\perp})/(\varphi^{\parallel} + 2\varphi^{\perp}) = \Delta\alpha/3\alpha_0<P_2(\theta)> \tag{4}$$

Knowing $\varphi^{\parallel}$, $\varphi^{\perp}$ and $<P_2(\theta)>$, the value of $\Delta\alpha/3\alpha_0$ can be easily obtained. Hamza et al.[20] measured the value of $\Delta\alpha/3\alpha_0$ for γ-irradiated Nylon-6 fibres and found that

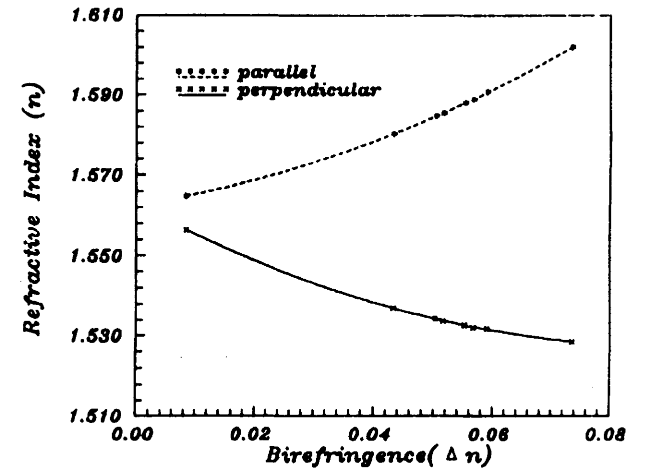


Fig. 4 The mean refractive indices $n^{\parallel}$ and $n^{\perp}$ plotted against the birefringence Δn. The values of n_1 and n_2 can be calculated (From Ref. No. 21).

it is constant with the dose. Moreover, measurement on the drawn polypropylene fibres show that $\Delta\alpha/3\alpha_0$ is constant with the draw ratio.

c) Effect of radiation on fibre optical parameters

The effect of γ-irradiation and ion-beam irradiation on some fibres optical parameters were studied by Hamza and co-workers. [17–19,40]

Empirical formulae were presented to relate the changes in the measured parameters with the irradiation dose. The effect of γ-irradiation on the interference fringe shift is clearly shown in figures 3 (b and c).

d) Opto-mechanical properties of fibres

The opto-mechanical properties of textile fibres were studied extensively using interferometric methods in the University of Mansoura.[26,43–49] In 1988, Hamza and co-workers designed an instrument used to stretch longitudinally (or twist) textile fibres. The fibre must be fixed from its ends and stretched during the measurement process. With the aid of this instrument the opto-mechanical properties of many textile fibres have been studied. Figure 5(a) shows a schematic diagram of the stretching instrument designed by Hamza et al.[26] Figure 5(b) shows totally duplicated images for Nylon-6 fibres with draw ratios 1, 1.5, 2 and 3.75, respectively.[40]

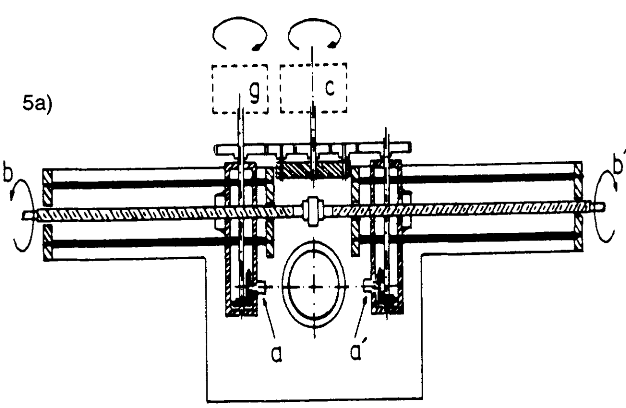
e) Determination of Opto-thermal properties of fibres

The study of textile fibre molecular structure shows a relationship with its thermal properties which have a direct effect on the structural properties[12,39,50,51] such as, refractive index, polarizability, orientation of the chain molecules and the value $\Delta\alpha/3\alpha_0$. Figure (6) shows a cross-section view of the opto-thermal device carried by the multiple-beam Fizeau system.[39]

f) The spectral dispersion of refractive indices and birefringence of fibres

One of the important parameters in textile fibre performance is its material dispersion. Different techniques[24] are used to obtain the spectral dispersion curves of polymeric fibres.[25] One of these techniques is the automatic VAWI.[28,52] This technique has the advantage that it could calculate the spectral dispersion of refractive indices and birefringence of a fibre directly without prior preparation and fastly.

5a)



5b)

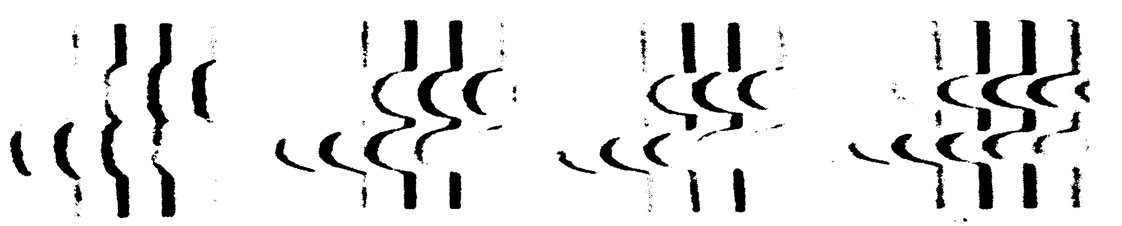
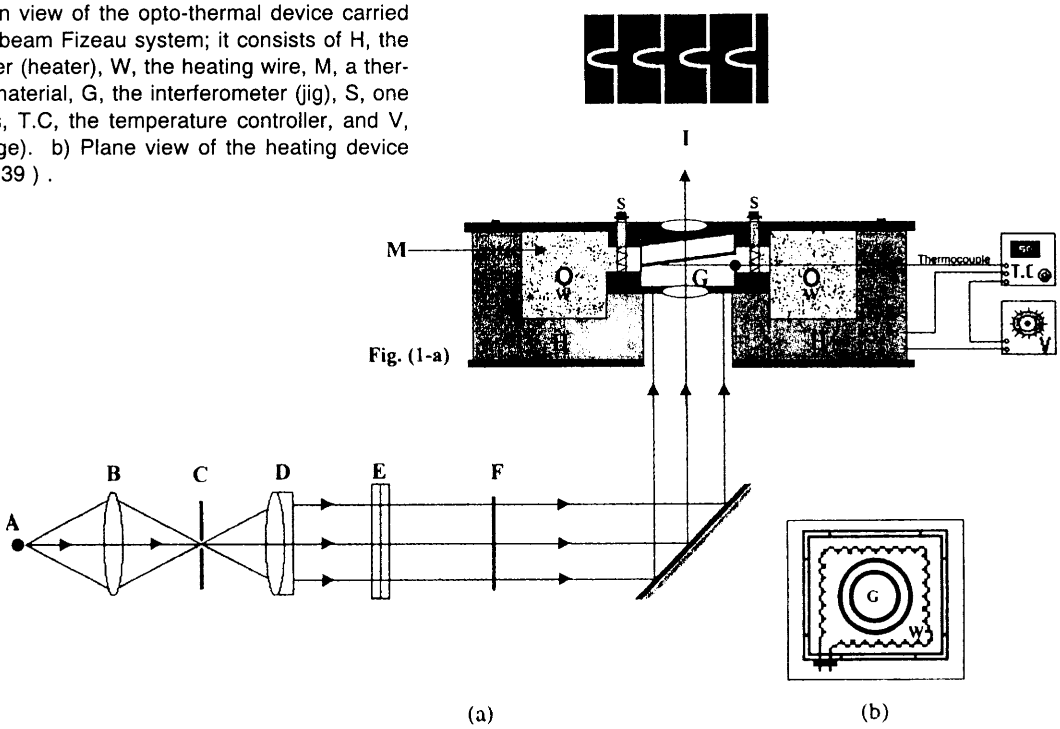


Fig. 5 a) Schematic diagram of the fibre manipulation device for opto- mechanical studies of fibres, where; a and a' are two small round clampes, b and b' are two wheels, c and g are gear boxes (From Ref. No 26). b) Totally duplicated images for nylon 6 fibres with draw ratios 1, 1.5, 2 and 3.75, respectively (From Ref. No 40).

Fig. 6 a) Cross section view of the opto-thermal device carried by the multiple-beam Fizeau system; it consists of H, the metallic chamber (heater), W, the heating wire, M, a thermal refractory material, G, the interferometer (jig), S, one of three screws, T.C, the temperature controller, and V, the varic (voltage). b) Plane view of the heating device (From Ref. No. 39) .



4. Modification in the Methods of Calculation of Reflective Indices and Birefringence of Fibres

a) Determination of refractive indices and refractive index profile of fibres.

Simmens[2] described an elegant technique using the Bapinet compensator to determine the birefringence in objects of constant weight per unit length but irregular cross-sectional shape.

Hamza[23] extended the application of the Pluta microscope to measure the mean refractive indices, birefringence of fibres with irregular transverse sections. The mean refractive index of fibre involves the thickness of both the skin and core regions. These measurements were carried out by the complementary use of the scanning electron microscopy and interference microscopy. The scanning electron microscope was used to determine the cross-sectional area (in mm^2) of the fibre.

Using Pluta interference microscope the refractive indices and birefringence are given as a function of the area enclosed under the interference fringe shift F as:

$$n^i = n_L + \frac{F^i}{h} \cdot \frac{\lambda}{MA} \tag{5}$$

$$\Delta n = \frac{(F^{\parallel} - F^{\perp})}{h} \cdot \frac{\lambda}{MA} \tag{6}$$

where n^i are the mean refractive indices using light vibrating in the i direction (parallel or perpendicular to the fibre axis), λ is the wavelength of the light used, n_L is the immersion liquid refractive index, h is the interfringe spacing, M is the magnification, A is the mean cross-sectional area of the fibre and Δn is the birefringence.

The above method was extended using multiple-beam Fizeau fringes to measure the refractive indices and birefringence of fibres having irregular transverse sections and with a skin-core structure[7] and also for cylindrical fibres having multi-layers structure.[8]

Mathematical expressions are derived form homogeneous[6] skin-core[7] and multi-layers fibres having irregular cross-section shape[8] using multiple-beam Fizeau fringes as follows (in case of multi-layer-fibre);

$$\frac{\lambda}{4h} Z' = \sum_{k=1}^{m} (n_k - n_{k-1})(r_k^2 - x^2)^{1/2} \tag{7}$$

λ is the wavelength of light, Z′ is the fringe shift, h is the interfringe spacing, m is the number of layers, n_k and n_{k-1} are the refractive indices of two successive layers, r_k is the radius at the layer k and x is the distance from the fibre axis to the mid-point of the layer k along the x-axis. $n_{k-1} = n_L$ when $k = 1$.

To overcome the presence of any irregularity in the cross-section of the fibre, integration of equation (7) between the limits a and b along the x-axis gives :

$$\frac{\lambda}{4h} F_m = \sum_{k=1}^{m} (n_k - n_{k-1}) A_{k,m} \tag{8}$$

where $F_m = \int_{\alpha}^{\beta} \bar{Z}' dx$ and $A_{k,m} = \int_{\alpha}^{\beta} (r_k^2 - x^2)^{1/2} dx$

where F_m is the part of the area enclosed under the fringe shift, and $A_{k,m}$ are the parts of the corss-sectional area of the fibre layer. Figure (7) shows a cross-sec-

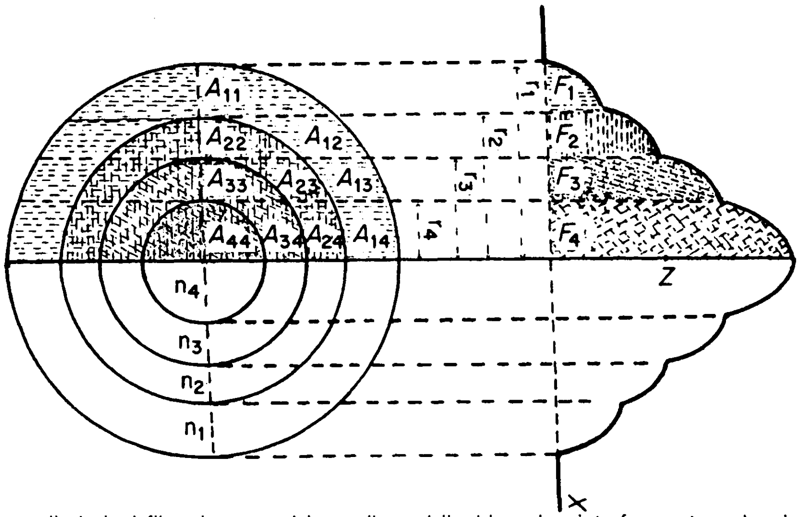


Fig. 7 A cross-section of a cylinderical fibre immersed in a silvered liquid wedge interferometer, showing the notation used for cross-sectional areas of the fibre and, on the right of the figure, the deviation of the rays passing through the fibre (fringe shift), (From Ref. No. 50).

tion of a cylindrical fibre immersed in a silver liquid wedge interferometer, showing the notation used for cross-sectional areas of the fibre and, on the right, the interference fringe shift (cf. Ref.50).

Equation (8) was solved for n_k as follows [50]

$$n_k = n_{k-1} + \frac{\lambda}{4h}\frac{F_k}{A_{k,k}} - \frac{\sum_{j=1}^{k-1}(n_j - n_{j-1})A_{j,k}}{A_{k,k}} \qquad (9)$$

where $$A_{j,k} = \frac{r_j^2}{2}\left[\sin^{-1}\left(\frac{r_k}{r_j}\right) - \sin^{-1}\left(\frac{r_{k+1}}{r_j}\right)\right] + \frac{1}{2}\left[r_k(r_j^2 - r_k^2)^{1/2} - r_{k+1}(r_j^2 - r_{k+1}^2)^{1/2}\right] \qquad (10)$$

and $A_{k,k}$ is the same as equation (10) putting $j = k$.

Dividing the multi-layer fibre into m-layers of equal thickness, each of which considered of constant refractive index, with r_k and r_{k+1} redii, one can easily measure the refractive indices at m points along the fibre radius.

b) Determination of the refractive index profile of fibres using a standard fibre to avoid the problems of using immersion liquid of high refractive index.

Hamza and co-workers[53–55] presented a method for the measurement of refractive indices and birefringence of fibres having high values of refractive indices. Liquids of highly refractive indices are normally unstable and rear. So, the present method overcomes the problems of using such liquids as an immersion liquids. The method used two homogenous fibres immersed in a suitable liquid.[53] The first is a standard fibre of known refractive index and dispersion properties, and the other is the tested fibre of unknown refractive index. A modified mathematical formula is used with the two-beam interference microscope to determine the refractive index of the fibre.

The bases of this method are applied to skin-core structure textile fibres to determine the skin and core refractive index using a standard fibre without need of known refractive index of the immerssion liquid.[54] An expression based on the same idea is used to calculated the refractive index at any point along the radius of multi-layer[55] fibre using a standard fibre.

c) Using the VAWI technique to determine the dispersion curve of fibres.

The variable wavelength interference system is attached with a computer via a CCD camera and frame grabber digitizer to form a system used in automatic interference fringes analysis. This system offers both accurate and fast measurements.[24,25,28] Hamza and co-workers modified the expressions used to measure the refractive indices and dispersion curves using the area under the interference fringe shift inside the fibre.[25]

5. Improving the Accuracy of the determined refractive indices of fibres.

a) Determination of the refractive index profile of a multi-layers fibre taking into consideration the effect of refraction of the incident ray when crossing the fibre.

When a beam crosses a fibre immersed in a liquid of different refractive index, it refracted according to the Snell's law. The effect of refraction on the measured refractive index profile of homogenous fibre has been

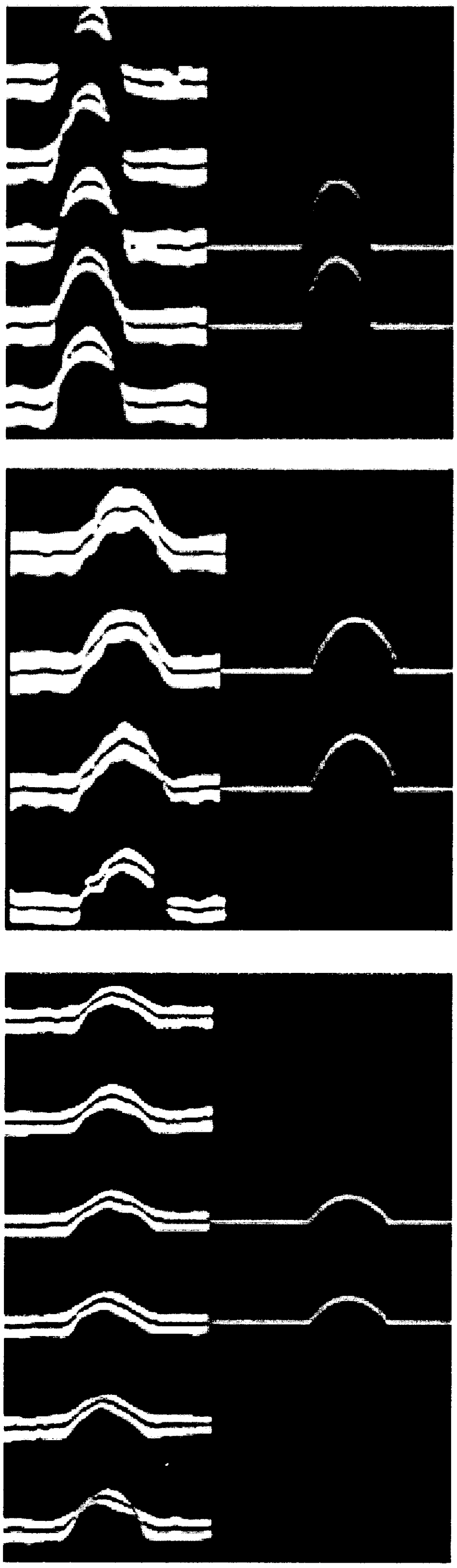


Fig. 8 The contour lines traced along a chosen fringes, while its average were fitted and plotted beside the fringes (From Ref. No. 29).

studied by Hamza et al.[9] In case of skin-core fibre they derived an expression to determine the refractive indices of both the skin and the core considering the refraction effect.[10] In an extension to this work, they considered the case when the fibre has Q-layers and derived a mathematical expression using multiple-beam Fizeau fringes as follows;

$$\begin{aligned}\frac{\lambda \bar{Z}_Q}{2h} = \sum_{j=1}^{Q-1} 2n_j &\left[\sqrt{(R-(j-1)a)^2 - \left(\frac{d_Q n_0}{n_j}\right)} - \right.\\ &\left. -\sqrt{(R-ja)^2 - \left(\frac{d_Q n_0}{n_j}\right)}\right]\\ &+2n_Q\sqrt{(R-(Q-1)a)^2 - \left(\frac{d_Q n_0}{n_j}\right)^2} - \\ &-n_0\left[\sqrt{R^2-d_Q^2} + \sqrt{R^2-X_Q^2}\right]\end{aligned} \qquad (11)$$

where $\qquad d_Q = \dfrac{n_Q(R-(Q-0{,}5)a)}{n_0}$

$\bar{Z}_Q$ is the fringe shift at the $Q^{\underline{th}}$ layer, h is the interfringe spacing, R is the fibre radius, $n_0 = n_L$ is the immersion liquid refractive index, X_Q is the immerged ray distance from the fibre center and d_Q is the incident ray distance from the fibre center.

b) Automatic determination of fibre refractive index profile.

A CCD camera is attached to the microscope of the multiple-beam Fizeau system. The camera is connected to a frame grabber digitizer and a computer to form an automatic system used to analyze the multiple-beam Fizeau fringes. A computer program has been prepared to enhance and analyze the interference fringes.[29] Figure (8) shows the contour lines traced along a chosen fringes, while its average were fitted and drown outside the fringes.[29]

c) Using Optical Fourier Transforms

Studying the spectral dispersion curves of polymeric birefringent textile fibres has been considered by Hamza et al. [27] They analyzed the optical Fourier transform (OFT) patterns when the wavelength of the light used is varied continuously. Using this technique, one can identify the positions of the anti-coincidence and coincidence of the fringe in the image of the fibre with its empty field when variable wavelength VAWI technique is applied manually.

Figure (9)[27] shows sequences of interferograms of PE fibre at different wavelengths using OFT and VAWI techniques.

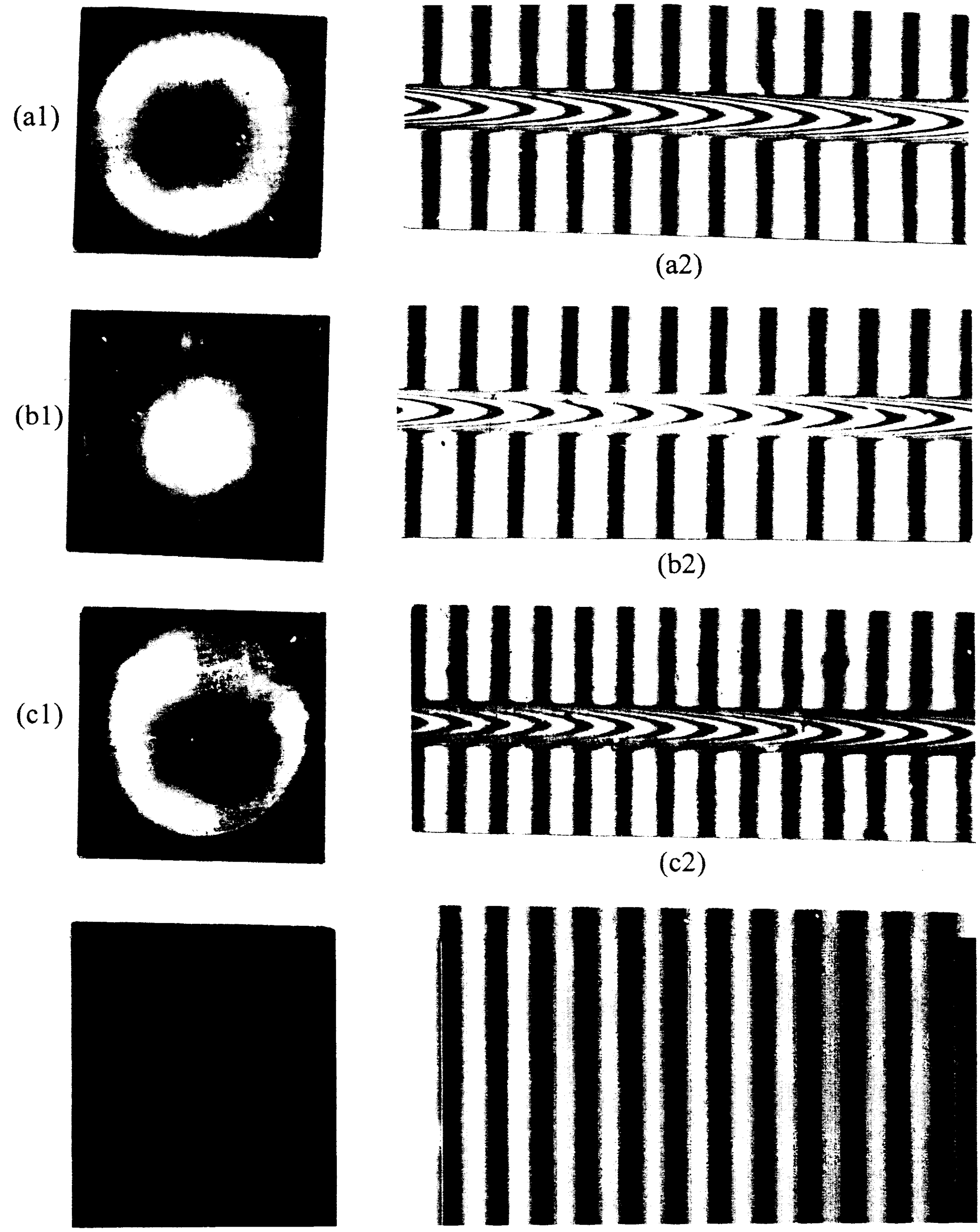


Fig. 9 A sequences of microinterferograms of Aramide fibre at different wavelengths using OFT and VAWI techniques (From Ref. No. 27).

The optical Fourier transform technique overcomes the problem of visually detecting of the coincidence and anti-coincidence of the fringes in the image of the fibre under study with empty fringe field especially in short wavelength at the visible region.

d) Design of a device to study the opto-thermal properties of fibres and effect of temperature on refractive index profile of these fibres.

Hamza and co-workers [39] designed a chamber that contains a set-up to regulate the samples temperature via a thermostat whose thermocouple ends close to the sample. A regular increase of temperature can be obtained and hence, the change in the optical properties of the fibre due to temperature change can be determined. Using this device, accurate measurements of the refractive index and refractive index profile with the correction of temperature can be obtained.

The opto-thermal device designed by Hamza et al. [39] is a controlled temperature chamber contains the interferometer (see figure (6)). It enables us to study the opto-thermal properties of fibres under test at given temperature.

e) Prediction of the reflectance curves of dyed fibres on the bases of refractive indices of fibres

A model to predict the colour of absorbing-scattering substrates, taking into account the effect of optical anisotropy of fibres and definite values of the indices of refraction in the visible spectral range is suggested by Sokkar et al.[56] This model based on a model of Allen and Goldfinger[57] in which the fabric was represented by a parallel bundle of cylindrical fibres. Using the suggested model and a computer program the spectral reflectance curves of dye-fibre polymer are calculated. This model allows the colour of absorbing-scattering substrates to be predicted from the optical properties of the fibres without recourse to sample dyeing. It is possible to optimize the dye concentrations with the optical properties of the fibre substrate to get the desired appearance.

6. Conclusion

Interferometric techniques are important tools in investigating the molecular properties of fibres. The range and detail of structural information provided by the interferometric methods are of grade potential importance in quality control in the textile industry. It is useful to use these techniques in conjunction with the evidence obtained from the scanning electron microscope, the transmission electron microscope and the x-ray diffraction studies in order to fully investigate the structural changes of fibres during processing.

Acknowledgment

The author would like to thank his co-workers and colleagues of the optical group in the University of Mansoura, for continuos cooperation and useful discussions during the performance of the ublished research work.

References

1. Faust R.C., Proc. Phys. Soc. B, **65**, 4B-61 (1952).
2. Simmens S.C, Nature, **181**, 1260 (1958).
3. Barakat N., Textile Res. J., **41**, 167 (1971).
4. Pluta M., J. Microsc., **96**, 309 (1972).
5. Hamza A.A., J. Microscopy, **142**, 35 (1986).
6. Hamza A.A., Sokkar T.Z.N. and Kabeel M.A., J. Phys. D: Appl. Phys., **18**, 1773 (1985).
7. Hamza A.A., Sokkar T.Z.N. and Kabeel M.A., J. Phys. D: Appl. Phys., **18**, 2321 (1985).
8. Hamza A.A. and Kabeel M.A., J. Phys. D: Appl. Phys., **19**, 1175 (1986).
9. Hamza A.A., Sokkar T.Z.N. and Ramadan W.A., Pure and Appl. Opt., **1**, 321 (1992).
10. Hamza A.A., Ghander A.M., Sokkar T.Z.N., Mabrouk M.A. and Ramadan W.A., Pure and Appl. Opt., **3**, 943 (1994).
11. Hamza A.A., Sokkar T.Z.N., Ghander A.M., Mabrouk M.A. and Ramadan W.A., Pure and Appl. Opt., **4**, 161 (1995).
12. Barakat N. and Hamza A.A., "Interferometry of Fibrous Materials", Adam Hilger, Bristol, (1990).
13. Ward I.M., J. Polym. Sci. Polym. Symp., **58**, 1 (1977).
14. de Vries H., Colloid Polym. Sci., **257**, 226 (1979).
15. Cunningham A., Davies G.R. and Ward I.M., Polymer, **15**, 743 (1974).
16. Foot J.S. and Ward I.M., J. Mater. Sci., **10**, 955 (1979).
17. Hamza A.A., Ghander A.M., Oraby A.H., Mabrouk M.A. and Guthrie J.T., J. Phys. D: Appl. Phys., **19**, 2443 (1986).
18. Hamza A.A., Ghander A.M., Oraby A.M. and Mabrouk M.A., J. Phys. D: Appl. Phys., **21**, 407 (1988).
19. Hamza A.A. and Mabrouk M.A., Radiat. Phys. Chem., **32**, No.4, 645 (1988).
20. Hamza A.A. Ghander A.M. and Mabrouk M.A., Radiat. Phys. Chem., 33, No. 3, 231 (1989).
21. Mabrouk M.A. and Shams-Eldin M.A., Pure Appl. Opt., **5**, 929 (1996).
22. Stein R.S. and Wilkes G.L., "Structure and Properties of Oriented Polymers", (Edited by Ward I.M.), Applied Science, London (1975).
23. Hamza A.A., Textile Res. J., **50**, 731 (1980).
24. Hamza A.A., Sokkar T.Z.N., El-Farahaty K.A., and El-Dessouky H.M., J. Opt. A: Pure Appl. Opt., **1**, 41 (2000).
25. Hamza A.A., Fouda I.M., Sokkar T.Z.N. and El-Bakary M.A., J. Opt. A: Pure Appl. Opt., **1**, 359 (2000).
26. Hamza A.A., El-Farahaty K.A. and Helaly S.A., Optica Applicata, **18**, No. 2, 133 (1988).
27. Hamza A.A., Fouda I.M., Sokkar T.Z.N., Sadek A.M. and El-Bakary M.A., J. Opt. A: Pure and Appl. Opt.(submitted for publication).
28. Pluta M., Manual of Automatic-Aided Microinterferometers, Institute of Applied Optics, Warsaw, Poland (1996).
29. Hamza A.A., Sokkar T.Z.N., Mabrouk M.A. and El-Morsy M.A., J. Appl. Polym. Sci. 2000 (in press).
30. Pluta M., Optica Acta, **18**, 661-75 (1971).
31. Pluta M., Optica Applicata, **15**, 375 (1985).
32. Pluta M., J. Microsc., **145**, 191 (1987).
33. Pluta M. J. Microsc., **149**, 97 (1988).
34. Sadek A.M., Ph.D thesis, Phys. Dept., Fac. of Sci., Univ. of Mansoura, Egypt (1998).
35. Tolansky S., "Multiple-beam Interferometry", Clarondon Press, Oxford (1942).
36. Dyson J., Proc. Roy. Soc., London A, **204**, 170 (1950).
37. Dyson J., Nature, **171**, 743 (1953).
38. Heyn A.N.J., Textile Res. J., **27**, 449 (1957).
39. Hamza A.A., Sokkar T.Z.N., El-Farahaty K.A. and El-Desouky H.M., J. Phys.: condens. Matter, **11**, 5331 (2000).
40. Hamza A.A., "Interferometry 89", SPIE, vol. **1121**, p. 340 (1990).
41. Yazdanian M., Ward I.M. and Brady H., Polymer, **26**, 1979 (1985).
42. Mabrouk M.A., Polymer Testing **13**, 67 (1994).
43. Hamza A.A., Fouda I.M., El-Farahaty K.A. and Helaly S.A., Polymer Testing, **7**, 329 (1987).
44. Hamza A.A., Fouda I.M., Kabeel M.A. and Shabana H.M., Polymer Testing **8**, 201 (1989).
45. Hamza A.A., Fouda I.M., El-Farahaty K.A. and Seisa E.A., Polymer Testing, **10**, 195 (1991).
46. Hamza A.A., Fouda I.M., Kabeel M.A. and Shabana H.M., Polymer Testing **10**, 305 (1991).

47. Hamza A.A., Fouda I.M., Sokkar T.Z.N., Shahin M.M. and Seisa E.A., Polymer Testing, **11**, 233 (1992).
48. Hamza A.A., Fouda I.M., Kabeel M.A. and Shabana H.M., Polymer Testing, **15**, 35 (1996).
49. Hamza A.A., Fouda I.M., Kabeel M.A. and Shabana H.M., Polymer Testing, **15**, 301 (1996).
50. Hamza A.A. and Mabrouk M.A., J. Modern Optics, **38**, 97 (1991).
51. Hamza A.A., Fouda I.M., Sokkar T.Z.N., Shahin M.M. and Seisa E.A., J. of Mater. Sci., 30, 2597, (1995).
52. Pluta M., Optica Applicata, **16**, no.4, 301 (1986).
53. Hamza A.A., Sokkar T.Z.N. and Shahin M.M., J. Appl. Phys., **69**, 929 (1991).
54. Hamza A.A., Sokkar T.Z.N. and Shahin M.M., J. Appl. Phys., **69**, 7231 (1991).
55. Hamza A.A., Sokkar T.Z.N. and Shahin M.M., J. Appl. Phys., **70**, 4480 (1991).
56. Sokkar T.Z.N., Kabeel M.A., Ramadan W.A. and Hamza A.A., Color Res. and Application, **17**, 219 (1992).
57. Allen E.H. and Goldfinger G., J. Appl. Polym. Sci., **16**, 2973 (1972).

Books:

1 „Interferometry of Fibrous Materials" by N.Barakat and A.A.Hamza, Adam Hilger, Bristol, January 1990.

Scientific Papers:

1. Hamza,A.A., Fouda,I.M., Kabeel,M.A., Seisa,E.A. and El-Sharkawy,F.M.: „Opthotermal properties of fibres. VII structure orientation study of annealed Egyptian polyester fiber", J.Applied Polymer Science, 65, 2031 (1997).
2. Hamza,A.A., Fouda,I.M., Kabeel,M.A., Seisa,E.A. and El-Sharkawy,F.M.: „Opto-thermal properties of fibres 2-structural characteristics of cold drawn annealed Egyptian polymer (PET) fibers", Polymer Testing, 16, 303 (1997)
3. Hamza,A.A., Fouda,I.M., Sokkar,T.Z.N. and El-Bakrary,M.A.: „Opto-thermal properties of fibres. V. opical anisotropy in silk fibers as a funcion of annealing process", J.Applied Polymer Science, 60, 1289 (1996).
4. Hamza,A.A., Fouda,I.M., El-Tonsy,M.M. and El-Sharkawy,F.M.: „Opto-thermal properties of fibres. VI. Effect of annealing on some of the optical and dynamic mechanical parameters of polyester fibers", Journal of Applied Polymer Science, 59, 1585 (1996).
5. Hamza,A.A., Fouda,I.M., El-Tonsy,M.M. and El-Sharkawy,F.M.: „Opto-thermal properties of fibers. II. Annealing effect on the Birefringence variations of polyester fibers". Journal of Applied Polymer Science, 60, 1239 (1996).
6. Hamza, A.A., Fouda, I.M., Sokkar,T.Z.N., Shahin,M.M. and Seisa,E.A.: „Opto-thermal properties of fibres: part 1. optical behavior of annealed polypropylene fibres as a function of the draw ration". Journal of Materials Science, 57, 262 (1995).
7. Hamza, A.A., Sokkar,T.Z.N., Ghander,A.M., Mabrouk,M.A. and Ramadan,W.A.: !On the determination of the refractive index of a fibre: II. Graded index fibre". Pure and Appl. Opt. 4, 161 (1995).
8. Hamza,A.A., Fouda,I.M., Sokkar,T.Z.N., Shanin,M.M. and Seisa,E.A.: „Interferometric studies on polymer fibres II. Application of multiple-beam Fizeau method for the characterization of multilayer fibres". Polymers and Polymer Composites, vol. 2, No.5 (1994).
9. Sokkar,T.Z.N., Kabeel,M.A., Ramadan,W.A. and Hamza,A.A.: „A contribution to the study of color of fabrics". Color Research and Application, 17, 219 (1992).
10. Hamza,A.A., Sokkar,T.Z.N. and Shanin,M.M.: „Interferometric determination of optical anisotropy in fibres, 3. multi-layer fibres". J.App. Phys. 70, 4480 (1991).
11. Hamza,A.A. and Mabrouk,M.A.: „A multiple-beam interferometric method for refractive index determination of graded optical fibres". Journal of Modern Optics, 38, 97 (1991).
12. Hamza,A.A., Sokkar,T.Z.N. and Shanin,M.M.: !Interferometric determination of optical anisotropy in fibres, 2.fibres with a skoncore structure". J.Appl. Phys. 69, 7231 (1991).

SCIENTIFIC INSIGHTS INTO THE THERMODYNAMIC PROCESSES IN THE CLEANING OF TEXTILES IN ORGANIC SOLVENTS

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INTRODUCTION

Compared with the finishing processes in the manufacture of textiles, restorative activities in the sense of preserving the serviceability of textiles may at first sight appear to be of secondary importance; however, on closer examination of the situation, the reverse is the case. Textile finishing can produce the most interesting, beautiful and promising fabrics, but if the clothing produced from them cannot be cleaned again by means of restorative measures such as washing or dry cleaning, and thereby restored to a usable state, such fabrics are not saleable. People take the term "textiles" to mean reusable materials.

From this point of view it is somewhat astonishing that restorative measures are accorded a relatively low position in practice - and also in science. The reasons for this are to be found in the human psyche. Anything that is new we find interesting, whilst the everyday is taken for granted.

New developments in textile finishing interest people, because they can be used for adornment. Regular care through washing or dry cleaning on the other hand is routine. But this routine too can be very interesting in scientific terms. The author of this article has been dealing with questions and problems of restorative textile chemistry and textile technology for around 40 years. Naturally there is a risk of overestimating one's own contribution, but in view of the many interfaces between textile cleaning and other areas of science, one can constantly measure oneself against the other disciplines.

Here, textile cleaning in organic solvent represents an extremely interesting research activity. The following article combines research and active contributions by the author to this area of knowledge:

1. Basic principle of dry cleaning

To start with, we must get rid of a misunderstanding: the whole world insists that dry cleaning is carried out in organic solvents. Whilst this is true in principle, science knows that organic solvents can loosen only fat and fat-like, i.e. non-polar, substances, and thus remove them from the textile. But every normal person knows that also contained in the textiles there are generally substances which are not fat-like. These are the polar substances such as amino acids, salts, carbohydrates, pectins and protein. To release these substances, one needs polar solvents. The most important and economical of these is water! And it is precisely this insight which leads on to the fundamental problems in textile cleaning in organic solvents. Textile cleaning actually requires two solvents, such as e.g. perchloroethylene, hydrocarbons or related compounds, possibly also compressed carbon dioxide as a future-oriented solvent - and to go with it, a certain amount of water. Expressed in physico-chemical terms, one uses a non-polar solvent together with a polar solvent; the special feature here is that these two solvents practically do not dissolve in one another. The solubility of perchloroethylene in water is only 0.01% at 25°C, the solubility of water in perchloroethylene being likewise 0.01 %.

There is no cleaning process used in practice in which solvents are used which are miscible in one another. In the first instance, there is just one reason for this: if the two solvents are not miscible with one another, they can easily be separated from one another, providing the specific density differs sufficiently. In the case of perchloroethylene in water, the ratio is 1.6 : 1.0; in hydrocarbons it is 0.8 : 1.0. In both cases the difference in density is quite sufficient to separate the solvents into two phases solely through the gravity of the room temperature, provided there are no emulsifiers in the two phases.

In relation to the use of solvents in dry cleaning, their non-miscibility is a huge disadvantage, which however also represents the reason for the scientific level of textile cleaning. This is due to the following reasons:

The non-polar solvent does not mix with the polar water. Through the mechanical movement of the liquid in the rotating drum of a cleaning machine, the two liquids are mixed with one another in purely mechanical terms, but they separate as soon as possible when the mechanical action is removed. This would in itself not be a problem, for the two phases could absorb non-polar or polar dirt unhindered. This would also be desirable. However, things happen rather differently in practice:

The predominantly hydrophilic textiles absorb the entire water present in the cleaning liquor, become moist in doing so, and suffer irreversible changes. For example, textiles made of wool would felt, since the water content of the [liquor], in conjunction with the mechanical action of a rotating drum, pushes the scale layer of the wool together. The result would be shrinkage of the textiles.

In the scientific sense, a one-sided diffusion of the water out of the cleaning liquid onto the textile fibre would take place. An enrichment of water would take place in the textile fibre. The water could lead to the swelling of the natural fibres. In the case of wool and silk, this would result in irreversible changes. In the case of cotton, the water could act as a diffusion sink for water-soluble dirt, which would lead to greying of the textiles. To this extent, free water, i.e. water as a phase of its own, is not suitable for cleaning textiles. The solution to the problem lies in the forming of micelles with the aid of surfactants. States of solubilisation arise in which the water is bound in such a way that it is no longer present as a free phase, but nevertheless retains the capacity of maintaining, at least in part, its own dissolving action for polar substances.

2. Solubilisation of water in the organic solvent

2.1 Principle

Similarly to the emulsification of water in organic solvents, the chemical constitutions and the concentration of the surfactant represent jointly decisive criteria for the procedure of a solubilisation.

According to the definition, solubilisation is taken to mean "making a non-soluble liquid soluble in another liquid"; here, for example, water in perchloroethylene. Solubilisation is the state between solubility and emulsion.

Solubilisation takes place on the individual surfactant molecules, which can then aggregate in the bond to form micelles. For the solubilisation of water in perchloroethylene, it is predominantly anionic surfactants, possibly mixed with [ionic] surfactants, which are used. In the case of anionic surfactants, the solubilisation takes place on the polar group.

The force of attraction K) between the surfactant and water is calculated for the molecules of the 1^{st} hydration sphere in accordance with the Coulomb equation for electrostatic attraction.

$$K = (e_{ion} \times e_{Dipole})/r^3$$

For the subsequent spheres, the rules for dipoles apply in accordance with the formula

$$K = (e^1_{Dipole} \times e_{Dipole})/r^4$$

e corresponds to the water which is not yet solubilised, e^1 corresponds to the dipole of the water molecule in the 1^{st} hydration sphere, r = spacing between charges.

The dipole of the water (e^1) is greater than the dipole of the non-solubilised water, since the water molecule is heavily induced through the negative charge of the surfactant ion. This induction decreases with the number of hydration spheres.

The solubilising power of the surfactants is exhausted when e^1 equals e, i.e. when the induction going out from the surfactant ion to the already solubilised water molecule is equal to zero. Then water can also collect outside the hydration spheres of the surfactants, to form molecule aggregates. This state then corresponds to that of the emulsion.

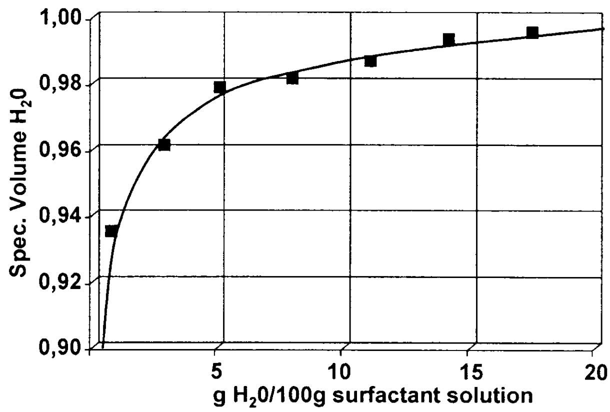

Fig. 1 With increasing water content, the volume of the water is drawn together less, due to the decreasing binding force of the surfactant ion. Once the binding power of the surfactant is no longer effective, the water retains its original volume of 1.0.

2.2 Micelle formation

In contrast to surfactants in aqueous systems, no lamillar micelles arise in organic solvents, but only globe micelles. The individual surfactant particles bring their hydration spheres as water into the micelle. Within the micelles, the water is bound to the surfactants. Due to the ion-binding, there is a stronger force of attraction between the water molecules than in water alone. This is expressed in a reduced volume of the water present in the micelles. As an example, show below is the specific volume of the solubilised water, bound in micelles, in a 10% anionic surfactant solution.

The end point of the solubilisation power of a surfactant can be defined – in thermodynamic terms – as the state in which the force of attraction between the electrical charge of the surfactant and the dipoles of the water is equal to zero. A measure of this could be the specific volume of the water. However, this method is not suitable for practical purposes in the sense of a technical application. What is usable, on the other hand, is indirect measurement of the chemical activity of the water as steam pressure equilibrium.

3. Composition of the cleaning liquid

Cleaning liquid refers to the liquid consisting of several components, in which the soiled textiles are treated and thereby cleaned.

The major part consists of organic solvents, normally perchloroethylene or hydrocarbons.

Water is present as the second "solvent". The amount of water lies between 0.5 and 5%, relative to the weight of the textile material to be cleaned, and not to the proportionate volume amount of organic solvents. The reason for this lies in the fact that different textile types can withstand only limited amounts of water without suffering irreversible damage (see also following chapter). If one converts the percentage amount of water for the textile types into volume percentages, then the water additions per litre of organic solvents lie at 0.5 to 5 ml. At first sight, this appears a negligible parameter, but it practice it is an extraordinarily important concentration.

Since organic solvents and water do not dissolve in one another, a homogenous phase is necessary for the practical execution of a cleaning process, surfactants are added which effect a solubilisation of the water within the organic solvent

The surfactants are usually not used as pure substances, but are used in preparations with dissolving agents; such preparations are called cleaning promoters. These are produced by chemical factories which specialise in the development of highly effective products in the textile cleaning sector.

The composition of the cleaning liquid of organic solvents, small amounts of water and cleaning promoters represents an extremely complex liquid with fluid phase transition points.

4. Interactions between the solvents and the textiles

4.1 Fundamental processes

Regardless of whether textiles come into contact with water, organic solvents or other liquids, there are four possibilities for how interactions can develop:

- Adhesion of the liquid in the macroscopic outer area (= adhesive liquid)
- Binding of the liquid within the capillaries (= capillary liquid)
- Absorption of the liquid into the textile substance, i.e. the fibre itself (= absorption liquid)
- Incorporation of the liquid into the chemical structure of the fibres (= crystalline liquid).

Whilst the amounts of adhesive liquid and capillary liquid depend predominantly on the technological condition of the textiles, the absorption liquid and the crystalline liquid depend on the specific fibre characteristics. This means for example that polyester behaves quite differently from cotton or silk. The considerations below relate only to the absorption fluid, since it plays a decisive role in the processes in cleaning technology.

4.2 Organic solvents

On the basis of the surface tension, one can make concrete statements about the polarity of the solvents. Perchloroethylene is 32.3, hydrocarbons 23–25 mN/m and water 71 mN/m.

It must now be assumed that the non-polar solvents such as perchloroethylene and hydrocarbon solvents act predominantly on the non-polar fibres with low electro-chemical potential. Experimental work has confirmed this impressively. Some trial data from a piece of research work carried out at the Hohensteiner Institutes are reproduced below in extract form.

The absorption of perchloroethylene into the textile fibres lies in the order of micrograms. For practical purposes, these amounts are of no economic importance, but they could be of significance in ecology, if the zero theories of the environmentalists become ever more widespread.

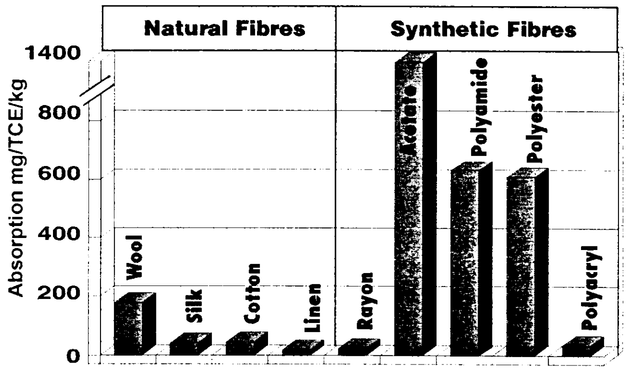

Fig. 2 Synthetic fibres, such as polyester, polyamide and polyacrylic, absorb considerably more perchloroethylene than natural fibres. What is surprising is that acetate too shows a relatively high absorption of solvent. On the basis of the chemical structure, this was not to be anticipated, since despite the acetylation of, on average, 2.5 OH groups in the cellulose, hydrophobicity comparable to the synthetic fibres should not arise. However, comprehensive investigations with the scanning electron microscope showed that it is not the chemical structure of the acetate fibres which is responsible, but the microscopic fine structure of the fibres themselves. The acetate fibre has a larger inner surface with canal-like structures, into which the solvent is deposited. Here, absorption and inclusion overlay one another.

5. Interactions of textile fibres with water

The fundamental interactions between water, whether in the liquid or gaseous state, and textile fibres are fairly precisely known in science, and are part of standard knowledge in textile chemistry. However, two of these phenomena are of particular importance for textile cleaning in organic solvents.

5.1 Isothermic water vapour equilibria in the gas phase

In the scientific sense, this is taken to mean the absorption or emission of gaseous water into or out of textile fibres in a gaseous environment. The corresponding values are known.

Now for textile cleaning in organic solvents it is particularly important that the rules of water uptake in the gas phase - referred to in practice as dry swelling - also apply when the water is present as a liquid phase in the state of the thermodynamic activity lying below the value 1. Such states are present in textile cleaning.

5.2 Hysteresis of water uptake/ release

The time delay between water uptake and water release in the gaseous state (hysteresis) has an influence on the moisture equilibria to the extent that the absolute amount of water present in the textile fibre depends on whether it was absorbed in the adsorption phase or was reached in the desorption phase. Since the water content, or the activity of the water, represents an important parameter for the cleaning effect, it is of importance whether the state of equilibrium between air and textile was reached in the adsorption or the desorption phase. In practice, one almost always works in the absorption phase, and thus ensures reproducible conditions.

6. Moisture transition points and steam pressure equilibria

Within the framework of a cleaning process carried out in practice in organic solvents, three phases are involved in water transport. These are the cleaning liquid, the goods to be cleaned (textiles) and the gas space above the cleaning liquid.

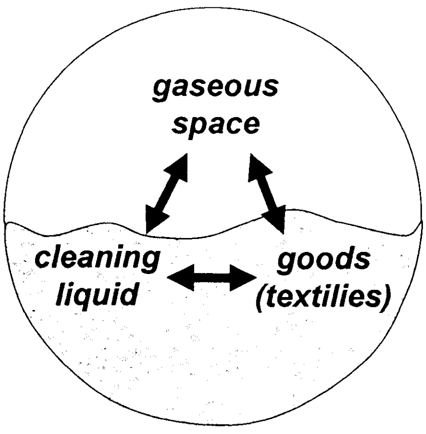

Fig. 3 The individual phases are liquid (cleaning liquid), solid (goods to be cleaned, i.e. the textiles) and gaseous (gas space above the liquid and textiles). The gaseous phase represents a measuring opportunity, since it does not directly have anything to do with the cleaning effects, but stands in equilibrium with the two other phases.

A scientific consideration of the individual phase equilibria must be based on the fundamental thermodynamic principles.

6.1 Moisture equilibrium between the gas phase and the cleaning liquid

The experimental pieces of work have shown that the water bound in the micelles of the surfactants stands in direct relation to the enthalpy of the water.

$$\mu_{H_2O} = \mu_0 + R.T.\ln a$$

$$a = c.f a = p/p_o$$

μ_{H_2O} = enthalpy, free energy, activity, c = mass of he water, μ_o = normal potential of the free energy, a = activity of water, p/p_o = relative water vapour pressure

According to that, the activity of the solubilised water bound in the micelles is in direct relation to the relative water vapour pressure in the gas phase.

By measuring the relative water vapour equilibria in the gas phase, the free energy of the water in the micelles can be established. The stronger the binding of the water to the surfactants, the lower the free energy. If there is no binding between the surfactant and water, then the free energy of the water is at its greatest. In the measurement, this is then expressed such that p/0 = 1, or in engineering terms the relative air humidity is 100 %. The steam pressure isotherms thus reflect the binding state of the water in the micelles.

Shown in the following illustration are some examples of steam pressure isotherms with different surfactants, in different constellations.

On the basis of the thermodynamic relations, it is possible, with a given surfactant and with defined concentration, to determine both the absolute amount of water in the cleaning liquid and the activity of the water. For the use of surfactants in organic solvents in cleaning technology, the activity is of particular importance, as can be seen from section 4.2.

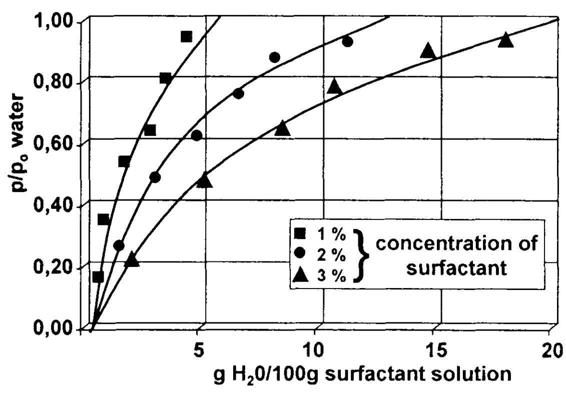

Fig. 4 Differing concentration of the surfactants influence the free energy of the water bound in the micelles.

6.2 Moisture equilibrium between textiles and cleaning liquid

Textile fibres, particularly natural fibres, have hydrophilic groups with polar characteristic, similar to the surfactants. In these groups, water can be deposited, through which - just as in the case of a solubilisation through surfactants - the free energy of the water, i.e. the activity, is reduced. Just as with cleaning liquids, the free energy of the water in textile fibres can be determined via the relative water vapour pressure.

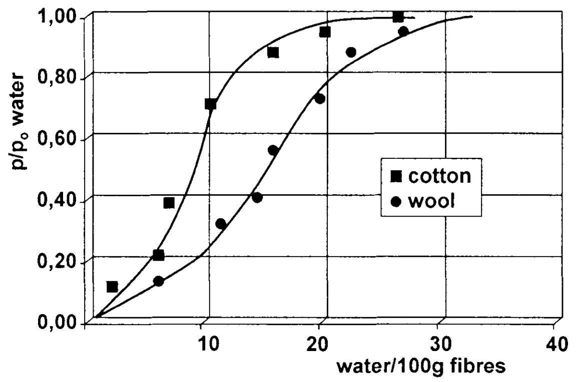

Fig. 5 Steam pressure isotherms for various textiles at 25 °. Just as with solubilisation, the activity of the water is greatest at $p/p_o = 1$.

Application of the laws of thermodynamics now allows one to draw the conclusion that transportation of water from the cleaning liquid to the textile fibre or vice versa runs in accordance with the differences in free energy of the water, and not according to the differences in the absolute concentration of the water. Through measurement of the relative water vapour pressure in the gas phase above the cleaning fluid, the water transportation to be anticipated can be checked, and also controlled if suitable technical equipment is available.

Knowing the content of active water is enormously important, to some extent even decisive, for the success of cleaning. If for example the activity of the water in the textile fibres is too great, then irreversible changes can occur. Experimental values for the limits of water activity are e.g. for wool: not higher than 0.82 p/p_o, cotton 0.87 p/p_o and silk 0.83/p/p_o.

7.Significance of the water content in the cleaning system for the cleaning action

Water in organic solvents can have positive and negative effects:

It has a negative effect if in the textile fibre it has a higher activity than corresponds to the relative water vapour pressure defined in section 6. The textiles then change irreversibly.

The water has a positive effect if in the activity range of approx. 0.4 p/p_o up to the limit value defined by the sensitivity of the textiles it has. In this range, it has an adequate soil release capability.

The solvent power of the water which has been solubilised by surfactants and bound in micelles depends decisively on the activity of the water. Here, fundamentally the same rules apply as for fibres.

Summary

Textile cleaning in organic solvents requires, in addition, water and surfactants in order to release out of the textiles as broad a spectrum of substances as possible. The removal of non-polar compounds such as fats, oils and waxes is taken care of by the non-polar solvent, usually perchloroethylene or hydrocarbon solvents.

The polar dirt can be released by added water. The amounts of water range between 0.5 and 2% of the textile weight. What is decisive for the effectiveness is the activity of the water. Activity which is too high can change the textiles irreversibly, whilst too little activity heavily restricts the solvent power for polar substances.

The activity of the water can be controlled through surfactants. Measurement of the activity is via the relative water vapour pressure in the gas phase above the cleaning fluid. The water transport in the cleaning liquid follows the laws of adsorption and desorption in the gas phase. Accordingly, the laws which apply there also apply in full.

Hohenstein Institute, 14.04.2000
Prof. Dipl.-Ing. Josef Kurz

DEPARTMENT OF TEXTILE STRUCTURES

1. Something from history or "HOW WE COME INTO BEING"

Production and usage of textiles belongs to the oldest activities of human civilisation. Archaeological discoveries from south Moravia proved that yarns and woven fabrics were used even 27,000 years ago. Almost all long time of its existence the textile structures were produced on purely empirical bases. Only in 19th century some first lonely attempts of more exact understanding of production processes, structures and properties of the textile formations can be found. More compact scientific knowledge on the topic is characteristic for the second half of 20th century.

Establishing of the technical higher education institutions at the end of 19th century brought textile problems on the academic field. In the Czech territory first textile department arose in Brno in the time of Austria-Hungary state. After 1948 the department moved into Prague and soon after it definitely on young institution in Liberec (present Technical university of Liberec). Faculty of textile engineering was established in 1960. Department of spinning and finishing and Department of weaving and knitting belonged to the oldest departments.

An interest to recognise regularities of the structure and properties of textile formations appear in the 60th. This word wide tendency was reflected in activities of the Czech textile departments and research institutes. So there were created foundations of own Czech "school" of structural mechanics of yarns, woven and knitted fabrics and non-woven products as well near the year 1968. In the 70th and 80th this development was, as a result of so-called "normalisation", slowed down. The intensive research of structure and properties of the fibrous formation was revived on technological departments after 1989.

Two new departments were originated after reorganisation of the faculty in 1997. It was Department of mechanical technologies and Department of textile structures. So came into being as well working place, that could its efforts devote to the recognition of inner laws of building – structure – of the fibrous formations and to understanding of the structural causes of behaviour – properties – of different textiles. When the main interest was put on mechanical behaviour, arouse structural mechanics of fibrous formations.

2. Something about us or "WHO WE ARE"

The corn of the department is formed by the team of 8 university teachers, namely by:

Ing. Mirka Dostálová, (didactic, technological relations),
Ing. Jana Drašarová, (theory and experiments of woven structures),
Prof. Ing. Radko Kovář, CSc., dean of the faculty (structure and structural mechanics of knitted fabrics, knitting technology),
Dr. Ing. Dana Křemenáková, (yarn theory, experimental methods of yarn structure research),
Ing. Mária Křivánková, department secretary (twisted yarns, technological relations)
Doc. Ing. Ján Marko, CSc., deputy head of the department (theory of yarn, theory of yarn twist, spinning technology)
Prof. Ing. Bohuslav Neckář, DrSc., head of the depatrment (structure and structural mechanics of general fibrous formations, yarn theory),
Prof. RNDr. Bohuslav Stříž, DrSc., (theoretical mechanics, mechanics of fibrous formations).

Co-operators in research activities are as well students of Ph. D. programmes *Ing. Kateřina Zelenková, Ing. Daniela Patejdlová, Ing. Irena Plachá, Ing. Marcela Hlavová, Ing. Leona Tvrdá and Ing. Zuzana Šoltésová.*

Other co-workers, namely Mrs. *Věra Marková, Ludmila Hladíková, Jana Voborová. Ing. Vít Roček, Ing. Pavel Hanus* works in the mechanical laboratories of the department, equipped for example with system of image analysis and processing, optical microscopy, special dynamometers etc. Secretary of the department is Mrs. *Jana Nováková.*

3. Several words about research or "HOW WE RACK OUR BRAINS"

The main scientific and research effort is concentrated on the structure and structural mechanics of general fibrous formations, yarns, woven and knitted fabrics. Original results are published in journals and on foreign conferences (annually about 20 papers). The main topics are next:

a) Structural theory of fibrous formations

- Theoretical (mathematical) modelling of structure of general fibrous formations
- Theoretical (mathematical) modelling of spun yarn structure (including stochastic model of components distribution, theory of twist, yarn packing density etc.)
- Theoretical (mathematical) modelling of the knitted structures (stitch models, yarn in the fabric interaction etc.)
- Theoretical (mathematical) modelling of the woven structures (binding element geometry, radial yarn deformation in fabric etc.)
- Special experimental methods development for research of textiles structure (microscope cuts, image analysis)

b) Structural mechanics fibrous formations

- Stochastic modelling of mechanical behaviour of fibrous bundles and nets (mechanics of multiaxial textiles, stochastic fibrous bundles, yarn strength and break elongation as stochastic process etc.)
- Models of continuum used for textile mechanics analysis (multi-axes load of the fabric, fibrous systems compression etc.)
- Special mechanical appearance of textiles (rheology of compressive stockings etc.)

In the department grant project of GAČR 106/97/0372 "Structure and structural mechanics of fibrous formations" was solved, now we deal with research project of our Ministry of higher education of the same name, we solved several projects of the Fund of universities development etc. In the department some special experimental methods of mechanics analysis of fibrous systems were developed, some of them are used for special expertises.

4. Something about teaching or "HOW WE TORTURE STUDENTS"

Department of textile structures is responsible for 19 textile subjects. In M. Sc. courses it is Basics of textile and clothing production, Structure and properties of textiles I and II, Knitting and subjects of specialisation Structural models of fibrous formations, Yarn theory, Worsted spinning, Quality control in spinning mills, Theory of knitting, Structure and properties of knitted fabrics, Weft knitting, Solid state mechanics, Basics of mechanics of continuum, Mechanics of textiles. In bachelor studies it is Introduction to textile, Survey of textile technologies, Longitudinal textiles production, Textile technologies I, II. The content of the most of the subject is original, issued from own results of research.

In "our" courses usually students needn't to learn mechanically many facts. In return at exams we toughly demand to understand all the laws and consequences in textile structures theory, what means that students need know "WHY" as well, not only "WHAT". (One student who failed claimed on the department "It is always WHY the sky is blue and WHY the grass is green"; another explained to examiner the cause of his failure "You want me to understand it"; he was quite all right!)

5 Something as conclusion or "SHORT VISION ON FUTURE"

When hearing the word *science*, usual image is something like black hole in the space, molecular biology, quarks in the nuclear physics or something like it. Ordinary people assume that this is something majestic, complicated and useful. "Shirt", "Handkerchief", "rag" usually do not associate the word science, as these terms are too ordinal and banal, not dignified of science nobility.

I believe, that in the near future this view can be substantively changed. The theory of structure and properties of textiles as well as other parts of textile sciences are becoming to be worked out in sufficient depth what allow us to think about other possibilities of its practical utilisation. One of the perspective directions is processing of existing relations into comprehensive systems of computer projecting (construction) of textile formations of required properties. As designers of machines or architects of buildings use systems of calculations, tomorrow textile designers and technologists will use some instruments alike. May be, that then the word *science* will associate handkerchief, shirt or even rag.

THE MECHANICAL STRUCTURE MODELING OF STAPLE YARN

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Textile Structure Department, TU Liberec, Hálkova 6, CZ-46117 Liberec.

It is well known, that to achieve high quality textile products, a lot of yarn properties should be deeply and carefully investigated. Yarn properties result from interacting of two main factors: 1) fibre properties and 2) the way of how they were arranged "spun", i.e. yarn structure. Fibre properties during processing "spinning" changes very little, but yarn structure during processing is directly created; this certainly affects significantly yarn properties. This article deals with some brief structural relationships of staple fibres, where these were in details investigated at Textile Structure department, TU Liberec. Here is short information about the main logical characteristics of yarn structure and the possibility of making use of the results of the introduced yarn structure models, these models based on the so-called „ structural mechanics of yarn relationships". This work introduces better understanding of yarn quality and offers some basic ideas for precise future projecting yarn staple structure.

1. PRINCIPLE RELATIONSHIPS AND BASIC DEFINITIONS(1)

1.1 Fibre materials

Staple fibre materials characteristics used for yarn production are widely. They are material type and their characteristics as *fibre density* ((usually 900 to 1500 kg m^{-3}), *fibre length l, mass of individual fibre m*, which is usually expressed by *fibre fineness* $t = m/l$ (normally 0,13 to 0,6 tex), also *area of fibre cross section* $s = t/\rho$ (2) (order of 10^{-4} mm^2) according to the different shape of fibre cross section. *Equivalent fibre diameter d* (regular circular diameter, $s = \pi d^2/4$), which takes the values between 0,01 and 0,025 mm. *Slenderness of staple fibres* $\Lambda = l/d$ range is in order of 10^3. If the *fibre circumference* is denoted by *p*, then the *cross section shape factor* [1] is given by $q = p/(\pi d) - 1$ (ranges between 0,03 for circular shape, and for real „circular" cross section 0,6 for viscose fibres). *Specific fibre surface* $\alpha = 4(1 + q)/\rho d$ is expressed as the surface area relative to the mass of one fibre (usually in the order of 10^3 m^2kg^{-1}). Mechanical fibre behaviour is described by the so-called *stress – strain curve, specific strength* (and *elongation a*. The ratio of the force *F* and the area of cross section *s* physically express the tension stress, $\sigma_f = F/s$; in textiles the strength „tenacity" σ is defined as the ratio of the force *F* and the fibre fineness *t* [tex], here $\sigma = F/t = F/(s/\rho) = \sigma_f/\rho$ (3) (for ex. in $Ntex^{-1}$).

For multi *n* component blend (i = 1,2,....,n) with weight portion of g_i, the mean blend parameters should be known. They are *the mean density* $\rho = 1/\sum(g_i/\rho_i)_{i=1...n}$, based on volume *portion of the components* $v_i = g_i\,\rho/\rho_i$, *mean fibre fineness* $t = 1/\sum(g_i/t_i)_{i=1...n}$ and the *mean specific surface area* $\alpha = \sum(g_i/\rho_i)_{i=1...n}$.

1.2 The yarn

Considering a yarn segment of *length L and mass M*, created from some fibres described before – see fig. 1. This yarn has *linear density* of $T = M/L$ [tex]. The hatched (black) fibre area in the yarn cross section *forms the yarn substance cross section* cross section $S = T/\rho$.(4) The imaginary yarn would not have any air gaps, and in this case should have THEORETICALLY THE SMALLEST DIAMETER, defined as *substance yarn diameter* $D_S = (4S/\pi)^{1/2} = ((4T/(\rho\pi))^{1/2}$ – see fig. 2 [D in mm]. For real *yarn diameter* $D > D_S$ and it is valid $D = (4S/(\pi\mu)^{1/2} = ((4T/(\rho\pi\mu))^{1/2}$,

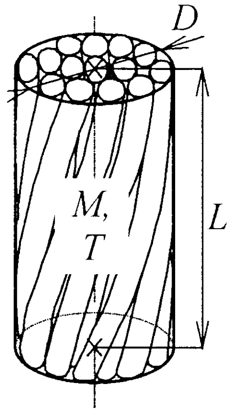

Fig. 1

(1) Where it is not listed else where, the given expressions in this article are valid with the defined units, for example the SI unit system. (According to SI the unit of fineness is $1 kgm^{-1} = 1 Mtex = 10^6$ tex.). The most practical equation form could be derived by correcting the units by the reader himself.

(2) It is clear that, *t* is dependent on the geometry "roughness" of fibre material surface, i.e. Area of fibre cross section *s*, also depends on fibre density ρ. ONE CANNOT COMPARE FIBRES THROUGH THE VALUE *t* which have different density! (according to fibre type „for viscose 1,7 dtex polypropylene also 1,7 dtex" is principally false)

(3) Physically, understood that the stress σ_f is not only dependent on the value σ, but also on the material density ρ. Therefore the values of type CANNOT BE USED IN COMPARING MECHANICAL BEHAVIOUR (strength and similar characteristics) of fibres with DIFFERENT DENSITY!

(4) Substance cross-section *S* is expressed also by the *fibre volume in unit yarn length*, i.e. As „roughness" of yarn in geometrical meaning. *T* is then depends as on this geometrical yarn „roughness", and also on the fibre density of the used material r. Similar to fibres (see remark **Error! Unknown switch argument.**) therefore by means of the value *T* WE CANNOT COMPARE YARNS PRODUCED FROM MATERIALS OF DIFFERENT DENSITY.

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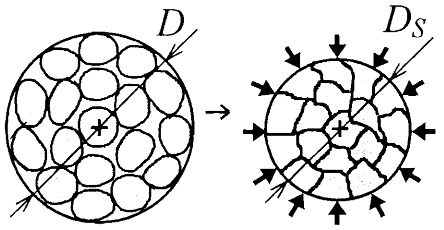

Fig. 2

where the so-called *packing* (expresses the portion of yarn occupied with air. (it is valid that $\mu = 4S/(D^2\pi) = (D_S/D)^2$). From the equation of yarn diameter D it is obvious, that the traditional used „equation" $D_S = K(T)^{1/2}$, where the nominator of the *diameter* $T = 2/(\pi\mu\rho)^{1/2}$ is constant, this is valid only for yarns from THE SAME MATERIAL DENSITY and twisted in such a manner that that they have THE SAME PACKING.

The ratio between yarn fineness and fibre fineness defines the *relative yarn fineness* $\tau = T/t$. Frequently this expression is used FALSE to express the number of in yarn cross section. The true is the NUMBER OF FIBRES IN YARN CROSS SECTION is $n = \tau.k_n$, where the factor $k_n \leq 1$ IS THE MEASURE OF FIBRE TAPERING in the yarn, then it is valid that $k_n = s/s^*$, s^* is the mean value of (shaded) area of one fibres in yarn cross section. (For open-end yarn the value of k_n is about 0,8, for combed and carded yarn is about 0,95 and for untwisted silk is k_n about 1.)

As a result of the twist in the yarn Z [Z in m^{-1}] the (idealised) fibres in the yarn take a helical shape. *The angle of inclination of the fibres on the yarn* surface β_D is shown in fig. 3. The tangent of this angle is the measure of yarn twist, which is known as the *intensity of twist* $\kappa = tg\beta_D = \pi DZ$. Another characteristics are the *Köchlin* [2] *twist coefficient* $\alpha = Z(T)^{1/2} = (Z(S)^{1/2})(\rho)^{1/2} = [(\kappa(\mu)^{1/2})/(2(\pi)^{1/2})(\rho)^{1/2}$ [α in $m^{-1}ktex^{2/3}$], or the Czech standard *Phrix twist coefficient* $a = ZT^{2/3}$ [a in $kg^{-1}ktex^{2/3}$].

From the other observed yarn characteristics, the behaviour of yarn during tension loading, described by work of rupture curve, relative strength(5) and elongation and further more the irregularity parameters(6), mainly the coefficient Of variation CV, amplitude spectrum, yarn imperfection etc..

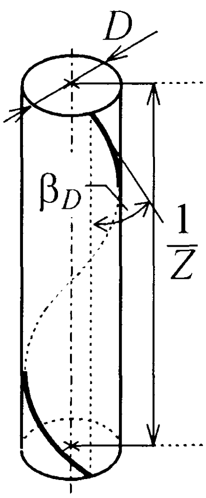

Fig. 3

(5) Remark **Error! Unknown switch argument.** is also analogously valid for yarn.

(6) Measured usually by Uster Tester and Classimat from Zellwewger – Uster.

2. DETERMINATION AND MODELLING OF YARN STRUCTURE

2.1 Relationship between fineness, twist and yarn diameter

The equation stated in chat. 1.2 shows that, the yarn diameter D depends on the values of yarn linear density T and fibre density (and on the less known coefficient of yarn packing m. Simple solution is introduced on idea that, it is „understood" that the yarns from the same material, produced on the same technology and for similar end use, have the SAME PACKING FACTOR (Köchlin model). In praxis SUCH IDEA IS NOT PROVED, it is evident that fine yarns with higher twist have higher packing values.

In fact, the packing results from the force interaction of twist and the material resistance against this compression. Solution of internal mechanics of yarn, requires specific models deal with fibrous material compression(7) [3], following two equations were derived from this theory.

$$\frac{(\mu/\mu_m)^{5/2}}{\left[1-(\mu/\mu_m)^{A+2}\right]^2} = \frac{M\sqrt{\pi}}{2000\mu_m^{5/2}\sqrt{\rho}}\left(ZT^{1/4}\right)^2 \qquad (1)$$

$$\frac{(\mu/\mu_m)^{3/2}}{[1-(\mu/\mu_m)^{A+2}]^2} = \frac{K}{8\sqrt{\pi\mu_m^3/\rho}\sqrt{T}\left(1-\sqrt{t}/\sqrt{T}\right)^2} \qquad (2)$$

where: A – *characteristics contact* between fibres (usually $A \cong 1$), μ_m – limit packing; generally $\mu_m \rightarrow 1$, taken in confederation the effect of outer layers of yarn, this value approaches $\mu_m \cong 0,8$. M – *over-all parameter of fibre compression in yarn*, DEPEND ON THE USED MATERIAL AND THE TYPE OF SPINNING TECHNOLOGY.

Some orientation values are given in the following table:

Material	Density	Values of $M_{[m]}$		
	$\rho_{[kg.m^{-3}]}$	Combed	Carded	OE (BD)
cotton	1520	0,0064	0,0042	0,0027
VS – c type	1500	0,0180		0,0077
PES – c type	1380	0,0125		0,0054
Wool	1360	0,090	0,0050	0,0027

Material	$K_{[mm]}$	Material	$K_{[mm]}$
Cotton – long	0,780	PES – C type	1,37
Cotton – middle.	0,975	wool	0,917
VS – C type	1,68		

(7) Introduced solution is based on the equations of a simple model for fibre material compression. It was found also a solution based on general model for two dimension fibre material compression, which is physically more accurate for solution. Equation derived are more complicated and numerical results are practically the same as found from the simplified described model.

K – twist *characteristic*, expresses „twist intensity“ (as well as the twist coefficient; DEPENDS ONLY ON MATERIAL TYPE. For ordinary yarn (weft yarn), orientation values are given as follows:

Equations (1) and (2) facilitate the solution of following tasks:

1. Knowing the values of M, K, (and t, it is possible to find for each yarn count T the suitable value of packing (as which is the root of equation (2). Definition expression for yarn diameter $D = (4T/\pi\mu\rho)^{1/2}$ can be calculated. From equation (1) the required yarn twist Z can be found.
2. Knowing the values of M, (and t for given yarn count T and twist Z, the packing (can be found and used as the root of equation (1). From equation (2) is then the value of the twist characteristic K. (This can be used for calculating the suitable twist for yarns of other counts according to point 1.)

The relation ship between the packing and product of $ZT^{1/4}$ according to eqn. (1) is illustrated in fig. 4.

For practical point of view, the calculation of both types are very long[8], therefore it reasonable to approximate the equations. The approximated expressions are relatively valid for wide range of *yarn characteristics, yarn count T^** and twist Z^*. The only required yarn parameters are packing μ^* and diameter D^*, which could be found from eqn. (1), (2). Then the following parameters are calculated (3)[9]:

$$b = 3\frac{1+(1+A)(\mu^*/\mu_m)^{2+A}}{1-(\mu^*/\mu_m)^{2+A}};\ u = \frac{3b+1}{3(2b-1)};\ v = -2{,}4u + 1{,}2;$$

$$a^* = \frac{Z(T^*)^{2/3}}{100};\quad Q = \frac{D^*}{(T^*)^u (a^*)^v};\quad B = \frac{2}{\sqrt{T^*/t^*}};$$

$$\xi = \frac{b-0{,}5}{b-0{,}5};\quad q = [\xi(1+B)+1]/4;\quad \alpha_q = Z^*(T^*)^q;$$

For a relative wide range around yarn characteristics, then the following APPROXIMATED EQUATIONS ARE VALID for yarn diameter and yarn twist.

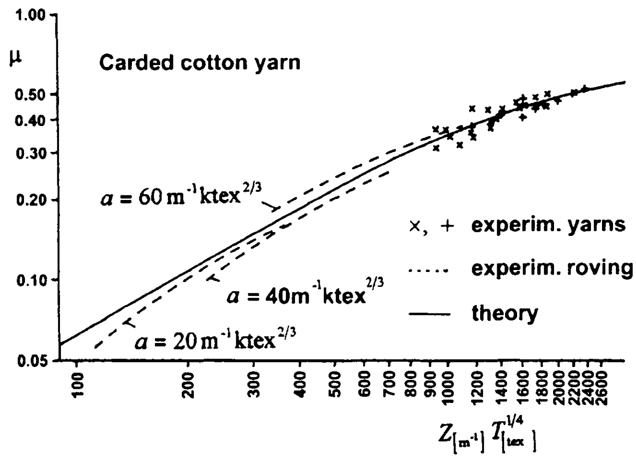

Fig. 4

$$D = QT^u a^v;\qquad Z = \alpha_q/T^q \qquad (4)$$

(Considering for ex. ordinary cotton carded yarn, this is t = 0,16 tex, ρ = 1 520 kgm^{-3}, A = 1, μ_m = 0,8, M = 0,0042 m, K = 0,975 mm and yarn characteristic $T = T^*$ = 29,5 tex, we find by applying eqn. (1) and (2) $\mu = \mu^*$ = 0,4573, $D = D^*$ = 0,2324 mm. Approximated equations gave then concrete form $D = 0{,}0792T^{0{,}591}\ a^{-0{,}219}$; $Z = 5825/T^{0{,}621}$. It is interesting, to find the *twist exponent* q = 0,621, which is very close to the empirical exponent 2/3 defined by Phrix twist coefficient.)

2.2 Porosity and equivalent diameter of pores between-fibres.

The yarn behaviour is to a great extend depends on size and the characteristics of the air space inside the yarn. The volume portion of the yarn filled with air is defined as *porosity* ψ.

$$\psi = 1 - \mu \qquad (5)$$

The air volume in yarn can be concentrated in small number of big "holes", as well as, contrary to this, the same air portion can be distributed in small "capillary" holes between fibres. The dimension characteristic of air volume between fibres can be expressed as *equivalent diameter of pores between fibres* d_p. According to some definite assumptions equation [4] was derived for the equivalent diameter of pores between fibres.

$$d_p = [c/(1 + q)][(1 - \mu)/\mu]d \qquad (6)$$

Equivalent diameter of pores is dependent on fibre diameter d and shape factor q, yarn packing m. General solution is derived in the work [6] instead of equation (6), the following is more general expression:

$$d_p = [1/(1 + q)][(1 - \mu)/\mu]^k d \qquad (7)$$

Where the parameters c and k essentially found empirically, according to the applied case (pores from the point of view filtration, capillary phenomenon etc.)

2.3 Number of fibres in cross section and coefficient k_n

For better understanding some yarn properties one can simplify the assumption by using *ideal helical path of fibres model.* This is based on the assumption that the fibres are arranged in a helical path. For such ideal yarn the *coefficien k_n* was derived.

(8) Packing should be obtained in advance from eq. (2), resp. (1) by using suitable numerical method, or by using in advance prepared tables.

(9) a^* is Phrix twist coefficient of dimension m^{-1}ktex$^{2/3}$. The value of α_q is the generalised twist multiplier with the dimension m^{-1}tex^q, where q is twist exponent .

(10) β_D in another form, it is the angle of inclination of the outer fibres; see chap. 1.2. and fig. 3.

$$k_n = [2/(\pi DZ)^2]\left[\sqrt{1+(\pi DZ)^2}-1\right] = \\ = 2\cos\beta_D / (1+\cos\beta_D) \qquad (8)^{(10)}$$

And for *the number of fibres in yarn cross section* the following expression was found

$$n = k_n\tau = k_n(T/t) = \\ = \left[2(T/t)/(\pi DZ)^2\right]\left[\sqrt{1+(\pi DZ)^2}-1\right] \qquad (9)$$

For a yarn with „good“ oriented fibres (twisted silk, combed yarn, carded cotton yarn), the value k_n (ranges about 0,95 for staple yarns) that is fitted to the expression (8), in this case also expression (9) is satisfactory. Yarns with „bad“ oriented fibres (rotor yarn, woollen yarn etc..), are never confirm with the ideal helical model, and therefore equations (8) and (9) could not be applied.

2.4 Yarn contraction

Twisting a fibre assembly of length ζ_0 form a yarn of length $\zeta < \zeta_0$. This shortening due twist is known as contraction due to twist $\zeta = (\zeta_0 - \zeta)/\zeta_0$. If the input fibre assembly is „sufficient“ parallel and optimal twist is inserted „not over twisted – no slippage between staple fibres", then the expression $\delta = 1 - k_n$ is used. Applying this expression and rearranging, the well-known equation according to Braschler [5] then it is valid:

$$\delta = 1 - k_n = \\ = \left[\sqrt{1+(\pi DZ)^2}-1\right] / \left[\sqrt{1+(\pi DZ)^2}+1\right] \qquad (10)$$

At almost staple yarns, due to twist the "so-called false twist“ may occur mainly, at the outer yarn layers, therefore the real contraction is smaller. To find out *the contraction of staple yarn,* formally eqn. (10) can be used, but instead of yarn diameter D, it is necessary to apply the smaller values D_δ, found according to [6] by the empirical form:

$$D_\delta = D[1 - 1{,}2(\mu_m - \mu)/(1180S^{1{,}88} + 1)] \qquad (11)$$

(Similar to chap. 2.1, it is suitable to use μ_m = 0,8. For substance cross section according to chap. 1.2, the equation $S = T/\rho$ is valid.)

2.5 Internal fibre arrangement in yarn – principle of experimental methods

A lot of yarn properties can be better understood, on base of deep information about the yarn arrangement inside the yarn. One of the most effective tools for experimental investigation of internal structure, is IMAGE PROCESSING ANALYSIS OF YARN CROSS SECTION. The procedure is as follows:

1) Preparation of a microscopically yarn cross section sample, i.e. pour the yarn sample to a polymer bitumen and cutting the cross section by ultra fine microtom with glass cutter, or pour the yarn to an adhesive type „dispersion adhesive“, after that to a wax and paraffin mix and cutting the sample by a quality steel cutter.
2) Enlarging the image of the yarn cross section through an optical microscope, which is transmitted to the computer an correction of image (i.e. insert more contrast, etc..)
3) Extracting position „centre„ of cross section of individual fibres and saving the data to the computer.
4) Using a developed software to evaluate fibre arrangement of fibres in yarn cross section..

2.6 Radial packing behaviour and blend ratio

In the previous chapter, packing was understood as *mean yarn packing.* In fact inner layers, i.e. the layers at the small radii(11), show the highest values of packing, and in the direction of the surface, i.e. at bigger radii, packing is characterised by S-curve decreased to 0. According to our experience, [6] and [7] this decrease is sharp at the most better arranged fibres (combed yarns), and in contrary to that, for yarns with less arranged fibres (rotor yarns), the decrease is some how moderate. The results of three cotton yarns are illustrated in fig. 5. (yarn No. 5 – 25 tex, rotor yarn BD; yarn No. 6 – 29.5 tex, rotor yarn BD; yarn No. 7. – 20 tex, ring spun carded yarn.)

For two components yarn (for example cotton – polyester) one can beside the radial packing behaviour, evaluate the radial *partial packing* behaviour of each component and then, finding *the radial blended ratio behaviour* [8] of components. Usually it is found that one component (for ex. polyester) has clear tendency to be at the yarn core, while the second component (for ex. Cotton) is to a great extend found at the yarn surface.

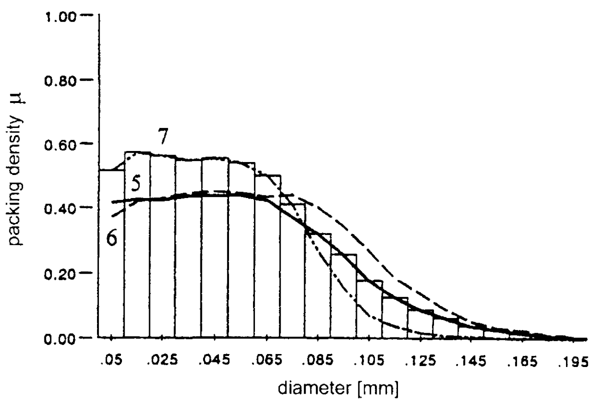

Fig. 5

(11) Except small space around yarn axis.

2.7 Component constitution "assembly" of fibres in blended yarn

During production of two-component yarn, the starting material is separated (in bales) and is blended firstly in spinning process, where cohesion and similar forces have the tendency to keep the fibres from one or other component together. In yarn cross section there for the higher frequency of number of fibres of one or another component are found in the observed places. In our method we arrange each fibre in yarn cross section as one *assembly* of *n* fibres(12).

The experimental procedure is as follows:

1) Arranging the fibres in yarn cross section according to their distance (distance of cross section) from the starting fibre.
2) First *n* fibre, i.e. starting fibre and *n* – 1 next the nearest to it, compose assembly of *n* fibres.
3) Establishing the number of fibres of the first and the second component in the observed assembly *n* fibres.

Repeating this procedure, where we chose EACH FIBRE in yarn cross-section as starting fibre. For evaluation we arrange assemblies of big (for ex. 60) random cross sections and we define *experimentally the distribution* of component portion in the assembly *n* fibres.

If the fibre distribution is to a great extend random, then the frequency distribution of fibres of one (for ex. first) component in assembly of *n* fibres is then can be fitted to the theoretical *hyper geometrical distribution.*

$$H_n(k)=\binom{n}{k}\binom{N-n}{M-k}\Big/\binom{N}{M} \qquad (12)$$

where H_n(k) – assembly portion with *n* fibres, in which is *k* fibres of the first component (k $\in\langle 0,n\rangle$), *N* – total number of fibres in yarn crosses section, *M* – number of fibres of the first component in yarn cross-section

In comparison to the theoretical distribution, it is found that the observed distribution of the assembly is of higher weight, for one or another component, and the frequency of assemblies with pronounced portion both component is small. This difference facilitate the possibility of quantities some kind of *measure of mutual interaction of blending of components,*

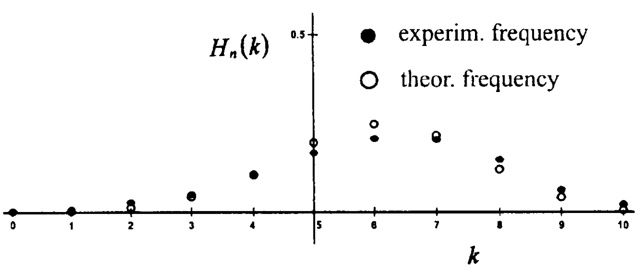

Fig. 6

which is a measure of the quality of *non-separation* of fibres during spinning process. Example according to [9] is evaluation of assemblies of *n* = 10 fibres of a blended combed yarn of 28 % cotton and 72% polyester and is illustrated in fig. 6.

2.8 Yarn hairiness

Recently some methods are developed for evaluating yarn hairiness via image processing analysis. The present experience [6] show that there ARE TWO REGIONS OF HAIRINESS and they are:

1) *Region of „dense" hairiness,* which consist of fibres at distance about one yarn radius far from its surface (from the observed place where yarn diameter is investigated). In this region the fibres are still in mutual contact, material is characterised as „elastic mesh", which is very important for hand and abrasion of textiles
2) The second region *„soft" hairiness* and contains mainly isolated (free „nested") fibre ends, which create some technological problems (for ex. the so-called „spinners") and appearance problems in fabrics. (By singing process such hairiness can be eliminated.)

2.9 Yarn mass irregularity

Real values of yarn irregularity *CV* are always higher, than the limit values CV_{lim} calculated from Martindale model, where it is assumed that the fibres are random distributed in yarn (The most simple equation for „limit" irregularity is CV_{lim} = $100/(n)^{1/2}$ where *n* is the number of fibres in yarn cross section). This is due to the fact that most probably the fibres moves in spinning process not individually, but in some FIBRE GROUPS AND ASSEMBLIES. Modelling an solution of this problem is given in [10], where we find for calculating the irregularity the following equation:

$$CV=100\sqrt{(a+Bn)/n} \qquad (13)$$

where *A* – parameter depend on fibre fineness variation, mainly the tendency of „clamping" ibre row material in RIGID FIBRE ASSEMBLIES („knots", fibre), *B* – parameter expresses the IMPERFECTION OF SPINNING PROCESS during individualisation of fibre row material.

From the stored data in spinning mill, the parameters *A*,*B*,(13) could be found, accordingly one can judge in case of bad values, of irregularity if the cause is occurred due to bad row material (*A*) or originated from bad spinning technology (*B*).

(12) Evaluating gradually assemblies containing *n* = 1, 2,...10 fibres.

(13) For example applying statistical method (linear transformation) of regression; from (13) also is valid $(CV/100)^2 = A(1/n)+B$.

3. STRUCTURAL RELATIONSHIP OF MECHANICAL PROPERTIES OF YARN

3.1 Yarn strength and span length

According to the so-called *weak point principle* it is observed that the mean value of yarn strength and its coefficient of variation *decrease* as the *span length increases*. If yarn strength is P for „short" span length l_0 by NON-CORRELATED *random process* with *distribution function* $F_0(P)$, then the *distribution function* $F(P)$ of strength for other span length l is given by [11] as

$$F(P) = 1 - [1 - F_0(P)]^{l/l_0} \tag{14}$$

If the distribution $F_0(P)$ is *normal* with mean value of $\bar{P}_0$ and standard deviation σ_0, then by applying expression [11] for calculating the mean value $\bar{P}$ and the standard deviation σ of yarn strength for span length l.

$$\bar{P} = \bar{P}_0 + 4{,}2\sigma_0[(l/l_0)^{-1/5} - 1]; \quad \sigma = \sigma(l/l_0)^{1/5} \tag{15}$$

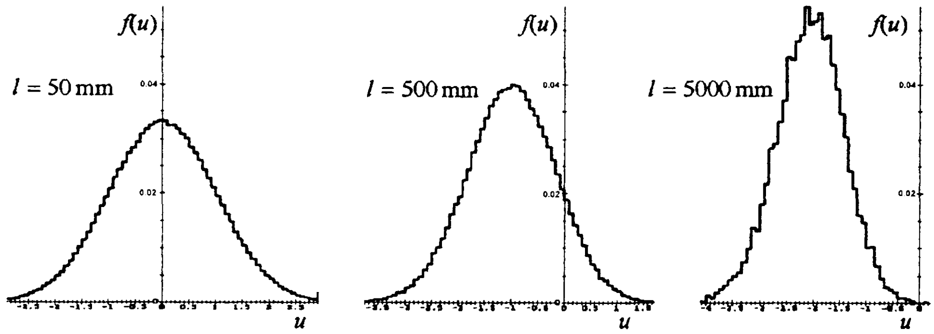

Fig. 7

The strength P at „short" span length l_0 is often creates CORRELATED *random process*(14) with *autocorrelation function* in the form of the sum of TWO exponential functions [4]. This means, that two different effects cause decreasing yarn strength. One of them is probably caused by yarn mass irregularity, The second effect was till now unexplained. Finding and modelling the distribution and statistical characteristics for strength at different span lengths is very difficult [4], applying and working out simulation software can be easy realised. Results of an example for a ring spun cotton carded yarn, (T = 29,5 tex, Z = 710 m^{-1}) is plotted in fig. 7.

Knowing probability density distribution of yarn strength at span lengths of 50, 500 and 5000mm. (in graph the linear transformation of the random variable $u = (P - \bar{P}_{50})/\sigma_{50}$ is used, where P is the random variable of yarn strength at given span length, $\bar{P}_{50}$ and σ_{50} are the mean value and the standard deviation of strength at span length 50 mm.)

(14) More accurate the sum of two independent stationary, ergodic, Markov and Gauss random processes.

3.2 Fibre utility of tensile strength and yarn breakage.

The relationship between yarn tensile strength σ_f and relative elongation ((average) of a fibre is described by *fibre stress-strain curve* $\sigma_f(\varepsilon)$. Similar to that the relationship between the tensile load (of a yarn and its relative elongation „extension" (is described by *yarn stress-strain curve* $\sigma(\varepsilon)$. Because the yarn is complicated in structure, created though different friction binding forces, so that, naturally at the same extension (the $\sigma(\varepsilon) < \sigma_f(\varepsilon)$. The difference between work of rupture of fibre and yarn is cauterised by *the substance tensile force utility,* given by the ratio:

$$\varphi(\varepsilon) = \sigma(\varepsilon)/\sigma_f(\varepsilon) \tag{16}$$

Experimental results [6] show, that the values of utility (except at the region of small extension e) is relatively high. For different yarns of the same viscose cotton type, the values are given in the table and illustrated in fig. 8.

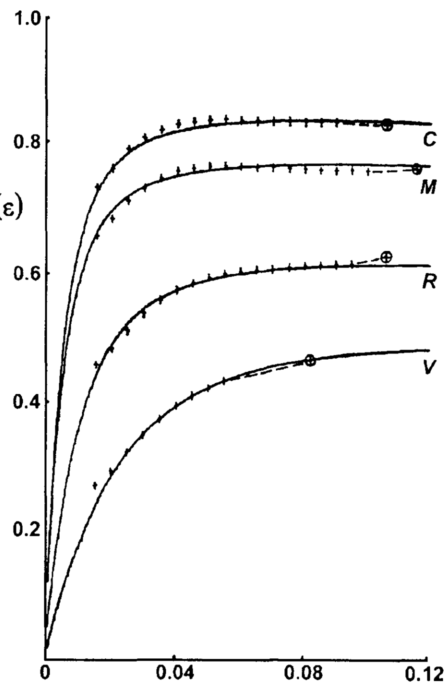

Fig. 8

Yarn	Type	T [tex]	Z [m^{-1}]	Settled value $\varphi(\varepsilon)$
C[15]	combed	40,5	400	about 0,83
M	carded	36,8	497	about 0,79
R	OE	38,3	517	about 0,62
V	woollen	101	372	about 0,45 (unsettled)

The settled values of $\varphi(\varepsilon)$ are really HIGHER, than strength substance η_P, defined from the ratio of the mean value of the relative fibre strength P_f and mean value of the relative yarn strength P.

$$\eta_P = P/P_f \tag{17}$$

Difference between the value $\varphi(\varepsilon)$ and η_P is explained by the EXTENSION DIFFERENCE of yarn and fibres, which caused due to the so-called weak point principle (see the previous chapter).

3.3 Effect of fibre inclination and substance tension force utility

Twisted inclined fibres are loaded by higher force during tension than those fibres of parallel assembly. In simple case [6] applying the ideal helical path model and further assumptions, the value of φ_Z which expresses *the total substance tension force utility, which is caused* only by this phenomenon. Further it is valid

$$\varphi_Z = (1 + c)\cos^2\beta_D + c\ln(\cos^2\beta_D)/\mathrm{tg}^2\beta_D \tag{18}$$

Where β_D – angle of inclination of outer fibres ($\mathrm{tg}\beta_D = \pi DZ$, see chapter 1.2 and 2.1), c – ratio of radial contraction ($c \in \langle 0;0{,}5\rangle$), for first approach the value may be chosen as c = 0,25).

This expression is suitable for „good" oriented yarns[16] (Twisted silk, combed yarns, carded yarns.)

3.4 Effect of fibre extension variability on substance strength utility

Fibres of high extension variability cause lower yarn strength. For simplifying this phenomenon can be

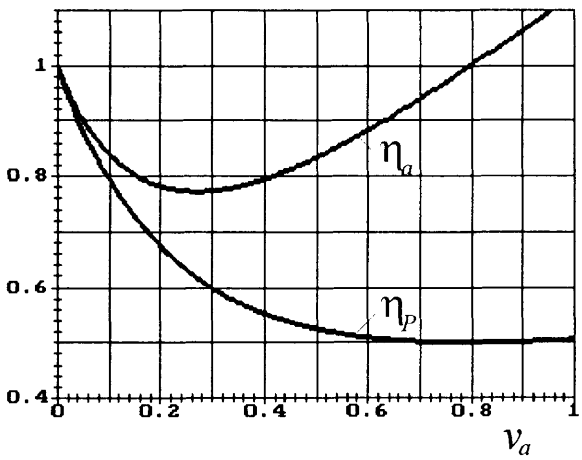

Fig. 8

modelled as *parallel fibre assembly*, and deriving stochastic substance strength utility model η_P (see eqn. (17), which is valid only for fibre assembly assumptions according to [4]. Putting the value of fibre extension a_f a_f and mean value of yarn extension a the *substance yarn extension utility* can be expressed as :

$$\eta_a = a/a_f \tag{19}$$

In simplified case according to [4] we find the following equation

$$\frac{v_a}{uv_a + 1}\frac{1 - G_N(u)}{g_N(u)} = 1 \quad (\Rightarrow u\ldots\text{root of egn.}) \tag{20}$$

$$\eta_a = uv_a + 1; \quad \eta_P = (uv_a + 1)[1 - G_N(u)]$$

where v_a – coefficient of variation *of fibre extension* (as a fraction and never in percentage), $g_N(u)$ – probability density function of standardised normal distribution, $G_N(u)$ – distribution function of standardised normal distribution.

(From the first equation the root u must be numerical calculated, other equation could be directly solved.)In such a manner, the relationship between η_P and η_a and the fibre extension coefficient of variation v_a are calculated and illustrated in fig.9; actually, the practical region is to about v_a = *0,3.*

3.5 Yarn hardness

Yarn hardness affect hand and other resulting textile properties. Yarn hardness depends on the applied fibre material and type of spinning process mainly the coefficient of yarn packing. By using the model of fibre compression (see also chapter 2.1) we can express *the yarn hardness* by the following equation:

$$E = k_p e \quad e = 3\mu^3[1 + 2(\mu/\mu_m)^3]/[1 - (\mu/\mu_m)^3]^4 \tag{21}$$

where E – *absolute value of yarn hardness* (with pressure dimensions, for ex. MPa), e *–relative yarn hardness* (dimensionless alue), k_p – *fibre material nd technology type parameter (*pressure dimensions, i.e. MPa), μ_m – packing limit (for yarn according chap. 2.1 about $\mu_m \cong 0{,}8$).

Calculating the value of k_p, and the absolute value of the yarn hardness is really difficult. In contrary to that, if the material and the type of applied technol-

(15) Combed yarn 100% viscose fibre was prepared only as special experimental material with extreme perfect fibre arrangement.

(16) If for ex. β_D = 25°, then for c = 0,25 we calculate φ_Z=0,800, which good corresponds to the settled value j(e) for combed and carded yarns in the table in chapter 3.2. Most probably, that the inclination of the fibres is for „good" oriented yarns with usual twist are the main reason for reaching the values of substance tension force utility.

ogy are known, one can judge yarns of different counts and twist via the relative values of hardness e.

3.6 Further mechanical properties

A lot of further information at and research works due to the course of mechanical structure as shrinkage due to washing of cellulose yarns, radial compression and yarn deformation, yarn abrasion, such detail information are found at the textile structure department TU Liberec.

4. CONCLUSION

The present work introduce short information about some less known problems, although some phenomenon are introduced in short and are imperfect, but it gives global idea about the present knowledge in the area of textile structure. Offering wide range of knowledge help in clarifying yarn behaviour and solve concrete problems. The global aim of our investigation is to realise the idea of YARN CONSTRUCTION SYSTEM, (extended to weaving and knitting) by means of special software. Such tool facilitates projecting more exact yarn properties suitable for praxis and industry.

***Acknowledgement**: The present work is sponsored by the research grant No. MSM 244100004.*

LITERATURE

[1] Malinowska,K., *Prace Inst. Wlok.*, **29**, Lodz, 1979 (Polish).
[2] Johansen, O.: Handbuch der Baumwollspinnerei 1. Band. Leipzig 1930 (German)
[3] Neckář, B., *Textil Res.J.*, **67**, 1997, p. 123.
[4] Neckář, B.: Morfologie a strukturní mechanika obecných vlákenných útvarů. *Technical University of Liberec*, Liberec 1998 (Czech).
[5] Braschler, E.: Die Festigkeit von Baumwollgespinsten. Zürich 1935 (German).
[6] Neckář, B.: Příze. *SNTL*, Praha 1990 (Czech).
[7] Křemenáková, D. – Patejdlová, D. – Wimmerová, K.: Vnitřní struktura rotorových přízí. In: *5. conf. STRUTEX, Proceedings*, Liberec 1998, p. 105 (Czech).
[8] Křemenáková, D., *Fibres and Textiles in Eastern Europe*, **6**, 1998, p. 24.
[9] Křemenáková, D. – Neckář, B. – Roček, V.: Distribution of Fibrous Bundles in Blended Yarn. In: *3rd Int. Conf. Textile Science, Proceedings*, Liberec, p. 328.
[10] Neckář, B., *Mell. Textilber.*, **70**, 1989, p. 480 (German).
[11] Peirce, F.T., *Textil. Res. J.*, **17**, 1926, s. T342.

DEPARTMENT OF EVALUATION OF TEXTILES

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Characteristics

A new department of Technical University of Liberec – Department of Evaluation of Textiles - was established at the Textile Faculty of Technical University in Liberec on 1st September 1999. The situation converged to this act some time ago and now it came true.

There has been an effort for some time already to establish a department, which would guarantee the BSc field of Textile Marketing, but only now after being staffed by specialised workers the new Department was created.

Thus, the creation of this new department partially follows the tendencies which appeared e.g. in the U.S.A. in last decades. Due to increasing import of cheap fabrics from Asia, the production of textiles stepwise moved form the Eastern coast to South, towards the resources of primary textile materials, mainly cotton. Consequently, also the tuition of classical textile technologies was strongly reduced in the study programmes of textile departments in the north of the U.S.A., whereas the study of textile technologies keeps important at universities of Carolinas, Texas, Tennessee and Georgia in the South of the States. In order to meet the increasing demands of the U.S. customers, new subjects respecting the necessities of textile end-users begun to be lectured in textile departments in the whole country. No wonder, that names of some new U.S. textile departments, like Dept. of Home Ecology, Dept. of Customer Services, reflect these world trends.

Teaching activities

The new Department of Evaluation of Textiles in Liberec should guarantee the university education of Textile Marketing in daily as well as in combined study. There is about 200 candidates for daily education every year from which just 70 students is admitted. The selection is based on compulsory tests, but the results of secondary school study (with respect to different level of tuition in various types of schools) are taken into account as well. The combined education presents only small part of the daily study and the main part is provided as the distance study, i.e. individual study according to time possibilities of students. This form is advantageous mainly in situation when workers of textile mills want to complete their education and gain the BSc title. The combined form of study consists of two parts: first one, lasting 3 semesters has to be covered by a student, the resting BSc part (6 semesters) is free of charge. Both mentioned types are concluded by the defence of BSc work and by State Final Examination after which the students receive the university title of BSc (Bc in Czech version).

Bachelor of Textile Marketing is a profession, which is strongly required in the field, because after retirement of many professionals there are many posts free and textile and commercial organisations call for graduates of this specialisation.

As for the disciplines taught, the department offers the disciplines of three BSc fields of Textile Faculty, as Textile expertise, Textile comfort, Strategy of sale of textile goods, and as for computing abilities, there is Administration on PC, Microsoft Access Database – disciplines aimed at requiring knowledge of textile professional and besides disciplines of economic character as Marketing, Finances, Taxes, Commercial law etc. which are taught by departments of Economic Faculty of the University.

The specialisation of individual stuff members at the new department is chosen so that all requirements of the study program are covered. The program is made up in order to meet the requirements of modern society and with the effort to offer to students interested in this field the disciplines which could determine their orientation in practical life.

Research activities

Besides the mentioned activities the Department members use to work up various expertises on new technologies, on projects ordered by Ministry of Industry and Commerce and they are also asked to evaluate new types of textiles and technologies prepared for domestic and foreign markets.

Within the framework of long time collaboration with TRUSTFIN a.s. there are many specialised research works executed for this company, where students of second year of Textile Marketing are also engaged, in order to enrich their knowledge and to learn to know the inland marketing milieu.

International collaboration is based on individual contacts of the Department members and is aimed at innovations of the teaching process in daily and distance study and also to research works embracing new types of textile materials and membranes used in production of garments and clothing to achieve their optimum sensorial and thermo-physiological comfort.

Mechanical and thermo-physiological properties of fabrics are also studied within PhD works of young members of the new department.

AN INDIRECT METHOD FOR FAST EVALUATION OF SURFACE MOISTURE ABSORPTIVITY OF SHIRT AND UNDERWEAR FABRICS

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Abstract: Customers wearing shirts understand, that the feeling of comfort when wearing shirts in hot days should depend on their vater vapour permeability and their moisture sorption capacity,but both these parameters do not characterise the thermal contact comfort feeling of shirt fabrics in wet state.

In order to explain the thermal contact comfort of superficially wetted shirts, a new parameter called moisture absorptivity was introduced and a simple equation of the moisture transfer between the fabric and skin was derived in the paper. Since the direct measurement of the moisture absorptivity is complicated, an indirect method for its experimental determination was described and used for the evaluation of thermal comfort of fabrics contacting wet human skin.

1. INTRODUCTION

Men generally prefer to wear 100% cotton shirts, because they consider their thermal and sensorial comfort better, especially in hot days, in spite of the common experience, that shirts containing even small portion of PES fibres exhibit less wrinkles, show smooth surface and can be easily ironed. Wearer generally believe, that higher thermal comfort of pure cotton shirts is due their higher water vapour permeability and sorption capacity compared with shirts made of PES/cotton blends.

In order to explain the effect of this first parameter, water-vapour permeability of both kinds of shirts was measured in this study. From the measurements made on the Permetest (Sensora) instrument resulted, that water-vapour permeability of the measured shirts depends more on their mass per area then on their composition, and that in all cases the relative vapour permeability was very good, exceeding 15 %.

The next parameter in question is the moisture sorption capacity (absorbency) of shirt fabrics. There are plenty of method to measure this parameter [1]. Nevertheless, the moisture absorbency characterises just the specific moisture retention corresponding to the state of full saturation of the fabric volume by water or sweat, and is directly proportional to the fabric mass. No transient aspects are considered here, and no different boundary conditions of moisture transmission between the skin and a fabric are respected.

Therefore, Scheurell and al. [2] reminded the importance of studying the dynamic surface wetness of fabrics, and developed a new method of their determination, which is based on humidity dependent colour changes of a special chemical agent deposited on the fabric surface. In their study, a cotton fabric freely exposed to saturate water-vapour increased its surface humidity 2–3 times faster then a PES fabric of similar parameters. The authors concluded, that the dynamic surface wetness is a very important factor influencing the clothing comfort of garments. A survey of other techniques to measure transplanar liquid transport into fabrics published Kissa [3].

Nevertheless, all the found measuring method are not suitable for simple standard measurements of transient fabric wetting, due to quite complicate preparation of the measurements, poor dynamic properties of some methods or due to inexact results evaluation in some cases. Moreover, the reduced comfort caused by wearing the PES/cotton shirts in hot day is felt mainly in the moment, when the suddenly wetted fabric touches the skin. Consequently, the local cool feeling occurs, which is considered as unpleasant. Within the contact time, heat is transferred by conduction through a thin intermediate layer, created by wet outstanding fibres. Thus, the boundary condition approximates to the heat transfer of 1st order, which should be respected within a measuring method in question.

Therefore, the first objective of the research work was to develop a method of an indirect experimental determination of the so called **surface moisture absorptivity B** [4], whose higher level apparently increases the contact comfort of wet fabrics and on the contrary. A new measuring method described in the paper is easy and reproducible, and reflects the real moisture and heat transfer conditions between the fabric and the skin.

2. THEORETICAL PART

2.1. Introduction of moisture absorptivity

The amount of liquid inside any porous structure or textile fabric can be expressed in terms of the fabric free volume saturation s [1]. Thus, for s = 0 the fabric is dry, and for s = 1 all the pores are full of a liquid.

In this case, the saturation propagation within a fabric, either along its surface, but also perpendicularly to its surface, can be characterised by the classical partial differential equation of diffusion processes:

$$(\partial s/\partial \tau) = A\ (\partial^2 s\ /\partial x^2) \tag{1}$$

where **A [m²/sec]** is so called **moisture diffusivity**. This parameter is for textile fabrics sometimes moisture dependent due to swelling. The solution of equation of this kind for A = const is generally known. If we consider just short time moisture conduction, then we can convert a textile fabric to a semiinfinite body, where the 1st order boundary condition is applied. In this case, the moisture saturation propagation in the x direction is given by the equation

$$s = \mathrm{erfc}\,(x/2A^{1/2}\tau^{1/2}) \tag{2}$$

The experimental determination of the moisture diffusivity from the moisture propagation along the measured fabric is possible. Unfortunately, the moisture diffusivity in this form does not characterise the volumetric capacity V of the fabric expressed in this case in m^3/m^2s to conduct the moisture (sweat) from the contacted skin away towards a fabric interior. To cope with this task, a Darcy law modified for the saturation gradient should be introduced as follows:

$$V = -\ \lambda_s(\partial s/\partial x) \tag{3}$$

where **λ_s [m²/s]** is the volumetric moisture flow conductivity, which is proportional to the fabric permeability. In the next step, we should remind, that in the first Fick's diffusion law, which is used to express the mass flow in the form formally identical with Eq. (3), the same diffusion coefficient D occurs, as in the second Fick's law for transient mass transfer by diffusion. By simplifying the problem solved to a simple diffusion, we can express the moisture flow conductivity in Eq. (3) λ_s by means of the moisture diffusivity A.

From applying this relation in equation (2) follows:

$$V = A^{1/2}(\Delta s/\pi^{1/2}\tau^{1/2}) \tag{4}$$

The first term in this equation fully characterises the fabric ability to absorb the moisture from any moist surface which contacts the fabric. Then this so called **moisture absorptivity B [m³s^1/2]** is defined by the next relation:

$$B = A^{1/2} \tag{5}$$

As shown in [3], many researchers have already measured the time-dependent longitudinal wicking of fabrics. From these results, the moisture diffusivity A could be determined and its square root used for the calculation of the spontaneous moisture uptake according to Eq. 4. Some research work in this field is going on at the MINHO University [4]. Nevertheless, this approach may produce inaccurate results, since longitudinal wicking rates not always correlate with the corresponding transplanar ones, due to the complexity of the wicking processes, which besides the diffusion processes include capillary penetration of moisture inside fabrics, and also moisture absorption of the on the fibre surface.

Therefore, the goal of this paper is to develop a technique, which would determine not the moisture absorptivity itself, but its real impact on the comfort properties of a surface wetted fabric. To achieve this, an indirect way was chosen, as explained in the next chapter.

2.2. Indirect method of the moisture absorptivity measurement

The suggested method is based on the objective evaluation of warm-cool feeling perceived by a wearer of a cloth, which suddenly comes into contact with a wetted skin. In this moment, the **cotton fabric absorbs the liquid sweat rapidly, and conducts it away from the fabric surface towards to the fabric inerroir. Due to high adhesion forces, the sweat keeps accumulated in the fabric close the places where the sweat was generated**. If the amount of sweat is not too high, within a short time the moisture concentration close to the fabric contact surface reduces, and the wearer feels the pleasant contact of nearly dry fabric.

The other mechanism of achieving the pleasant dry feeling of underwear and shirts is based on the use of **PES microfibres, which, due to higher surface, absorb in some extend the humidity also, but the liquid sweat is rapidly distributed by capillary forces in larger area** surrounding the perspiration zone, thus reducing the average relative humidity of fabric under the limit, which would result in unpleasant wet feeling. Unfortunately, this mechanism requires also some additional dymamic contact forces typical for sport activities.

In the case **of blended fabrics containing too much poorly absorbing PES fibres of common section and fineness, the sweat keeps adhered on the skin**, and provokes an unpleasant cool feeling due to sweat evaporation.

The suggested method is based on the objective evaluation of cool feeling effect within an experimental procedure which simulates the real fabric wearing conditions described above. Before the method is explained, the instruments for the objective warm-cool feeling determination are described.

2.2.1. Instruments for the evaluation of thermal contact feeling of textile fabrics

Warm-cool feeling means the feeling which we get when the human skin touches shortly any object, in our case textile fabric, leather or any polymer used in clothing, furniture or carpets. It was found, that this parameter characterises with good perfection the transient thermal feeling which we get in the moment, when we put on the undergarment, shirts, gloves or other textile products, especially these in wet state. Since this feeling strongly affects the choice of people when buying the clothes or garments, the objective assessment of this feeling became very important in the last decade.

The first instrument, which was able to evaluate the warm-cool feeling of fabrics objectively, was developed by YONEDA and KAWABATA in 1983 [1]. They have introduced also the maximum level of the contact heat flow $\mathbf{q_{max}}$ **[W/m²K]** as a measure of this transient thermal characteristics, and KAWABATA has published the first objectively determined values describing the thermal-contact properties of textile fabrics. The instrument, called THERMO-LABO, was commercialised and became used in laboratories.

Some years later (in 1986 – see in /2/), an other instrument for the objective evaluation of warm-cool feeling of fabrics, but of different concept, was completed at the Technical University in Liberec (in Czech Republic). This computer controlled instrument called ALAMBETA works in the semi-automatic regime, calculates all the statistic parameters of the measurement and exhibits the instrument auto-diagnostics, which checks the measurement precision and avoids any faulty instrument operation. The whole measurement procedure, including the measurement of thermal conductivity λ, thermal resistance **R**, $\mathbf{q_{max}}$, sample thickness and the results evaluation, lasts less than 3–5 min. As the objective measure of warm-cool feeling of fabrics, so called **thermal absorptivity b [Ws$^{1/2}$/m^{2}K]** was introduced [3].

This parameter (formerly used in the civil engineering and health protection sciences) was derived similarly as the moisture absorptivity above mentioned. Provided that the time τ of thermal contact between human skin and a fabric is short, textile fabric was again idealised to a semiinfinite body of finite thermal capacity $\rho\mathbf{c}$ [J/m^3] and initial temperature $\mathbf{t_2}$. Transient temperature field between human skin and a fabric is then given by the following partial differential equation

$$(\partial t/\partial\tau) = a(\partial^2 t/\partial x^2) \tag{6}$$

and can be used for the calculation of the initial level of heat flow **q** passing between the skin (characterised by a constant temperature $\mathbf{t_1}$) and textile fabric according to the next equation, whose derivation for the boundary condition of 1st order is similar to derivation of the Eq. (4):

$$q_{dyn} = b(t_1 - t_2)/(\pi\tau)^{1/2} \tag{7}$$

Thus derived thermal absorptivity **b** [Ws$^{1/2}$/m^{2}K] is given by the following relation:

$$b = (\lambda\rho c)^{1/2} \tag{8}$$

As it can be see, the level of thermal absorptivity depends neither on the temperature gradient between the fabric and skin, nor on the measurement time. This value just depends on the contact pressure, which also correspond to the real situation. The pressure is adjustable.

The simplified scheme of the instrument is shown on Fig. 1. The principle of this instrument protected by several patents depends in the application of a direct ultra thin heat flow sensor 4, which is attached to a metal block 2 with constant temperature which differs from the sample temperature. When the measurement starts, the measuring head 1 containing the mentioned heat flow sensor drops down and touches the planar measured sample 5, which is located on the instrument base 6 under the measuring head. In this moment, the surface temperature of the sample suddenly changes (i. e. the boundary condition of first order is worked out), and the instrument computer registers the heat flow course. Simultaneously, a photoelectric sensor measures the sample thickness.

All the data are then processed in the computer according to an original programme, which involves the mathematical model characterising the transient temperature field in thin slab subjected to different boundary conditions [5]. To simulate better the real conditions of warm-cool feeling evaluation, the instrument measuring head is heated to 32 °C (see the heater 3 and the thermometer 8), which correspond to the average human skin temperature, while the fabric is kept at the room temperature 22 °C. Similarly, the time constant of the heat flow sensor, which measures directly the heat

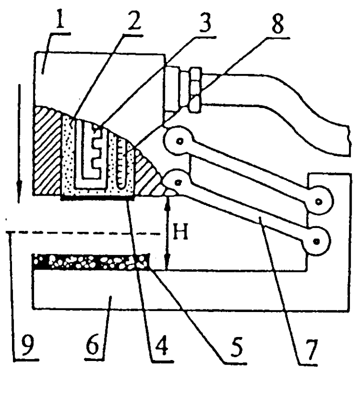

Fig. 1 Measuring system of the ALAMBETA instrument.

flow between the automatically moved measuring head and the fabrics, exhibit practically the same value (0,07 sec), as the human skin. Thus, the full signal response is achieved within 0,2 sec. The validity of thermal absorptivity as a new parameter expressing the warm-cool feeling of fabrics was confirmed by several tests where the results of subjective feeling of nearly 100 persons were compared with the values of thermal absorptivity found by means of the ALAMBETA instrument. During this experiment, the subjective and objective levels of warm-cool feeling of nine woven samples of similar structure (plain weave), thickness (from 0,22 to 0,33 mm) and weight per area (ranging from 0,120 to 0,165 kg/m^2), but made of nine different fibres and polymers, were determined.

The results were treated statistically and evaluated by means of the **Spearman's Rank Correlation Coefficient**. It was found, that the level of this coefficient exceeded 0,9, when comparing the subjective warm-cool (short-time) feelings and the values of thermal absorptivity and q_{max} determined by means of the ALAMBETA instrument, whereas the subjective feelings for longer time, correlated to the thermal resistance values, exhibited lower levels of thic coefficient, see in [5].

During the research projects conducted at the Technical University Liberec the thermal-insulation and thermal-contact properties of all common textile product were experimentally investigated. It was found, that the practical values of thermal absorptivity of dry fabrics range from 20 to 300, where the lowest (warmest) values exhibit special nonwoven interlinings made from PES microfibers – see the next table. The higher is this value, the cooler feeling represents. For wet textile fabrics the level of **b** could increase even more than twice.

As results from the table, the thermal – contact feeling of the tested fabrics is strongly affected by their structure and composition. It was found – see in [7], that, as expected, the fibres and fiber polymers exhibiting higher equilibrium humidity, provide also cooler feeling. Therefore, the warmest feelings can be achieved at fabrics made from PVC, PP, PAN, whereas viscose, flax, cotton and PAD 6 or 66 fibers show the coolest feeling. Which feeling is better, depends on customer: for hot summer garments cooler (cotton) feeling is demanded, whereas in the north of Europe warmer clothing, based on the PES/wool yarns, is preferred.

An important aspect of the "warm-cool" feeling evaluation is the change of this feeling when the textile product gets wet. Because the time of the warm-cool feeling evaluation of samples in the ALAMBETA instrument is very short, less than 3 minutes, the evaluation of humid samples is reliable (the sample does not turn dry during the measurement). Because the thermal conductivity and thermal capacity of water is much higher than these of the fibre polymer and the air entrapped in the textile structure, the "warm-cool" feeling of garments moistened by sweat can exceed 1000. The resulting thermal contact discomfort is generally known.

Since the thermal absorptivity is mainly the superficial property, its level can be changed by any superficial or finishing treatment, like raising, brushing coating, as it was proved in papers [6,7]. Also the spinning technology affects the warm-cool feeling of knits – see in [8], where the ring-spun yarns provide warmer feeling than OE yarns. By means of the new measuring technique, some finishing processes can be controlled and optimized.

2.2.2. Methodology of the indirect measurement of the moisture absorptivity of fabrics

The intention of this research was to characterise the contact comfort felt by a wearer of a shirt during a hot day, a special very thin interface fabric was prepared,

Tab. 1

ALAMBETA A	Efect of fabric structure, composition and treatment on the level of thermal absoptivity b [Ws$^{1/2}$/m^{2}K], head pressure 200 kPa
20–40	microfibre or fine fibre nonwoven insulation webs
30–50	low density raised PES knits, needled and thermally bonded PES light webs
40–90	light knits from synthetic fibres (PAN) or textured filaments, light synthetic raised carpets
70–120	light or rib cotton RS knits, raised light wool or wool/PES fabrics, brushes microfibre weaves
100–150	light cotton or VS knits, rib cotton woven fabrics
130–180	light finished cotton knits, raised light wool woven fabrics
150–200	plain wool or PES/wool fabrics with rough surface
180–250	permanent press treated cotton/VS fabrics with rough surface, dense microfibre knits
250–350	dry cotton shirt fabrics with resin treatment, heavy smooth wool woven fabrics
300–400	dry VS or Lyocell or silk woven fabrics, smooth dry heavy cotton weaves (denims) non- treated
330–500	close to skin surface of humid cotton/PP or cotton/spec. PES knits (0,5 ml of water applied)
450–650	heavy cotton weaves (denims) or knits from special PES Fibres (COOLMAX) in wet state
600–750	rib knits from cotton or PES/cotton or knits from microfibres, if superficially wetted
> 750	other woven and knitted fabrics in wet state
1600	liquid water (evaporation effect not considered)

which should simulate the effect of a sudden sweat discharge on the skin. It was found, that this sweat simulator should be as thin as possible, in order not to influence (in dry state) the thermal capacity of the measured fabric, but this interface fabric should absorb a certain amount of liquid injected in the centre of this interface fabric and mainly – it should distribute the liquid fast and uniformly within a circle of approx. 50 mm diameter (in order to cover the area 25 x 25 mm of the heat flux sensors). After some trials, a thin (0,1 mm) nonwoven fabric containing PP on one side and viscose fibres on the other side was found to fulfil all demands. In order to reduce the amount of liquid, the interface fabric was uniformly perforated.

At the beginning of the measurement, the ALAMBETA instrument is switched on and the measured shirt was placed on the measuring base of the instrument. Then, the volume of 0,2 ml of water (containing detergent) was injected on the centre of the interface fabric surface, covered by the viscose fibres. Within one minute, the liquid distributed uniformly within a circle of 45-50 mm, and stopped. When this occurred, this interface fabric was turned by the viscose side down and inserted into the space between the measured sample and the centre of the measuring head of the instrument (see the position number 9 in Fig. 1). At the same time, the interface fabric and the measuring head of the instrument dropped down towards to the measured shirt fabric.

Within a few seconds, the liquid from the interface fabric was more (in case of pure cotton shirt) or less (in other cases) taken away by absorption in the lower fabric. In the case of low absorption into the shirt fabric, the thermal capacity of the interface fabric is kept quite high due to higher relative moisture and the initial level of thermal absorptivity b is significantly higher

In the case of measurement of "warm-cool" feeling of the wetted pure cotton fabrics, characterised by higher moisture absorptivity, the moisture is rapidly distributed within the whole thickness of the fabric, so that the interface fabric gets nearly dry, and the instrument shows a lower level of the resulting thermal absorptivity.

3. EXPERIMENTAL RESULTS AND THEIR EVALUATION

3.1. Thermal-contact comfort after sudden wetting

The composition of the investigated plane fabrics varied from 100t% cotton to 100 % PES fibres, in the first case also PP fibres were applied. Medium values of the results are shown in the following Table II.

The following conclusions were drawn from these first experiments:

1. With an increasing portion of PES fibres in common woven shirt fabrics increases the unpleasant cool feeling (i. e. increases thermal absorptivity) when worn in conditions of surface wetting, which matches the practical experience of wearing the tested shirts.

2. Special fabrics with improved thermal comfort properties like double layered knits [11] or T shirts knitted from Coolmax modified PES fibres reveal more pleasant contact feeling in conditions of superficial wetting.

3. Exceptionally some cotton/PES blend fabrics made from common fibres may exhibit relatively good thermal contact comfort in the wet state, even with quite high portion of PES fibres, due to some unknown effect or due to a special fabric structure (confirmed by wearers).

4. Cotton shirt weaves containing too much chemical agents deposited inside the fabric may show worse contact comfort feeling in the wet state, in spite of the fact, that their steady-state water vapour permeability

Table II. Cool feeling of various fabrics measured by the ALAMBETA instrument in conditions simulating their wearing on suddenly wetted skin

Sample composition and structure	Sample thickness h [mm]	Thermal conductivity λ [mW/mK]	Peak value of heat flux q_{max} [mW/m^{2}K]	Temperature diffusivity a[m^{2}s] [Ws$^{1/2}$/m^{2}K]	Thermal absorptivity b
50% cotton 50% PP smart knit	0,66	100	2,20	0.057	421
100% PES knit Dupont Coolmax	0,54	97.2	2.29	0,048	443
100 % cotton denim	0,71	86,2	2,72	0.028	452
100% cotton shirt	0.43	83.1	2,32	0,027	508
100 % cotton shirt	0.38	90.1	2,61	0,025	565
70 % cot. 30 % PES woven shirt	0.21	78,7	2,41	0,012	731
35 % cot. 65 % PES woven shirt	0,28	120	2,52	0,026	751
75 % cot. 25 % PES woven shirt	0,23	88,9	2,99	0,010	875
35 % cot. 65 % PES woven shirt	0,26	123	2,77	0,017	935
100% cotton shirt resin treated	0.22	149	2,68	0,016	1178

keeps very high. Lukas proved in [12], that closing-up the finest capillary channels (for example by resins) should reduce the vertical suction height of water in these fabric (which should result in worse moisture uptake).

From other author's measurements [13] follows, that resin treated cotton fabrics show highest angle of the recovery, but the pure cotton ones show the lowest one, which may drop to 57 % of the former maximum value. This undesired situation often appears after several washings of the anti-crease treated cotton shirts. For blend fabrics with 30 % of PES fibres or more, the recovery angle keeps fixed at the level of 77 % of the mentioned maximum value, independently of the washing applied. As regards the fabric smoothness, the best results were found for the blends with 20 and 25 % of PES fibres. The lowest levels of the shear values (highest ability of deformation in the bias direction) was found for the classical blend containing 55 % of PES fibres. Nevertheless, all the differences in mechanical properties did not reveal any significant differences among pure cotton and blend fabrics, except the angle of recovery, where the results for the blend fabrics are better and do not reduce with washing.

Regarding the thermal properties of the tested samples in dry state, samples containing more PES fibres showed fairly lower thermal conductivity and substantially warmer feeling (up to 60%), then the pure cotton samples.

All these results have preliminary character and some measurements should be repeated. Nevertheless, even in this research state the following observations can be presented:

1. shirts containing 25–40% of classical PES fibres blended with cotton, compared with non-treated pure cotton shirts have shown similar or even better water vapour permeability, fairly warmer feeling in dry state, better shear, fairly better ability to keep the form and a bit lower moisture absorptivity (worse thermal contact comfort feeling in the case of superficial wetting). Moreover, thermal-comfort properties may be still improved by the use of modified PES fibres [14].

2. The cotton anti-crease treated shirts compared with the non-treated ones can be characterised by similar water vapour permeability, relatively cool (less pleasant) feeling in dry state, temporary smooth surface, high but temporary form keeping and by substantially lower (less pleasant) moisture absorptivity.

3. Theoretical shirt containing up to 50–70 % of special liquid transporting fibres (e.g. Du Pont COOLMAX) may exhibit, compared with pure cotton non treated shirts, higher water vapour permeability, warm feeling in dry state, smooth surface, good shear, very high ability of form keeping and excellent (most pleasant) thermal contact comfort feeling in the case of superficial wetting (high moisture absorptivity). The cotton fibres then would contribute to the lower bending and shear rigidityand softer handle of the fabric.

4. CONCLUSIONS

From the first application of the indirect method of experimental determination of the moisture absorptivity described in this paper, may be concluded that superficially wetted non – finished 100% cotton fabrics show substantially warmer (more pleasant) feeling then those of cotton/PES blends, which correlate with practical experience. Special products like Coolmax knits made of modified PES fibres or double layered cotton/PP knits exhibit the same or even better "warm-cool" feeling as the pure cotton woven fabrics. On the other hand, fabrics containing low percentage of PES fibres, may exhibit higher complex quality, due to their better ability to keep the form and easier maintenance, whereas the reduction of their moisture absorptivity might be relatively low.

LITERATURE CITED

[1] CHATTERJEE, P.K.: Absorbency. Elsevier Science Publ., Amsterdam 1985S

[2] CHEURELL, D.M., SPIVAK S. M., HOLLIES, N. R. S.: Dynamic Surface Wetness of fabrics in relation to Clothing Comfort, *Textile Res.J.* **55**, 394–399 (1985).

[3] KISSA, E., Wetting and Wicking. *Textile Res. J.* **66**, 660–668 (1996).

[4] HES, L., A New Indirect Method For Fast Evaluation of the Surface Moisture Absorptivity of Engineered Garments: In: Internat. Conference on Engineered Textiles, UMIST, May 20–22nd, 1998

[5] YONEDA, M. and KAWABATA, S., Analysis of Transient Heat Conduction in Textiles and Its Applications, Part II, *J. Text. Mach. Soc. Jpn* **31**, 73–81 (1983)

[6] HES, L., Thermal Properties of Nonwovens, in: Proc. INDEX 1987 Congress, Geneva 1987.

[7] HES, L. and DOLEZAL, I., New Method and Equipment for Measuring Thermal Properties of Textiles, *J. Text. Mach. Soc. Jpn* **42**, T124–128 (1989)

[8] HES, L., PROMMEROVA, M., The Effect of Thermal Resistance and Absorptivity of Various fabrics on their Thermal Contact Characteristics. In: 21st Textile Res. Symp. at Mt. Fuji, 1992

[9] HES, L., DOLEZAL, I., HANZL, J., MIKLAS, J., Neue Methode und Einrichtung zur objektiven Bewertung der thermokontakten Eigenschaften der textilen Flaechengebilde, *Melliand Textilber.* **71**, 679–681 (1990)

[10] HES, L., ARAÚJO, M., and DJULAY, V., Effect of Mutual Bonding of Textile Layers on Thermal Insulation and Thermal-Contact properties of Fabric Assemblies, *Textile Res.* **66** 245–250 (1996)

[11] HES, L., ARAUJO, M., STOROVA, R., Thermal-Comfort Properties of Socks Containing PP Filaments, in: World Congress on Polypropylene in Textiles, Huddersfield 1996

[12] LUKAS, D., 3d Ising Model for the Lucas-Washburn Equation, in: 3rd. Internat. Conerence TEXSCI 98, Tech. Univ. of Liberec 1998

[13] HES. L. And DOLEZAL, I. Optimisation of the Shirt Fabrics Composition In: 27th Mt. Fuji Textile Reseach Symposium, Japan 1998

[14] MILITKÝ J. et al, Modified Polyester Fibres, ELSEVIER 1991

DEPARTMENT OF TECHNOLOGY AND MANAGEMENT OF APPAREL PRODUCTION

TEACHING STAFF

Assoc.Prof.Ing.Otakar Kunz,CSc., Head of Department
Mgr.Ing.Nejedlá Marie
Mgr.Luboš Zatloukal
Ing. Smékalová Marta

It is one of the youngest departments of our Faculty of textile engineering. The department was established in 1997 in Prostejov town in the central Moravia as detached faculty department. Department is responsible for bachelor study program "Technology and operation of apparel production", orientation clothing production. Contemporary there is about 105 students enrolled into this program.

Not only staff members of the department, but also external teachers from other departments of our Technical university, from Palacky university Olomouc, and last but not least experts from company OP Prostejov and other institutions.

Prostejov and its surroundings provides students, thanks to extremely great clothing industry concentration, with excellent conditions to recognise contemporary technologies, machines, organisation of industrial processes etc.

In a relatively short time of the department existence it became supervisor of two projects of the "Higher education development fond", first was connected with building of the CAD systems laboratory and second with the change of study programmes (completing the studies with industrial praxes). Department is as well co-operator of the project of Grant Agency of Czech Republic called "Sensorial comfort of clothes and shoes", main supervisor is Faculty of technologies in Zlin.

Beside it, the department is oriented on

- development of new communicative computer programmes for clothing production,
- compressive effect of the elastic clothes on human body,
- apparel design for disabled young people optimisation,
- computer aided clothing etc.

DEPARTMENT OF MECHANICAL TECHNOLOGIES

Teaching staff

Prof. Ing. Petr Ursíny, DrSc., Head of Department
Prof. Ing. Stanislav Nosek, DrSc.
Ing. Aleš Cvrkal
Doc. Ing. Vladimír Moravec, CSc.
Ing. Eva Dušková
Ing. Eliška Chrpová, CSc.
Ing. Alena Fridrichová
Dr. Ing. Petr Tumajer
Ing. Petra Jirásková
Ing. Václav Bejček
Ing. Lenka Nevyhoštěná
Ing. Ingolf Brotz
Ing. Tomáš Moravec (part time)

Characteristics

The Department of Mechanical Textile Technologies was established in 1997. The Department provides education for students both in basic as well as in advanced courses. The Department concentrates on theoretical and experimental training in mechanical textile technology with attention given to spinning, weaving and knitting. These 3 fundamental technological branches create the predominant part of the textile industry. These professional branches are focused upon technology, machinery and their facilities and are connected with relevant questions, especially those dealing with the quality of the entire textile processes.

Teaching activities

The Department offers 3 courses for basic study, 14 courses for specialised advanced studies and 20 courses for bachelor studies.

The Department supervises the Diploma Theses in the specialisation "Textile Technology".

The Department offers postgraduates studies in spinning, weaving and knitting.

Research activities

Main research topics of the Department are related to:

- technology of spinning, twisting and texturing
- optimisation of technological processes in spinning
- new spinning technologies
- analysis of fibrous structures
- structure and stability of woven fabrics during the process of fabric formation
- dynamics of the beat-up process and weaveability at high weaving rates
- influence of dynamic motions of the reed, back-rest and shed on weaveability
- transition processes after parameter variations (weaving speed, tension) in fabric

Postgraduate Students and Their Theses

Ing. Aleš Cvrkal: Fabric forming process and weft slipping into the cloth fell during a beat-up pulse.

Ing. Eva Cihlářová: Structure of mass irregularity of yarns.

Ing. Monika Dřínovská: Influence of dynamic coefficient friction on the dynamic weaving resistance.

Ing. Petra Jirásková: Relation between mass irregularity of the linear and the plain textiles.

Ing. Irena Mrazíková: The dependence of static weaving resistance on fabric binding.

Ing. Jaroslava Richterová: The anisotropy of mechanical properties of the fabric in various directions influenced by the weaving process and by the structure of the fabric.

Ing. Brigita Sirková: Model of the shape of binding wave while using the Fourier series.

Ing. Duong Tu Binh: The influence of weaving dynamics on the quality of the product.

Main Scientific Projects

The Solution of Dynamics of the Weaving Process and Building of the Laboratory for Diagnostics and Measurement on Textile Machines

Project manager: Prof. Ing. Stanislav Nosek, DrSc.

Project objectives: the work focused on problems of interactions within the systems < weaving loom – textile material on the machine> during the process of fabric formation on the loom at very high weaving rates. The researchers used the theoretical approach to solve dynamic questions based on dynamic statistics as well as nonlinear differential equations. For the sake of verification of theoretical results, as well as for empirical induction of various solutions at the beginning of any theoretical work, the team members in their experiments used the devices of the built laboratory comprised of measurements systems, signal analysers, high speed video camera with picture analysis, etc.

The activity of the project is aimed at increasing the knowledge of the weaving process, gaining data for applications in the industry for the design of machines as well as exploitation, and also for training students in both the engineering and PhD. programs.

Network for Studying Warp Related Weaving problems
Project manager: Prof. Ing. Stanislav Nosek, DrSc.

Project objectives: The task of the project is to exchange information between partners from about 17 European countries about present directions and the results of research in the field of weaving technology. The project also seeks to influence the weaving process and quality of produced fabrics by changing or improving the properties of the textile materials on the loom and by new solutions of the dynamics of the loom and its individual mechanisms.

The project is dealing with problems in the following main areas of research in weaving and of properties of the resulting product:

1. Mechanical properties of textile materials processed on the weaving loom, and
2. Influencing or improving of these properties from the point of view of quality and stability in the weaving process.
3. Chemical origin and properties of fibres from the point of their further processing on the loom.
4. Mechanical properties of produced goods – fabrics.
5. Dynamics of the weaving process and interaction between the weaving mechanisms and the textile material.
6. Measurements and new research methods applied in the weaving technology.

Novel Visualisation System for Control and Monitoring
Project manager: Ing. Eliška Chrpová, CSc.

Project objectives: Continuously increasing the amount of technologically demanding products in industries requires the development of objective measurement and control methods for materials, processes and production itself.

The project brings new techniques, relating to image measurement and fractal measures appropriate to chaotic systems, to practical industrial settings. The goal of our work is to be able to monitor and control the product and process with feedback to the production process. For the solution we use a video camera that allows on-line evaluation. The segmentation of the scanned surface into pixels and its description with a map creates appropriate conditions for the application of means and procedures. This project also provides educational opportunities for training at the PhD level.

The Relationship between structure and Properties of OE-rotor yarns
Project manager: Prof. Ing. Petr Ursíny, Dr.Sc.

Project objectives: In this project chosen questions were solved within the systems <technology – structure – properties> during the process of OE-rotor spinning. A new relationship was discovered. It concerns the clarification of new legalities in connection with the use of higher frequency of rotor revolution, that also needs a smaller diameter of a collecting surface of the spinning rotor.

On the basis of new science-research knowledge about the structure of the mass irregularity it was possible to clarify the changes of the mass irregularities of rotor spun yarns.

From a defined rotor speed onward, when a replacement of the rotor with a rotor of a smaller diameter becomes necessary, it becomes a smaller measurable mass irregularity, in spite of the reduction of the cyclic doubling, due to the reduced number of noncompensatabilities of the mass irregularity of the fiber flow. The analysis of the actuating variables, which act upon the size of the square irregularity according to the derived relation, reveals that the harmonic components of the mass irregularity, which cannot be evened out by cyclic doubling system, constitute an essential component of a very small amplitude. The findings from the application of rotors with differing diameters of collecting surfaces for a given rotor speed also bear this out.

Theoretical and experimental investigation of the structure of the mass irregularity of rotor spun yarns provided the scientific-research basis for a new solution to ensure significant properties of rotor spun yarns (mass irregularity) in difficult technological conditions with high productivity of the spinning unit of OE rotor spinning machine.

The project was solved in co-operation with student of engineering.

SOME FACTORS OF BREAKAGE RATE IN OE-ROTOR SPINNING PROCESS

Petr URSÍNY

Technical University of Liberec, Czech Republic

1. Introduction

Yarn break frequency rises with increasing rotor speed, reduced yarn twist and increased spinning count, to the extent that, in the most unfavourable circumstances, an increase in the effective production rate can be prevented and yarn quality inadmissibly imparied.

It is essential therefore to consider the demands on yarn strength resulting from feed sliver quality and OE rotor spinning parameters in conjuction with yarn break frequency [1].

2. Theoretical analysis of the relationship between tensile strength and yarn break frequency on the OE rotor spinning machine

Yarn breakage always occurs when yarn tension in the spinning process momentarily exceeds tensile strength (Fig.1).

As various studies have shown, measured yarn tension and tensile strength values are standardly distributed relative to time, and are statistically independent of each other [2]. The following statistical parameters can therefore be introduced for yarn tension F_Z and tensile strength F_H:

$$F_H \in N[\bar{F}_H, \sigma^2(F_H)]$$
$$F_Z \in N[\bar{F}_Z, \sigma^2(F_Z)]$$

$\bar{F}_H$, $\bar{F}_Z$ mean tensile strength and yarn tension, $\sigma^2(F_H)$, $\sigma^2(F_Z)$ tensile strength and yarn tension scatter

As the difference $(F_H - F_Z)$ also has a Gaussian distribution, yarn break probability results from the following relationship:

$$P(F_Z - F_H > 0) = P[F_Z - F_H - (\bar{F}_Z - \bar{F}_H) > -(\bar{F}_Z - \bar{F}_H)]$$

$$= P\left[\frac{F_Z - F_H - (\bar{F}_Z - \bar{F}_H)}{\sqrt{\sigma^2(F_Z) + \sigma^2(F_H)}} > \frac{\bar{F}_H - \bar{F}_Z}{\sqrt{\sigma^2(F_Z) + \sigma^2(F_H)}}\right]$$

$$= 1 - F\left[\frac{\bar{F}_H - \bar{F}_Z}{\sqrt{\sigma^2(\bar{F}_Z) + \sigma^2(\bar{F}_H)}}\right] \quad (1)$$

Probability of the yarn breakage:

$$P[F_Z - F_H > 0] = 1 - F\left[\frac{\bar{F}_H - \bar{F}_Z}{\sqrt{\sigma^2(F_Z) + \sigma^2(F_H)}}\right] \quad (2)$$

If the standardized form of the Gaussian distribution is deduced for this relationship, the incidental standardized dimension u can be defined as follows:

$$P[F_Z - F_H > 0] = 1 - F(u) \quad (3)$$

$$u = \left[\frac{\bar{F}_H - \bar{F}_Z}{\sqrt{\sigma^2(F_Z) + \sigma^2(F_H)}}\right] \quad (4)$$

If the scatters are replaced by the variation coefficients of the maximum tension v_H and yarn tension v_z the relationship for the standardized random dimension u as follows:

$$u = \left[\frac{\bar{F}_H - \bar{F}_Z}{\sqrt{v_Z(\bar{F}_Z)^2 + v_H(\bar{F}_H)^2}}\right] \cdot 100 \quad (5)$$

From the last relationship (5) can be seen the effects of the mean tensile strength and yarn tension together with their coefficients of variation on the stability of the spinning process. The mean level of the two tensile loads id determined by the specific technological conditions of the OE rotor spinning process. The coefficients of variation of yarn tension and tensile strength are affected by various non-fixed influences, e.g. the mass irregularity and purity of the supply sliver. The standardized form of the Gaussian distribution of yarn break probability follows the curve in Fig. 2. In Figs. 3 and 4, the probability of yarn breakage relative to the mean tensile strength parameters (8.0 to 10.5 cN/tex) and their coefficient of variation (5 to 20%) is represented as an example, from which the technological limits for rotor spinning process stability can be deduced.

3. Experimental study of relationship between the coefficient of variation of tensile strength and yarn irregularity.

The stability of the spinning process is dependent on the mass irregularity of the OE rotor yarn. The theoretical representation of the relationship between

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Table 1 Correlation between the coefficients of variation of yarn mass and tensile strength CV_H

Spinning conditions	variable	Coefficient of correlation Calculated	critical	Statistical analysis result
constant	CV_m-CV_H	0,146	0,322 in 38 test series	no linear dependency
variable-rotor cleaning	U_m–CV_H	0,986	0,950 in 8 test series on 4 levels	linear dependency

the coefficient of variation of tensile strength and yarn irregularity relative of drawframe sliver regularity does not produce practically applicable results, and therefore we deduced by experimental studies the effect which the efforts to achieve a high degree of mass regularity in OE rotor yarn has on yarn break frequency. The trial programme includes the following investigations:

A) Constant spinning conditions

From a drawframe sliver (CV = 4.2 %), a 100% cotton 25 tex OE rotor yarn is produced, the spinning conditions remaining virtually constant through adherence to the specified production conditions. The mass irregularity of the OE rotor yarns is the result of feed sliver quality and the OE rotor spinning process in unchanging production conditions.

B) Systematic change spinning conditions

Rotor cleaning is dispensed with in producing a 100% cotton 35.5 tex OE rotor yarn, producting a systematic change in the technological spinning conditions. Deposits of trash and dust in the rotor groove are not removed, and have a detrimental effect on yarn irreqularity. The coefficient of variation of tensile strength and yarn mass are measured after 1,3,5 and 7 hour machine operation without rotor cleaning [1].

The dependence of the coefficient of variation of the yarn mass CV_m and the linear irregularity U_m of the OE rotor yarn on the coefficient of variation of its tensile strength CV_H can be seen in the correlation coefficients (Table 1).

It can be seen from Table 1 that, in unchanging spinning conditions (good feed sliver quality, observance of all the technological conditions for OE rotor spinning process stability), there is no statistically significant relationship between the coefficients of variation of yarn mass and tensile strength. Random yarn strength variations correspond with random drawframe sliver weight variations.

If individual marginal OE rotor spinning process technological conditions (e.g. rotor cleaning cycle) are ignored, yarn mass irregularity increases, resulting in a linear relationship between the linear irregularity of the yarn mass and the coefficient of variation of tensile strength.

Systematic technological changes in spinning conditions [3], which improve OE rotor yarn mass irregularity, reduce the coefficients of variation of maximum yarn tension and therefore yarn break frequency. Spinning process stability with increased output in the production of finer yarns therefore requires further endeavours for evening the fibre flow and therefore the yarn.

Literature

[1] URSÍNY,P.-MÄGEL,M.: Neue Erkenntnisse zur Stabilität des OE- Rotorspinnprozesses. Melliand Textilberichte, 76 (1995), 11, S. 960–961.

[2] RIPKA,J.: OE-rotorspinning at 90 000 revolutions per minute of rotor. Book of lectures "Progressive Textile Technologies". Organized by CSVTS Prague, 1974, P. 95–124 (Czech)

[3] URSÍNY, P.: Vergleichmässigende Wirkung der kombinierten Dublierung und deren Anwendung auf des OE-Rotorspinnsystem. Melliand Textilberichte, 74 (1993), 6, S. 478–483.

RESEARCH ACTIVITIES OF THE DEPARTMENT OF MECHANICAL TEXTILE TECHNOLOGIES

Production of linear and plain textiles is known nearly for 30 thousand years, however it has been developed very slowly and incidentally. Not before the second half of the 20-th century its development has started to take in rate and then new principles have arisen, such as open-end spinning, gripper looms, jet looms or multiphase looms. Since the beginning of the 1950-ies production and working frequencies have increased almost ten times as we can see on Fig. 1. Unfortunately there arises another problem at the increased working frequencies of textile machines, the problem of functioning of the system <textile machine – processed textile material>. The textile machine is a system of massive bodies connected together by relatively rigid transfer links as well as by compliable textile material. With increasing frequencies of the machines there is a necessity to decrease the weight of its mechanisms, which leads to the increase of their compliance. In such a system varies the action forces influencing the processed textile product. There changes also the structure as well as the quality of the final textile product. In addition to that there exist several textile materials and products, which are not able to undertake the increased state of stress at high working frequencies, and/or the system <machine - textile object> can become unstable and the product is irregular. At the same time the textile process is strongly affected by breakdowns and the machine output decreases.

That is why the researches on the Department is linked to the situation mentioned above, considering the textiles, textile machinery and measuring and control techniques. Research activities are focused on the behaviour of the system <textile machine – processed textile object> as well as on the behaviour of its individual components in connection with increasing working frequency. The results will be applied as changes in the process of design of textile machines and in the option of construction materials. The results can also influence proper adjustment of the processed materials and the construction of the final textile products. In connection with mentioned results efforts have been made to find new research methods and new measuring and evaluating methods for the quantities arising at the contemporary producing processes.

Particular problems solved at the Department shows Fig. 2

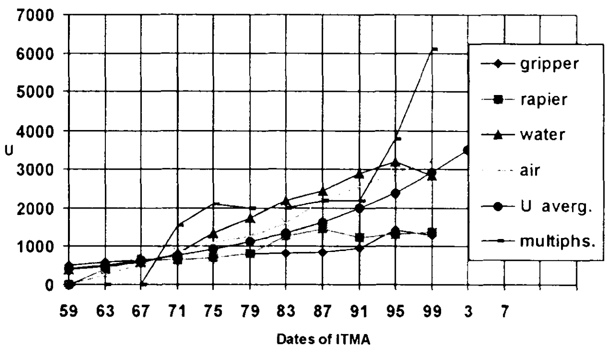


Fig. 1 Steep rise of the textile machines output

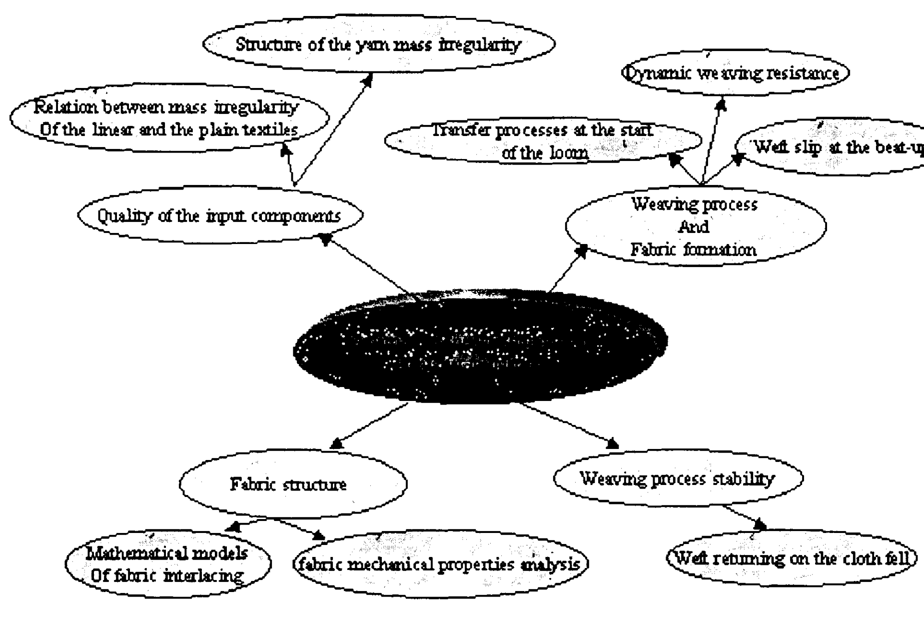


Fig. 2 Scheme of the problems solved at the Department

I. SPINNING TECHNOLOGY

Spinning process

The long term scientific research activiy is oriented to the theory and technology of spinning and spinning machines. It is especially focused on the following partial subjects: the basic research and optimisation of technological process in spinning, the analysis of the unevenness of fibrous structure and influences of technology, the simulation of spinning process, the automation in the spinning mill, technology of the high speed open-end spinning, technology of new unconventional spinning system, new method of the evaluation of mass irregularity of spinning products and new method of the simulation and optimisation of spinning processes and systems.

Recently a lot of scientific research themes have been resolved in the framework of co-operation on research design "Formation, structure and structural mechanics of textiles."

It generally deals with the problems of technology of production of the linear textiles, mechanics of their production and the relation between technological process and properties of the linear textiles.

In the field of open-end rotor spinning system the scientific research problems were resolved from the individual technological zone. The probability simulation of sliver opening and transport process in the opening roll zone was created. This simulation enables to optimise the shape of opening zone with the aim to obtain the even fibrous flow for next treatment in the open-end spinning system.

Furthermore the probability simulation of fibrous flow in the air-transporting channel was created. This simulation makes possible to choose the optimal length of the channel with respect to maximum degree of the separation of fibres.

Application of the probability theory in the fibre opening and transport process in the opening roll zone is following. The probability of fibre transfer from the peripheral speed of the feed roll to that of the opening roll can be described with the aid of the Markov chain laws.

The fibre transfer matrix forms the basis for determining fibre dwell time in the feed roll and press plate nip zone before transfer to the opening roll (average time, time scatter). The transfer probabilities p_{ij} are therefore the probabilities of fibre transfer from condition i (movement at the peripheral speed of the feed roll) to condition j (movement at the peripheral speed of the feed or opening roll).

The mean fibre dwell time in the comb-out zone and its scatter can be deduced from this.

If a minimum mean fibre dwell time is achieved in the comb-out zone, fibre scatter, and therefore the possibility of additional fibre flow unevenness due to the draft, is also reduced.

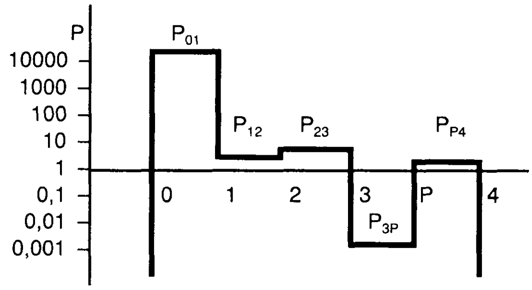
Performance increases in OE rotor spinning technology and the production of finer OE rotor yarns place stringent requirements on feed sliver quality and the technological control of all part processes. A low OE rotor yarn level of unevenness is favoured by the formation of a uniform fibre flow in the opening roll zone. The structural design of the feed roll/ press plate part system must ensure minimum fibre dwell time scatter in the comb-out zone.

In the field of open-end spinning system was analysed the problem of breakage rate (theoretical analysis of the relationship between tensile strength of yarn and yarn break frequency on the open-end rotor spinning machine and experimental study of relationship between the coefficient of variation of tensile strength and yarn irregularity).

In the field of technology of spinning was analysed the problem of changes of mass-irregularity (theoretical solutions of transformation of mass – irregularity in the spinning technology and influence of selected technological systems and processes).

Structure of mass irregularity

The variance-length curve transcribes an influence of the particular technological levels on structure of the mass irregularity. The processes of evaluation of this variance-length curve are known from the 50th years. They have been designed for classical cotton and woollen technologies. However, these technologies are characterised by the gradual drafts. The rotor spinning machines work on the different principle comparing with the classical spinning machines. This principle does not consist in the gradual refinement but in combination of the super draft and the thickening by the cyclic doubling. The question is how



0 feeding device (sliver)
1 zone of fibres transport by stripping roller (fibrous flow)
2 zone of fibres transport by air
3 collecting surface (fibrous flow)
P collecting point (fibre band)
4 draw-off (yarn)

Fig. 3 Partial drafts P of rotor spinning system – e.g.: $P_{01} = 1{,}115.10^4$; $P_{12} = 1{,}12$; $P_{23} = 4{,}1$; $P_{3P} = 5{,}1.10^{-3}$; $P_{P4} = 0{,}95$

the rotor spinning system will influence the variance-length curve, respectively how the particular segments of the curve are formed.

The aim of this work then is: the investigation of the transformation of mass irregularity by the rotor spinning system, theoretical analyse of the variance-length function from view of the influence of the technology on its course, the possibility of application variance-length function in the cotton rotor spinning mill and the evaluation of its meaning from view of rotor spinning. The attempt to develop some process of evaluation of variance-length curve corresponding to open-end spinning system is closing of whole work. Then the possibility to extend the application of the variance-length curve in the rotor-spinning mill and to obtain so the image of influence whole technology on the mass irregularity will be given to users of the apparatus USTER-TESTER.

Mass irregularity of the linear textiles with appearance of the plain textiles

Irregularity of the plain textiles is caused by the irregularity of yarns and also by the own process of production – weaving or knitting. This thesis deals with influence of linear textiles. Evaluation of their irregularity is described by parameters and functions usually used in the practise. There is used the visual evaluation of appearance in case of plain textiles. This is mostly a subjective method and it is not based on any quantitative parameters. On the other side there exist effective measuring methods, precisely evaluating mass and volume regularity of linear textiles in the form of spectrogram. We can identify the periodic defects using spectrogram analysis. Defects affect final appearance of the yarn according to wavelength of the defect and they can appear in the fabric or in knitwear. Defects with short wavelength show as "moiré effect". Defects with longer wavelength show as streakiness. Defects with medium wavelength show at the specific conditions. The unperiodical defects of the yarns are identified by length curve of variability and they show as an unsettled, cloudiness appearance of the plain textiles. Today the computer simulation is used for evaluation of the influence of the yarn irregularity on the appearance of the plain textiles. We can model the final fabric or knit work on a computer using obtained parameters of the yarn. There was an effort to describe the irregularity of the plain textiles by characteristics similar to yarns (e.g. area variance coefficient, area variance curve of fabric or knit work), but they are not used in practise. The main effort is to find the quantitative parameters or characteristics, which will be able to determine appearance of the plain textiles on basis of obtained parameters of the yarn.

II. WEAVING TECHNOLOGY

Weaving process

Today textile firms aim at keeping the productivity of weaving and the quality of produced goods on the possibly highest level. However, these requirements of modern weaving mills are determined by ability of weaving machines to keep the required values of weft density in final fabrics at permanently increased weaving frequency (this is the so-called weaveability). Friction coefficient between weft and warp is then getting a very important parameter. We speak then about speed dependent friction of weft on warp.

The aim is to define the practical existence of dependence of friction coefficient on sliding velocity. It appears that there exists a functional dependence of friction coefficient on the time course of velocity

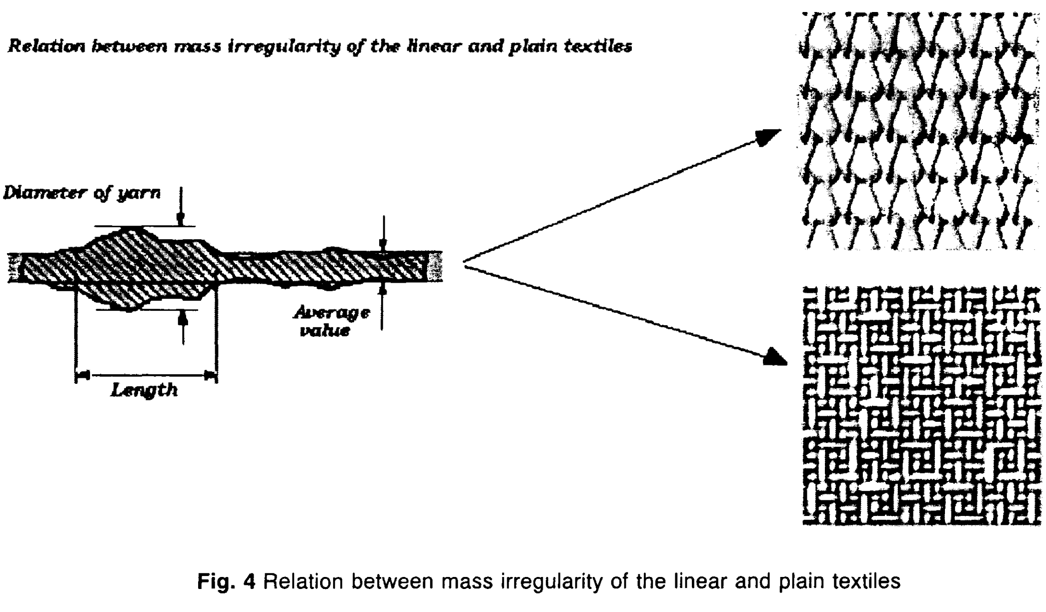
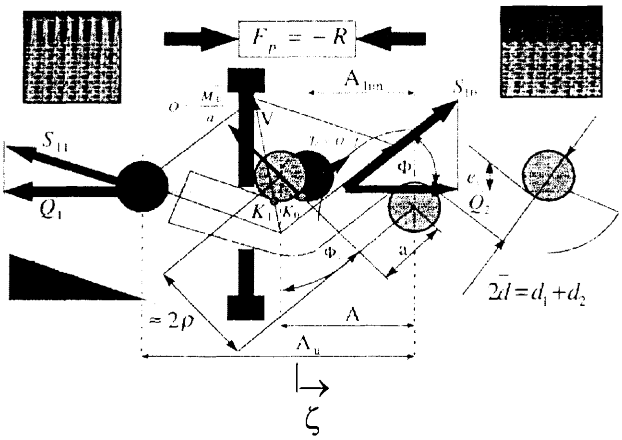


Fig. 4 Relation between mass irregularity of the linear and plain textiles

and on the time-distance from the beginning of weft sliding. The course of weft sliding into the cloth fell is the result of weaving resistance, which is again the result of a form of friction coefficient dependence.

Weaving process is expressed then by equations in the following order:



$$F_P - R = 0$$
$$F_P = (C_1 + C_2).X$$
$$R = \alpha.\xi + \beta.f^*$$
$$Y = \xi + X$$

Fig. 5 Distribution of forces on the cloth fell

where F_p is beat-up force; R is weaving resistance; C_1, C_2 are spring constants by which warp and fabric can be substituted; X is cloth fell elongation; α,β are constants given by the fabric structure; f* is functionally dependent coefficient of friction; Y is beat-up pulse; ξ is weft slip into the fabric; A is required pickspacing and A_u is an inserted weft position. However some quantities are varying with weaving frequency, particularly the weaving resistance. It is necessary to investigate this analytically and experimentally.

The aim is to create complex laboratory method, which would enable measurements of weaving resistance and of the track (depth) of weft slip into the fabric (into the cloth fell) at the same time. Two possible approaches of weaving resistance measurement are available. They are strain-gauge using methods. Their require additional mathematical elaboration which leads to the resultant weaving resistance.

The task to measure the weft sliding path into the fabric leads either to application of an optical method using a high speed video recorder or to application of static photo camera with a speed shutter, controlled by device measuring important intervals of the observed process. The method enables to record and visualize the weft slip. So the validity of speed dependent friction theory can be verified. The first step is to determine which course of weft slip correspond to reality the best. We aim to find out how the friction coefficient influences the intensity of weaving resistance and the weaveability mentioned above.

Fabric formation

The next problem is the formation of fabric structure at the beat-up of the weft.

At the moment of beat-up the reed strikes on the last inserted (zero) weft and pushes it into the fabric. However at the same moment a certain number N of wefts woven into the fabric before the zero weft acts on each other and gets pressed a little deeper into the weave than it corresponds to their right position in the setting. Yet after the beat-up, most of these "wandering" wefts (N-1wefts) are shifted again backwards, out of the fabric. Only the N-th weft (in the practice about the 3rd or the 4th weft) remains pushed into its farthest position, which is the first correct one in the fabric setting, counted from the cloth fell. Also the binding angles of warp ends on this N-th and further (deeper) wefts are correct and definite. The area of the N-1 "wandering" wefts is called the zone of fabric formation. The limited wefts motions ahead and backwards may be called "weft returning". Springing wefts as a matter of fact cause the flexibility of the cloth fell and this can influence the whole beat-up process and then the whole weft motion.

This work about the cloth fell is divided into two parts:

Theoretical part deals with the solution of the beat-up and weft motion, an analyzing model of friction is considered. The motion of wefts in the forming zone is caused by mutual forces of wefts on each other, acting through the "shearing effect" of warp ends crossed between the wefts. Yet the frictional resistance of wefts sliding on the belted warp threads restricts the weft motion (wandering) in both directions.

Experimental part deals with a determination of the course of the frictional coefficient dependent on variable velocity between warp and weft yarn. It is realized by measuring equipment in the laboratory (tension meter, analyzer). Observation of the course of weft motions was focused on different materials used in weft, and the formational zone was monitored by the high-speed camera SpeedCam-500, which represents high level of measuring technique which is very unusual for this area.

Dynamics of the weaving loom

Formation of the fabric is not only the matter of textile material on the loom, but it is also the matter of own weaving loom. Therefore the dynamics of the loom is investigated and analysed.

Work is focused on analysis of the transfer proc-

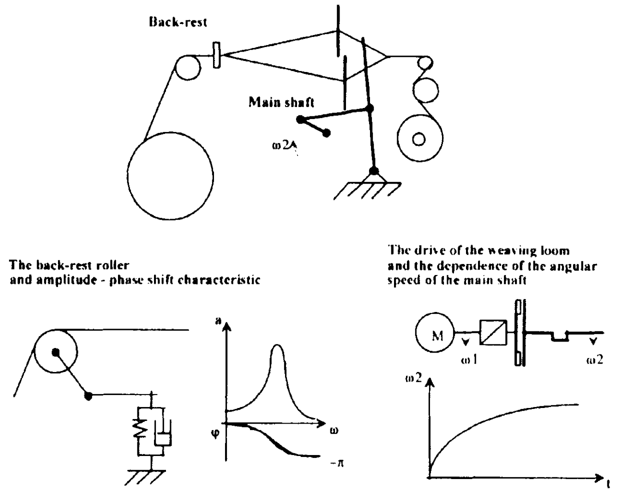


Fig.6 Mechanisms influencing dynamics of the loom

esses arising on the loom (start and stopping of the loom) and their consequences in the fabric structure. Stopping of the loom represents a pause in the weaving process. During this pause the position of the cloth fell is changing due to rheological properties of textile material. At the start of the loom the angular speed of the main crankshaft is also changing. The decreased value of this speed causes the insufficient intensity of the beat-up. This fact shows as so-called stop-mark in the fabric structure. It is possible to eliminate this negative phenomenon by a suitable optimisation of the loom mechanisms and its reaction on the changes of the cloth fell position at the loom start. Another task is increasing of weft density of the fabric, produced on high speed weaving looms, using vibration of the backrest roller or reed. As was mentioned earlier in the text the decreasing of the weft density at high frequencies of the loom is caused by dependence of the friction coefficient on the speed of sliding weft into the fabric. Vibrations of the parts of the loom, e.g. backrest roller, reed etc., can positively influence the process of the beat-up and enable to achieve higher weft densities.

Fabric structure formulation

Loom setting at the particular process of weaving (shuttles, shuttle less, multished weaving) and various transition processes connected with starting of the loom, transition to different bindings (borders), change of the tension of threads in the interlacing etc., influenced the final structure of fabrics. Models of the structure known from literature are not enough operative and can hardly reflect an influence of the weaving process on the interlacing and the shape of threads in the fabric. All necessary information about the fabric can be deduced from the description of the shape of binding wave. Binding wave is basis for evaluation of the fabric from the aspect of the spatial geometry.

For the interlacing of threads it is characteristic that the binding repeats regularly in the whole area of fabric. Any deviation or change of the binding repeat is usually caused by properties of the material in the warp and the weft (irregularity) or by the influence of the weaving process.

From the cross sections it is perceptible, that the shapes of the binding wave are necessarily periodic. For this reason for the description of the binding wave a mathematical model using the Fourier series was created. This model for description of binding wave we can use for valuation of the fabrics in the plain as well as in the other than plain interlacing.

The approximation means the expansion of the function "f(x)" in Fourier series in the form:

$$\frac{a_0}{2}+\sum_{n=1}^{\infty}\left(a_n \cos(nx\omega)+b_n \sin(nx\omega)\right)$$

where a_0, a_n, b_n are the coefficients of series

From the approximation of the course by a sum of the Fourier series we obtain also the spectral characteristic of the waviness of the interlacing threads in the form of the sequence of members of the series. The wave characteristics or the wave spectrum represent certain properties of the interlacing.

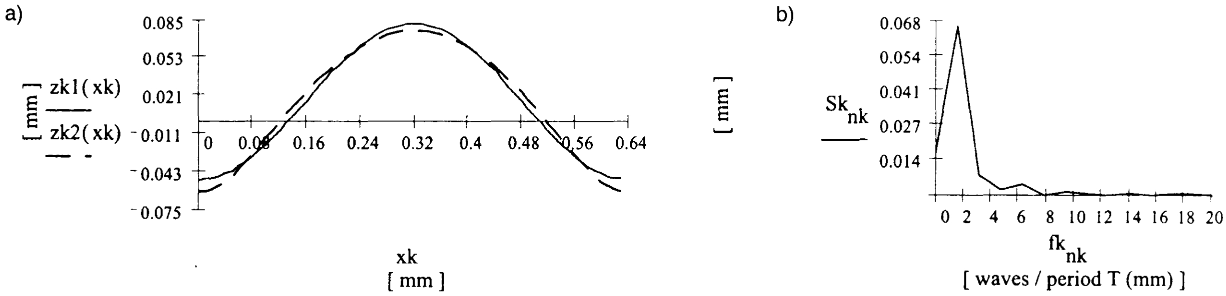


Fig. 6 a) Approximated shape of the binding wave in the twill weave. Course zk1 (xk) – Approximation with one harmonic component only. Course zk2 (xk) – Approximation with two harmonic components. b) Spectral characteristic of the binding wave for twill weave

State of stress of fabric and its influence on the application properties

Fabric is plain textile product, which is getting greater importance than it has ever had in the clothing industry. It is mainly obvious from its using in the technical field as a basic material for various composites. It leads to a detailed research of their properties, particularly the mechanical ones.

The whole process of the weaving is process of creation of the binding point, which is the fundamental structural element of the fabric. The binding point is the area of warp and weft crossing, which dimensions as well as its state of stress varies from the place of origin into depth of the fabric.

Mechanical properties of fabric represent very wide and complex area, which includes the knowledge of properties of the initial product, i.e. yarn, the knowledge of relation of the mutual interlacing between warp and weft and the knowledge of fabric design (weave, linear density of the fabric, etc...).

Dependencies between individual parameters of the structure (distance between yarns, high of the weave wave of warp and weft, binding angle, etc...) in relaxed and stressed state are studied.

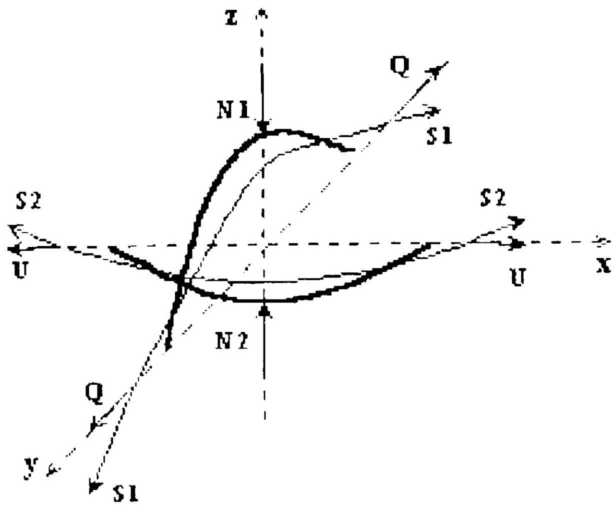


Fig. 7 Deformation of binding element

There is an effort to develop a method of fixation and subsequent cutting of the fabric sample in the stress state due to a comparison of the theoretically calculated parameters and the real fabric parameters. The aim is to define the shape of the interlacing of yarns under the stress.

DEPARTMENT OF NONWOVENS

Teaching staff

Doc. RNDr. Oldřich Jirsák,CSc., Head of Department
Prof. RNDr. David Lukáš, CSc., rector
Ing. Iva Macková
Ing. Jaroslav Hanuš, Ph. D.
Ing. Lenka Martinová, CSc.
RNDr. Bohuslav Charvát
Technicians: Václav Kotek, Filit Sanetrník, Jaroslav Moravec, Hamouz.
PhD students: Kotišová, Hrůza, Věra Soukupová.

Characteristics

One of the best known and active departments in the field of non-woven textiles structure and production. For example new STRUTO technology, developed in this department, is now used in many countries including USA.

Teaching activities:

a) Production of nonwovens (Jirsák) one-term basic course for students in technological streams
b) Subjects for the specialization nonwovens:
   Polymeric adhesives (Martinová)
   Theory of nonwovens (Lukáš)
   Stereology (Lukáš)
   Mechanical technologies of nonwovens (Macková)
   Chemical technologies of nonwovens (Jirsák)
   Thermal technologies of nonwovens (Jirsák)
   Industrial fabrics (Hanuš)
   Processing of waste fiber materials (Hanuš)
   c) Teaching nonwovens on PhD level

Research activities

a) New high-loft nonwoven technologies and fabrics (Struto, Rotis)
b) Machinery for production of perpendicular laid bulky fabrics (lapper, through-air bonding chambers)
c) Research in melt-blown technology
d) Thermal insulating
e) Filtration properties of textiles
f) Sorption properties of textiles
g) Filling properties of high-loft textiles

Laboratory equipment

- a line to produce cross-laid needled fabrics
- a Struto plus thermobonding line
- hot press
- colender
- chemical bonding
- melt blown laboratory unit
- tensiometer Krüss K12
- testing filters – the NaCl bench Rig System (BS 4400)
- testing mechanical properties (tensile, compressibility, etc..)
- testing thermal insulating properties
- eletrostatic charging device TANTRET

Selected publications

Journals:

Lukáš, D.: Three-dimensional Monte Carlo simulation of droplet motion on heterogenous surface, *EUROPHYSICS LETERS*, 1999.

Jirsák,O., Gok,T.,Ozipek,B.,Pan,N.: Comparing Dynamic and Static Methods for measuring Thermal Conductive Properties of Textiles. *Textile Res. J.* **68** (1), 47–56 (1998).

Krčma, R., Jirsák, O.: Fortschritte bei der Entwicklung hochvoluminiser senkrecht verlegter Textilien. *Technische Textilien/Technical Textil* **39**, (1), 32–34 (1997).

Krčma, R., Jirsák, O.,Hanuš, J., Saunders, T.: What's New In Highloft Production? *Nonwovens Industry* **28**, (10), 74–78, (1997).

Lukáš, D.,Glazyrina, E.,Pan, N.: Computer simulation of liquid wetting dynamics in fiber structures using the model, *J. of Text. Institut*, **88**, (2), 149–161, (1997).

Monograph:

Jirsák, O., Wadsworth, L. C.: Nonwovens Textiles, Carolina Academic Press,133 Durham, NC 1999.

PERPENDICULAR LAID FABRICS OF FLAX, JUTE AND KENAF FIBERS

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INTRODUCTION

Technology of production perpendicular laid highloft fabrics was developed at the Technical University of Liberec, Czech Republic in the late 80's [1]. Since then, a number of machines have been installed in the Czech Republic, Germany, Austria and other countries. In 1998, the installation of production lines begun in the USA. The working width of machines is usually 1M, 2M and 2.5M, the production of the latter up to 500 kg/hod.

Production lines consist of a card, perpendicular lapper and a through-air thermobonding chamber. A blend of base fibers and bonding fibers is processed.

A wide variety of specific fabrics have been developed in range of base weight 100–2000 g/m^2, thickness 15–35 mm, density 5–60 kg/m^3 depending on fiber material and end-uses. The fabrics show excellent compressional behavior and found the use in furniture, sleeping bags, automative industry, as filter materials etc.

Most of producers process various kinds of polyester fibers or waste fiber materials. A wide variety of bonding fibers are available namely:

- mono-component polypropylene, polyethylene, co-polyester and co-polyamide fibers,
- bi-component (core/sheath) polyester/co-polyester, polyester/ polyolefine, polypropylene/polyethylene etc.

2. PROCESSING JUTE, FLAX AND KENAF FIBERS

2.2 Carding

Blending, opening and carding these fibers requires special machinery which is well known and available, nevertheless it is not available at the Technical University in Liberec. To process the fibers, woolen carding machines were used. This fact should not considerable influence resulting fabrics.

2.3 Bonding fibers

Proper bonding fibers must be selected for every specific base fibers considering

- bonding capacity,
- price of final fabric.

Coarse flax, jute and kenaf fibers can be successfully bonded using mono-component higher dtex, low melt viscosity and non – shrinkable bonding fibers. The base fibers with high content of impurities create a non-consistent carded web. Therefore the bonding fibers should be of a long staple to help the consistency of carded web. Low price of fibers is desirable considering the price of final fabrics.

After preliminary tests, the polyethylene bonding fibers 7 dtex 75 mm (producer Drake, England) were selected for following experiments. Their price is about 1.5 USD/kg. Polypropylene bonding fibers of 3.9, 6.7 and 17 dtex were also tested as bonding fibers. These were not selected for following reasons:

- polypropylene fibers usually show some level of shrinkage below melting temperature which leads to irregularities in fabrics
- polypropylene fibers require rather high bonding temperatures (over 170 °C). These temperatures proved to bring a fire hazard when processing the fibers materials containing high amount of dust.

Bi-component bonding fibers were not chosen because of rather high price when considering possible price of jute, kenaf and flax fabrics.

2.3 Experimental part

The base fibers were preblended with polyethylene bonding fibers in a roller carding machine. The carded web was cross-layered and slightly needled. The matt was then led into second roller card and the carded web processed by the vibrating perpendicular lapper into a fiber layer formed on the sieve conveyor belt of through-air thermobonding chamber.

The process was accomplished using a laboratory pilot line with following parameters:

A. Fiber blends

A.1 20 % PE 80 % Jute
A.2 35 % PE 65 % Jute
A.3 35 % PE 65 % Kenaf
A.4 35 % PE 65 % Flax

B. Process parameters

Area weight of cross-laid fabric	440 g/m^2
Input speed into second card	1 m/min
Output seed of carded web	10 m/min
Area weight of carded web	44 g/m^2
Frequency of lapper	155/min

Linear speed of conveyor belt (bonding oven)	0.2 m/min
Bonding temperature (˚C)	140 ˚C
Dwell time in oven	5 min

Dwell time in oven was extremely long due to required high area weight of fabrics. In the production process the dwell time cca. 1 min would be sufficient.

Following materials have been prepared:

Material (No of blend)	Thickness (mm)	Area weight (g/m^2)	Density (kg/m^3)
A1	35	1000	28,6
A2	35	1400	40,0
A3	35	2000	57,1
A4	35	2300	65,7

Note: The processed fibers materials contained high amount of impurities which fell out of carding machines. That is why the composition of samples is not equal to that of fiber blends A1, A2, A3. Approximate amount of lost fibers was

A1	45 %
A2	37 %
A3	41 %
A4	28 %

CONCLUSIONS

The technology of processing jute, kenaf and flax fibers by perpendicular layering carded web and following through-air thermobonding has been developed. Various kinds of bonding fibers were tested. Polyethylene bonding fibers have been selected as an optimum choice concerning processability, bonding capacity, process security and price.

The fabrics show rather poor properties concerning compressional resistance and elastic recovery. Their end-uses could be found in:

- thermal moulding process, production of sound - and thermal insulations. Here the perpendicular-laid fabrics show some advantages like formability when compared with conventional needled fabrics.
- filling material
- water filtration
- thermal insulations (provided the flammability is reduced)
- carrier of grass seeds for re-cultivation of land.

REFERENCE

[1] KRČMA, R., JIRSÁK, O., HANUŠ, J. and SAUNDERS, T.: Nonwovens Industry **20** (1997), 10, pp. 74–78

DEPARTMENT OF CLOTHING

Teaching staff

Doc. Ing. Zdeněk Kůs, CSc., Head of Department
Doc. Ing. Antonín Havelka, CSc.
Ing. Dagmar Růžičková
Ing. Bc. Vera Glombíková
Ing. Petr Tylínek
Ing. Andrea Halasová
Ing. Jana Zouharová
Ing. Milena Kaprasová, CSc.
Ing. Helena Vargová, Ph. D. student
Ing. Petra Komárková
Iveta Kinclová, secretary
Ing. Milada Kubíčková
Gerhard Geisler, technician
Ing. Blažena Musilová
Jana Podzimková, technician

Characteristics

Department of Clothing engineering is a part of Faculty of Textile Engineering of Technical University of Liberec. The Department of Clothing engineering guarantees courses in all special areas of Clothing Technology in Masters and Bachelors Degree studies and PhD study as well at the Faculty of Textile Engineering. The department guarantees guidance of Bachelors, Masters and Doctors thesis.

Master of Science Degree: Branch Clothing technology, Orientation on Processes of Clothing Fabrication and Aparel Production Design.

Bachelor of Science Degree: Branch Technology and directing of clothing manufacture.

Teaching activities

Staff of department guarantees courses in Bachelors, Masters Degree studies of the full-time form and part-time form of study and in PhD Degree.

Bachelor of Science Degree:

- Apparel Production
- Properties of Clothing Materials
- Introduction to Computers
- Organisation and Management of Clothing Production
- Technology Production Preparation
- Basis of Pattern of Clothing
- Clothing Technology
- History of Fashion Culture
- Pressing, Forming, Mounting and Finishing Technology
- Process of Dividing and Connecting
- Pattern and Styling of Cloth
- Automation in Clothing Industry
- CAD/CAM systems in Apparel Industry
- Special Methods of Measurement

Department of clothing engineering provides subject "Apparel production" for branches "Textile marketing" and "Mechanical textile technology" too.

Master of Science Degree (for full-time form and part-time form students)

- Joining Technology and Machinery
- Pattern Design I, II
- Clothing Materials and Clothes Physiology
- Steam Ironing and Finishing
- Introduction to Computers
- CAD systems in Apparel Industry
- Technology of Clothing
- Production Preparation in Clothing
- Organisation and Management of Clothing Production
- Automation of Cutting and Production Preparation
- Unconventional Connecting and Cutting
- Robotics in Apparel Production
- Aesthetics
- Computer simulation of clothing Production
- Industrial Garment Products
- Special Methods of Measurement

For all M.Sc. students of Faculty of Textile Engineering in the full-time form and part - time form of the textile technology the following courses is given the subject "Apparel production".

Members of Staff of the department take part in Final State examination at Technical University in Liberec, Prostějov, Trenčín and Prešov as chairmen and members of the committees.

Teaching is realised in these special laboratories:

- Laboratory of clothes physiology
- Laboratory of testing of mechanical properties of clothing products
- Laboratory of technology of clothing
- Laboratory of joining processes
- Laboratory of CAD systems
- Laboratory of automation and robotics
- Software for computer simulation in common computer classroom TF

Research activities

Research activities of Department of clothing are connected with special abilities of its members. The part of activities is financed by grants and economic activities. The aim is to publish general results of successful solution in specialised journals and presentation at international conferences.

The main areas of research are:

- Computer simulation of apparel processes, machines – optimisation of production
- Evaluation of physiology and clothing comfort

- Application of frame analysis on detection and classification of selected facts of clothing production
- Application of finite element method to selected problems in clothing
- Objective evaluation of organoleptic properties

In connection with the international project COPERNICUS and the 5th program of EU these branches will be extended in future.

The Department take part at the following research projects:

Research project of the Ministry of Education:

- VZ Organoleptic properties of the 3D textile products (Zdeněk Kůs)

Grant projects solved in 1996/1999:

- GAČR 1999–2001 č. 106/99/1184 – PSOTEX (Militký Jiří)

Other projects solved in 1998–1999:

- FRVŠ 381/1998 Kůs Zdeněk, M.Sc. Ph.D.: Application finite elements method in student research thesis

International co-operation

International co-operation enters into contact with many departments of the same orientation, mainly in Europe. Reciprocal scientific contacts are used with colleagues for example of Manchester Metropolitan University, Great Britain, University of Leeds, Hong Kong Polytechnic, University of Minho, Portugal. The members of Clothing department give special seminars and they attend science congresses to realise scientific co-operation. The last international congress was Textile Science in 1998 in Liberec. Within the frame of scientific co – operation and solution of common tasks following foreign experts visited the Department of clothing in the years 1996–1998:

- Prof. Bereznenko and colleagues, Kiev Polytechnics, the Ukraine,
- Prof. Kawabata, Shiga University, Japan,
- Prof. Ibrahim and colleagues, Mansoura University, Egypt,
- Dr. A. Vlasenko, Kiev Polytechnics, the Ukraine,
- Jintu Fan a Ji Li, Hong Kong Polytechnics, Hong Kong,
- Kim Lee, Polytechnic Korea,
- Assoc. Prof. Jelka Geršak, Maribor, Slovenia,
- And others.

Recently and in the future will be used contracts of Faculty of Textile Engineering of Technical University for realisation collective science projects.

Development plans of the department:

To ensure the necessary of new subject will be realised by feedback from students (questionnaire). Study materials for some subjects will be prepared. The filling of some lab-exercises will be modified. The aim is to have two lectures for one subject at least and all of the leading teachers will have the science - pedagogical degree – minimally senior lecturer.

Especially in the higher classes it will be necessary to introduce colloquial study forms leading in to master thesis. It is necessary to introduce available literature for every subject. It appears that applied studying texts on Intranet are very helpful. A control of the level student knowledge in the clothing education courses will be needed, just like control of knowledge in connected branch. This is possible to attain to discussion of student projects. The department will keep on tackle all noticed scientific themes.

Long-term and prospective themes are mainly:

- Simulation of clothing process and clothing production,
- Evaluation of physiology and clothing comfort,
- Solution selected problems with method of final elements,
- Application of frame analysis,
- Application automation in clothing production.

Solution of these themes is supported not only by staff respect, but also by instrument equipment and by contacts with practise.

By help of the grants we try to buy the equipment and devices for research. Nearly every year the department hands over grants aiming to modernisation of laboratories, ensuring the teaching of new subjects etc.

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COMPUTER SIMULATION OF APPAREL PRODUCTION

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INTRODUCTION

The possibilities and difficulties of the computer simulation applied on the apparel production are described. The application for the existing small apparel manufacture with the use of the Witnessâ software is added.

The model was used for the investigation of the bottlenecks in the apparel production in the small factory. There was found the good matching between the model and the actual production.

BASIC IDEAS

The computer aided simulation methods are widely used for the solving of many problems of industrial design, production and testing. There is possible to find its utilization for the simulating of the complex systems with many employees and machines. On the other hand the applications focused directly on the computer modeling of the apparel production are not so widely used.

The problem of the simulation of the apparel production is caused by the different character of such production (for instance in comparison with the mechanical engineering).

The production line contains of the operations. The basic features of typical operation are on the Fig.1.

The important features for the true modeling are the breakdowns. There were necessary to make complex investigation of the breakdowns appearing in the apparel production process. The example of classification of the experimentally found values for the group of the sewing machines is described in the Tab. 1.

The importance of the detailed study of the rate of break types is clear from the example on the Fig. 2. which shows measured rates of the different of breaks for the chain stitch sewing machine.

The important part of the breakdowns is type No. 3 – Time loss caused by the bad organization – that has a big influence on the productivity. The application of the computer simulation in the appropriate way, how to minimize this time loss.

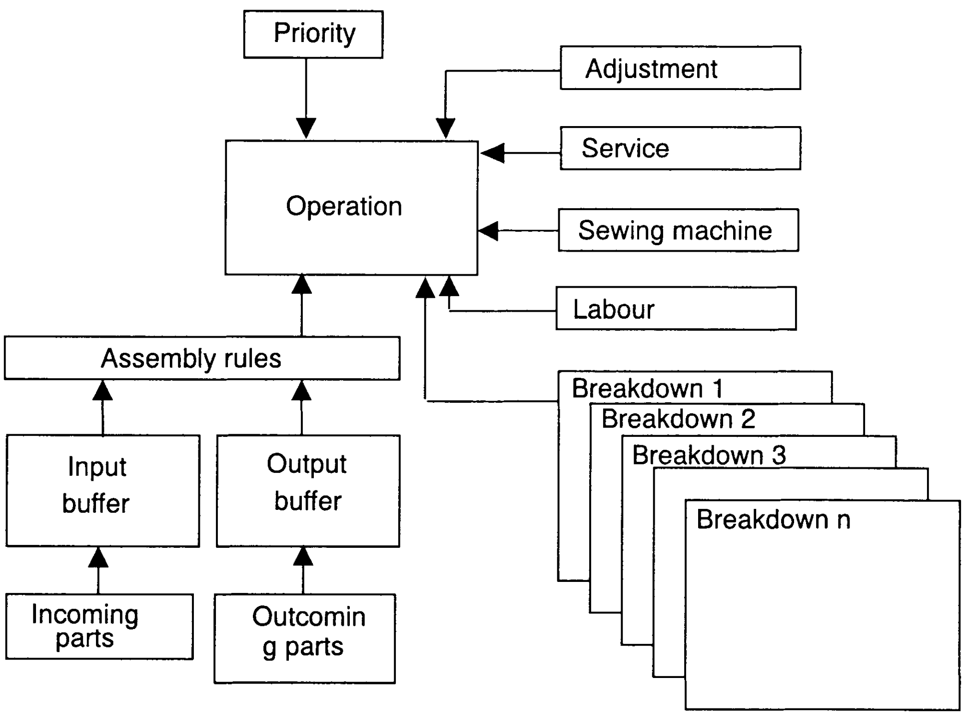

Fig. 1 Features od the sewing operation

type	Breakdown characteristics	Breakdown Time between failures	Repair time
1	Machine maintenance	Lognorm(36.2;36.8)	lognorm(1.5;1.26)
2	Personal breaks	Lognorm(57.6;48.6)	lognorm(1.34;1.19)
3	Bad organization time loss	Lognorm(34.1;26.6)	lognorm(1.37;1.2)
4	Needle thread replacement	Gamma(2.7;0.98)	lognorm(1.06;0.98)
5	Needle thread breakage	Gamma(2.2;0.94)	lognorm(0.5;0.40)
6	Looper thread replacement	Lognorm(109;66.7)	lognorm(0.77;0.71)
7	Looper thread breakage	Lognorm(99.7;106.3)	lognorm(0.53;0.23)
8	Sewing needle replacement	Lognorm(70.5;59.0)	lognorm(2.89;1.94)
9	Other failure		
10	Changeover of operation	Gamma(1.08;0.935)	lognorm(25.1;43.7)

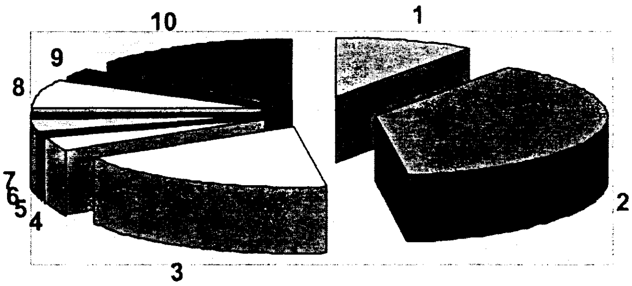

Fig. 2 Rate of different breakdown types for measured group of sewing machines

MODELS

The model elements must represent several object types: sewing machines, different skill labors, parts of the sewed product, buffers, etc. The relationships between elements include also the different importance of the products, workers, etc. All of these elements can work in shifts. The complex model has to be designed with help of these elements and with actual statistical parameters, which were found experimentally.

Model1

The simple way how to create simulation model is to use the scheme showed on the Fig. 3.

The model is based on the investigating of the time necessary for pulse (representing the sewed apparel product) passing through the model of the production line. Each operation of the line is represented similar way.

The sewing machine is designed as the defined time delay for the incoming pulse. The time interval between the pulse input and output depends on several factors that were experimentally measured in the apparel factory and answer the real production.

Time delay for the pulse is caused by the delay element, which time delay is set by the sum of the four influences. The value of three of them are generated like a random number, the last one is the operation time depending on the type of the operation and is constant.

This model is used not only for the sewing machines but for the other operations too.

The part of the designed model of production line is on the Fig. 4. The model of the whole production line consists of the blocks. Each block represents one operation and contains from the elements of the Fig.3. The fabric piece that is sewed in the operation is modeled as a single pulse coming to the block. The delay time depends not only on the exact time of the operation, but also on the sewing machine breakdowns, the influence of the thread and of the worker. These influences are modeled by the additional time interval to the exact operational time. This additional time is counted as a random number with the experimentally found distribution functions.

The assembly operations are modeled by the logical

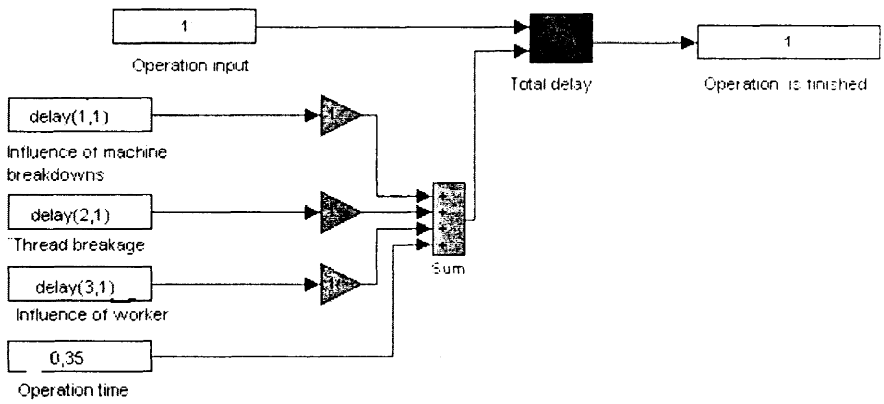

Fig. 3 The simple sewing machine operation model

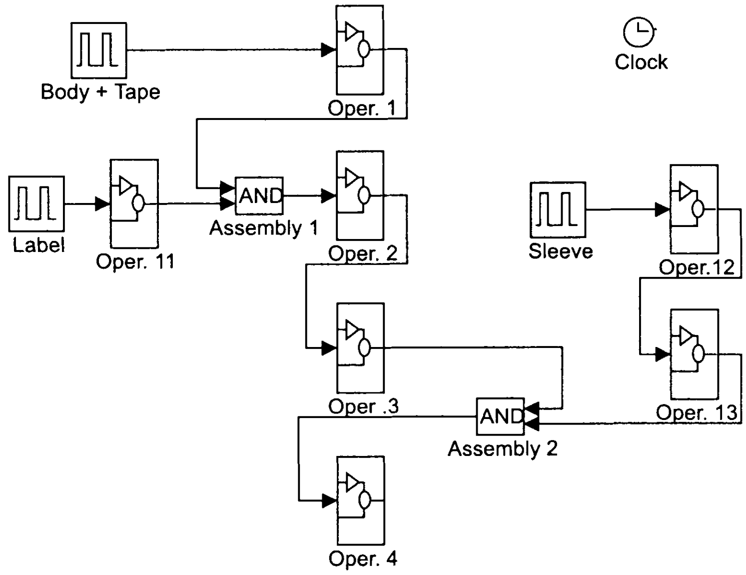

Fig.4 Simple simulation of the part of the production line

functions AND so that the output pulse of the block. Assembly1 appears when there are simultaneously both input pulses on this block, coming from Oper. 11 and Oper. 1.

The time that the pulse coming to the Oper. 1 needs to pass through the model m to the output of the Oper. 10 is equal the production time for one single product.

There were studied the influence of the breakdowns on the pulse propagation time.

This simple model of production line can be used for the first problem study, as it does not cover all of the aspects of the operation from the Fig. 1.

MODEL2

There is necessary to use of the other sophisticated software for the complex simulation.

The appropriate software is Witness®. This software is a commercial product designed for the simulation of the behavior of the sophisticated systems. It could be very useful for the design of the optimal amount of the special machines, the amount of the workers or the testing the system sensitivity for the bottlenecks.

The complex simulation model of the small apparel manufacture is described. It was designed with the aim to reduce the time loss and to enhance the productivity of the production. The scheme of the production (for two types of swimming suits) is on the Fig. 5.

The definition of the simulation elements is complex and enables the use of all of the model aspects from the Fig. 1.

For all of elements is defined the shift, quantity and the allowance, that give the element to finish the work after end of the shift. In addition to these parameters are defined the distribution functions, that characterize several types of the mistakes, e.g. the regular machine service, repair time (when the machine is broken), time interval between the needle and the thread breakage, the time for the coffee break for the workers, the time for the lunch, etc. The exact parameters of these distributions are mentioned above.

The operations are modeled so that they need the presence of the worker and the sewing machine. As the amount of these elements is limited (similarly as in the real production), there is necessary to define the priority levels, which decide machines and workers distribution between operations.

The simulation was performed under different conditions (numbers of workers (from 13 to 20), the different number of the sewing machines, etc.). The aim was to find the optimal number of them or the small production and to predict the production.

Advantage of OLE model creating

The preparation of the model of the apparel production line takes long time as there are many parameters of the simulation elements, which is necessary to define and to set to appropriate values.

Even the repeated simulation for the different model parameters needs so much time to be changed. One of the ways, how to generate simulation models is the application of OLE technology, which gives the possibility to connect several Windows programs to each other. Then it is possible to define simulation model parameters in the other software, e.g. MS Excel, send them to Witness and on the other hand to get the simulation results back to OLE controller.

No.	Total no. of sewing machines	Total no. of workers	Profit/day/ [$]
1	30	26	*240*
2	30	26	*165*
3	30	31	*285*
4	30	33	*405*
5	25	36	*440*

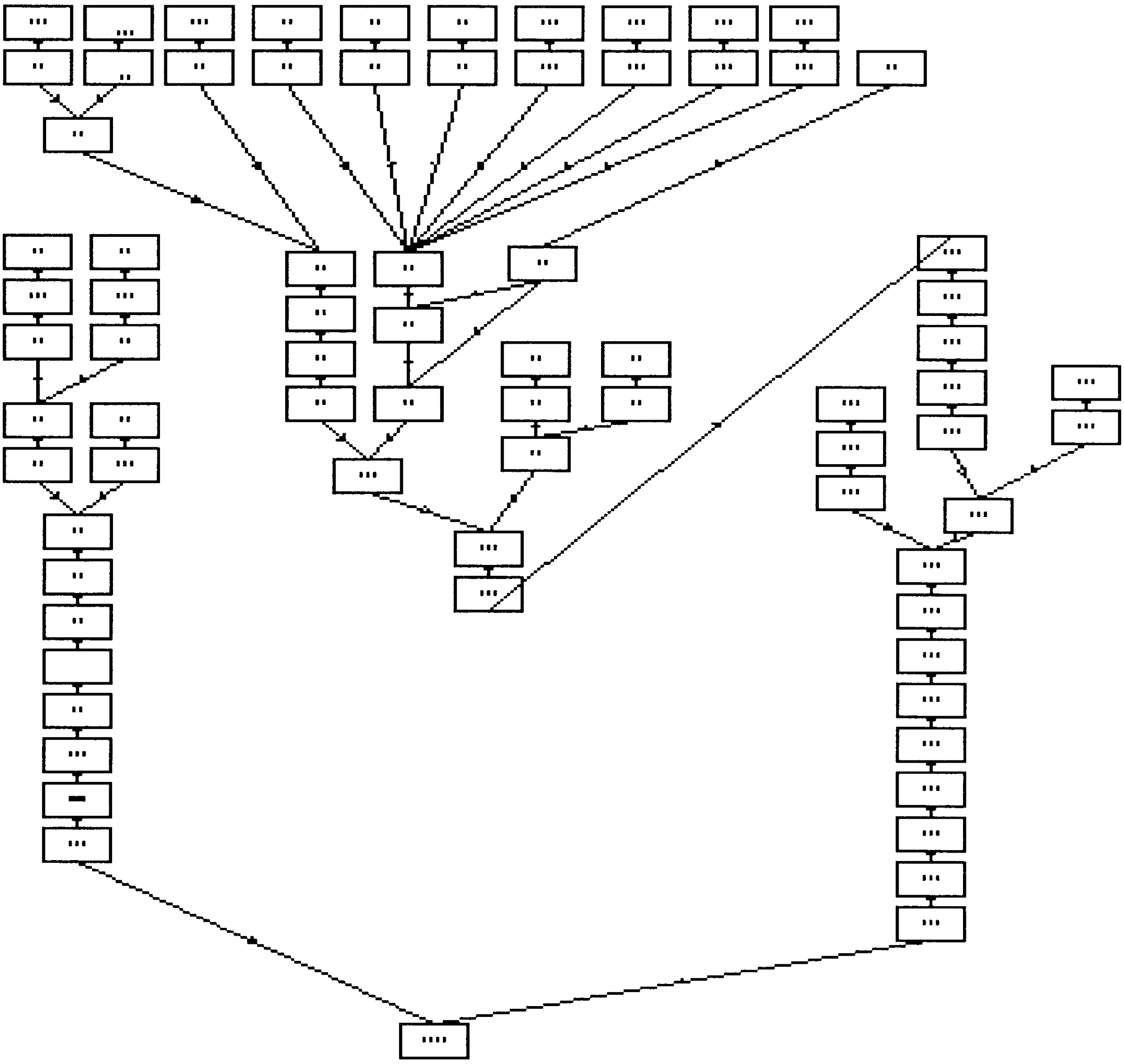

Fig. 5 Process view of the simulated apparel production line

The selected results of the repeated simulation for the production line are in the Tab. 2.

The important enhancement of the sewing machine utilization and the productivity growth were reached.

RESULTS

The practical production arranged according to the model results gave very good matching with the simulated production. The preparation of the simulation needed not only the construction of the model, but also the experimental measurement of the exact time parameters for all of the break types.

These measured parameters can be used for the other model under the condition, that are used similar or the same types of the sewing machines, and similar workers.

The finding of the optimal amount of the sewing machines can save costs particularly in the case of the small producers.

REFERENCES

[1] WITNESS software – manuals

[2] Masnicakova, M. :Dipl. Ing. Thesis, Liberec 1996, Czech Republic

[3] Plesak,R.: Dipl. Ing. Thesis, Liberec 1996, Czech Republic

[4] KUS, Z. –TRUNG, N. C.: Application of Computer Aided Simulation for Productivity Improvement of Small Apparel Manufacturers, IMCEP'97, Maribor, Slovenia 1997

[5] KUS,Z. – TRUNG,N.C.: Computer Aided Simulation of Apparel Production with help of Witness software, TECNITEX, EXPO'2000, Turin, Italy 1996

[6] KUS, Z.: Application of OLE for programming of Simulation models in Witness software, Proc. Of Int.Conference Textile Science 98, Liberec 1998, Czech Republic

[7] Pivnička, P.: MSc. Thesis, Faculty of textile, TU Liberec, 1998

DEPARTMENT OF TEXTILE MATERIALS

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Characteristics

The department of textile materials is one of the oldest departments of textile faculty. Traditional orientation to the problems of textile testing and description of textile fibers properties has been extended after velvet revolution to comprehensive system of textiles evaluation from design of experiments and measuring apparatus via realization of measurements and statistical evaluation of uncertainty to the creation of mathematical models and quality control. The new areas of research and education including composites, image analysis, thermo-mechanical analysis, hand evaluation and objective measurement of color have been developed. The application of selected chemometrical and computer intensive statistical methods to the textile branch has been realized. In sequel are described the main teaching and research activities only. The deeper explanation of departmental activities and full list of publications are on the faculty private page www.ft.vslib.cz

Teaching activities

The department provides courses oriented towards: textile fibers (structure, properties, utilization), textile metrology (principles of measurements and analysis of textile structures), experimental data treatment (analysis of laboratory data), textile based composites, and quality control. These courses are focused on Textile Technology and Textile Material Engineering MSc specialization. It also has corresponding courses in Bachelor studies.

M. Sc. courses:

For all students of the textile technology the following courses are given.

- Textile fibers (Militký, Kovačič)
- Textile testing (Militký, Kovačič)
- Experimental data treatment (Militký)
- Quality Evaluation (Militký, Bajzík)

For students in a specialization of textile materials the following courses are given:

- Structure and properties of textile fibers (Košková)
- Textile composite materials (Košková)
- Special testing methods (Kovačič)
- Design of experiments (Militký)
- Mechanical properties of textiles (Košková)
- Mathematical modeling in textile technology (Militký)
- Special fibers (Militký)

Research workers of department are supervisor of diploma works as well as (about fifteen MSc students yearly).

Research activities

Research activities are concentrated on the investigation of specialty fibers, mathematical modeling of textile structures and their properties, evaluation of textile quality, investigation of kinetic processes in solid state, analysis of special measurements (image analysis, thermo-mechanical analysis), software for laboratory data analysis, objective color measurements and hand prediction. Selected results of research activities were published in books, journals and proceedings from conferences.

The main areas of research are:

- Unevenness of textiles properties and appearance in the plane
- Analysis of clean room textiles
- Air permeability and porosity prediction
- Particle size analysis in textile branch
- Complex evaluation of textiles quality
- Subjective and objective methods of hand evaluation
- Software for statistical analysis in textile laboratories
- Properties of modified PET fibers
- Special environmental optical methods (AQUASEM)
- Visco-elastic behavior of textile materials
- Modeling of textiles structure vs. properties relationships
- Ultimate mechanical properties of polymeric and non-polymeric materials
- Modeling of diffusion phenomena in polymeric fibers
- Utilization of Image Analysis for textiles characterization
- Application of Basalt fibers for special fabrics
- Thermo-mechanical analysis of fibrous structures
- Composites with textile reinforcement, carbon-carbon composites
- Structure and properties of textile reinforcements for composites
- Development of new testing methods
- Objective color measurements
- Compute intensive statistical methods

Main Scientific Projects:

A lot of projects and research themes are solved in frame of grants. The two main grants of Czech grant agency are:

GAČR 1999-2001 Surface Structure of Textiles – head Prof. Militký

GAČR 1999-2001 Quantitative Analysis of Textile Reinforcements – head Assoc. Prof. Košková.

The department is involved in the solution of long term research project of Czech ministry of education "Finishing of textile structures according to their quality".

There are a lot of projects of Czech ministry of education (development fund for higher education – FRVŠ) solved on the department. For example

- FRVŠ 1999 Kovačič Extension of Material Research Laboratory
- FRVŠ 1999 Militký Special Applications of Image Analysis
- FRVŠ 2000 Militký Image Analysis System for Students

Further grants are oriented to the evaluation of protective textiles hand (Czech ministry of industry and trade) and characterization of retted flax (Necoflax project of INCO COPERNICUS). Some new projects of grants are now given to grant agencies for inspection. These relative rich grant activities are main source of support in development of laboratories and creation of new testing methods.

Postgraduate Students and Their Theses:

Vladimír Kovačič – Special inorganic fibers
Vladimír Bajzík – Hand evaluation methods
Michal Vik – Subjective and objective color differences
Jitka Rubnerová – Application of image analysis
Mirka Znojilová – DSC of special fibers
Hana Boušková – Thermo-mechanical Properties of Inorganic Fibers
Mirka Maršálková – Antistatic properties of clean room textiles
Jaroslav Netík – Complementary colorimetry
Jana Šmilhausová – Optimization of zone fluctuation model of color assessment
Stanislav Vopička – Structural analysis of woven composites
Martin Palán – Process-ability of special fibers
Martin Krula –Tubular reinforcements
Margit Burešová – Porosity of C/C composites
(full time PhD students are underlined).

Selected publications:

The full texts of some publications listed below are obtainable from authors upon request.

[1] Militký J. et all.: Modified PES Fibers (1991), Elsevier,

[2] Meloun M., Militký J., Forina M.: Chemometrics in Instrumental Laboratory (1992), vol. 1, Statistical Data Analysis Ellis Horwood London

[3] Meloun M., Militký J., Forina M.: Chemometrics in Instrumental Laboratory (1994), vol. 2, Statistical Data Analysis Ellis Horwood London

[4] Militký J., Vaníček: The Influence of Spinning Rate on Structure and Mechanical Properties of PET Fibers (1991). Acta Polymerica **42**, No 7, p. 326

[5] Militký J.,Šesták J.: Building and Statistical Interpretation of Nonisothermal Kinetic Models (1992), Thermochim. Acta **203,** 31

[6] (1998), Vlákna a textil, No 3, p. 72/076, Vol. 5 ISSN 1335-0617

[7] Meloun M., Militký J.: Zpracování experimentálních dat (1998), East Publishing Praha, p. 839. ISBN 80-7219-003-2

APPLICATION OF IMAGE ANALYSIS FOR NONWOVENS VISUAL IRREGULARITY EVALUATION

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**Rieter Elitex, Ústí nad Orlicí, Czech Republic*

The main aim of this work is attempt to describe visual irregularity (surface appearance) of light weight nonwoven textile structures. Visual and subjective methods for evaluation of visual irregularity of chemically bonded nonwovens are compared. The image analysis system LUCIA is used for estimation of characteristics describing visual irregularity. The analysis of subjective and objective estimates of visual irregularity is realized by the variation coefficient and by the ANOVA type model. The Moran's spatial autocorrelation index is used for identification of organized pattern in data.

KEYWORDS Surface Appearance, Visual Irregularity, Porosity, Image Analysis

1. INTRODUCTION

Surface appearance (visual irregularity) is interesting for woven structures and in some cases for nonwovens as well. This characteristic is closely connected to the variation function for transparency, reflectivity, planar mass and to the another properties as e.g. air permeability.

Corresponding to the description of unevenness of linear textile structures by the length variation function, there can be constructed surface variation function for textile fabrics. The surface variation function can be easily used for description of unevenness or uniformity.

The unevenness can be categorized according to the investigated characteristics to the following main groups:

- Mass unevenness (mostly used)
- Structural unevenness
- Visual (optical) unevenness
- Mechanical or physical properties unevenness
- Appearance unevenness.

There are some connections between above-mentioned categories of unevenness.

The main aim of this work is attempt to describe uniformity of appearance of light weight nonwoven textile structure. For quantification of appearance uniformity the characteristics of visual unevenness are used. These characteristics are measured by the image analysis and subjectively by the human eye. The evaluation of appearance uniformity is based on the variation coefficient estimation and on the ANOVA (analysis of variance) model. The organized patterns in data are checked by the Moran's spatial autocorrelation index.

2. UNEVENNESS CHARACTERIZATION

Traditional methods of uneveness characterization in two dimensions are based on the measurement of relative variance (variation coefficient) of some geometrical quantities between selected (rectangular) cells dividing the investigated area. The same principle can be used for visual irregularity estimation. In this work, the visual irregularity has been evaluated from selected visual characteristics measured in cells of defined size (see Fig. 1). These rectangular cells divide the microscopic image of sample and create rectangular net.

As the visual characteristics of appearance unevenness in individual cells the following ones were selected:

- Number of white spots evaluated by the human eye NE
- Number of white objects NW evaluated by the image analysis (see white areas in the Fig.2)
- Relative surface porosity (portion of white area) AF defined on the Fig 2.

The characteristics AF is computed from relations (see Fig. 2)

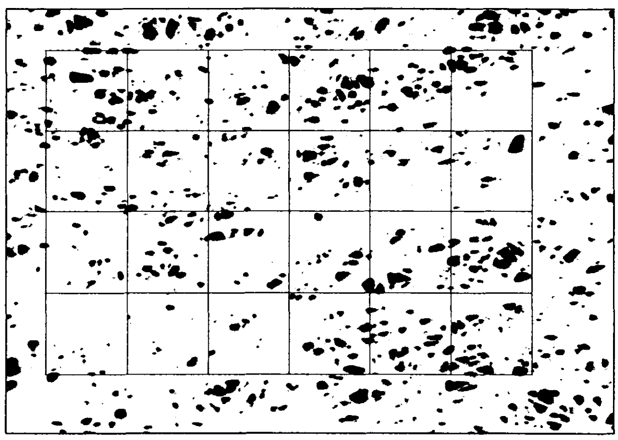

Fig. 1 Inverted Image of tested sample (planar weight is 60g/m^2). White spots are here black.

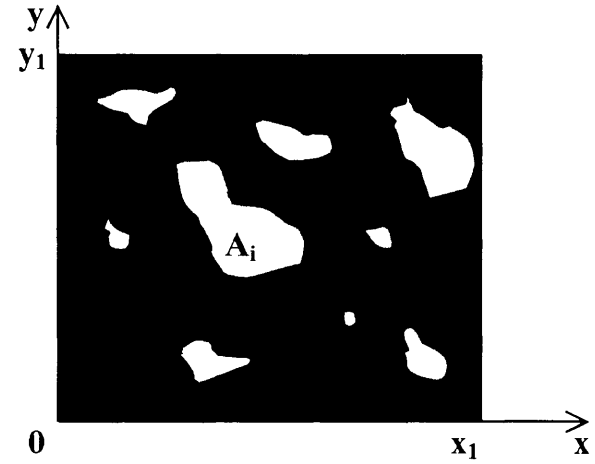

Fig. 2 Definition of relative surface porosity (A_i is the area of white object)

$$AP = \Sigma A_i$$

$$AE = x_i . y_i$$

$$AF = A_P / A_E$$

Samples (cells) were oriented in the following way (see Fig. 1).

- Direction X is equivalent to the machine direction (cells denoted i). In this direction are N cells.
- Direction Y is equivalent to the cross direction (cells denoted j). In this direction are M cells.

Results of evaluation are rectangular data arrays NE_{ij}, NW_{ij}, AF_{ij}, $i = 1...n$, $j = 1...m$.

Appearance uniformity is analyzed by the following methods:

a) Coefficient of variation (CV),

b) Analysis of variance (ANOVA).

Traditional method based on the variation coefficient is more suitable for characterization of degree of overall unevenness. Analysis based on the analysis of variance is useful for testing of evenness in selected orthogonal directions.

2.1 Analysis based on CV

Coefficient of variation is traditionally used as the characteristics of unevenness. According to the common definitions we can simply computed the overall mean

$$m = \frac{1}{MN} \sum_i \sum_j (P_{ij}) \tag{1}$$

variance

$$s^2 = \frac{1}{MN} \sum_i \sum_j (P_{ij} - m)^2 \tag{2}$$

and coefficient of variation

$$CV = s/m \tag{3}$$

Here P_{ij} is selected visual characteristic of appearance (NE_{ij} or NW_{ij} or AF_{ij}).

The quantity CV is external variation coefficient CB(F) between cell areas F.

The total variance s^2 can be divided to the two terms by using of means in the machine direction and cross direction

$$m_{i0} = \frac{1}{M} \sum_j P_{ij}$$

$$m_{0j} = \frac{1}{N} \sum_i P_{ij}$$

Symbol „$_0$" denotes index used for summation *i.e.* m_{i0} is mean value for i-th position in the machine direction. For the *machine direction* (expansion of eqn. (2) by using of the m_{i0}) the following relation results [1]

$$s^2 = s_L^2 + s_{HL}^2 \tag{4}$$

where the variance in the machine direction is

$$s_L^2 = \frac{1}{N} \sum_i (m_{i0} - m)^2 \tag{5}$$

and the variance in the transversal direction is

$$s_{HL}^2 = \frac{1}{MN} \sum_i \sum_j (P_{ij} - m_{i0})^2 \tag{6}$$

For the *cross direction* is

$$s^2 = s_H^2 + s_{LH}^2 \tag{7}$$

where the variance in the cross-direction is

$$s_H^2 = \frac{1}{M} \sum_j (m_{0j} - m)^2 \tag{8}$$

and the variance in the longitudinal direction is

$$s_{LH}^2 = \frac{1}{MN} \sum_i \sum_j (P_{ij} - m_{0j})^2 \tag{9}$$

Dividing the corresponding standard deviations by the mean m the variation coefficients CV_L, CV_{HL}, CV_H and CV_{LH} results.

These coefficients are from statistical point of view the point estimates of population variation coefficients CVP_L, CVP_H, etc. For creation of confidence intervals the variance of point estimates have to be computed. The rough formula of sample variation coefficient variance $D(CV)$ has the form [2]

$$D(CV) = CV^2 \left(\frac{c + CV^2(2c+1)}{2c(c-1)} \right)$$

where c = (N or M) is number of cells in the corresponding direction.

Asymptotic 95 %th confidence interval for CVP is then defined as

$$CV \pm 2\sqrt{D(CV)}$$

The coefficients of variation are statistically different in the cases when corresponding confidence intervals are not intersecting.

2.2 Analysis by the ANOVA

The P_{ij} can be interpreted as discrete presentations of random field on the discrete two-dimensional integer valued rectangular mesh [1]. Let the P_{ij} are described by the following model [2]

$$P_{ij} = \mu_{ij} + \varepsilon_{ij} \tag{10}$$

where μ_{ij} is true value in the ij cell and ε_{ij} is random error. The term μ_{ij} can be decomposed to the terms

$$\mu_{ij} = \mu + \alpha_i + \beta_j + c\alpha_i\beta_j \tag{11}$$

where μ is total mean α_i are **effects in the cross direction**, β_i are **effects in the machine direction** and c is constant of Tukey one degree of freedom non – additivity [2].

Uniformity in the machine direction is equal to validity of hypotheses $H_0 : \beta_j = 0, j = 1......M,$ and uniformity in the cross direction is equal to validity of hypotheses $H_0 : \alpha_i = 0, i = 1......N.$

Testing of these hypotheses can be realized by the ANOVA (model with a single observation per cell). For the ANOVA model the following constraints are imposed

$$\sum_i \alpha_i = 0, \sum_j \beta_j = 0, \sum_i \alpha_i\beta_j = 0, \sum_j \alpha_i\beta_j = 0$$

For the pure additive effects the interactions $\tau_{ij} = c\alpha_i\beta_j =$ 0 and then

$$\hat{\alpha}_i = \frac{1}{M}\sum_j (P_{ij} - m) \quad \hat{\beta}_j = \frac{1}{N}\sum_i (P_{ij} - m)$$

where m is estimator of the total mean defined by the eqn. (1).

From residuals $\hat{e}_{ij} = P_{ij} - m - \alpha_i - \beta_j$ the parameter c can be simply estimated

$$c = \frac{\sum_i\sum_j \hat{e}_{ij} \cdot \hat{\alpha}_i \cdot \hat{\beta}_j}{\sum_i\sum_j \hat{\alpha}_i \cdot \hat{\beta}_j} \tag{12}$$

For ANOVA testing the sum of squares due to machine direction (effects $\hat{\beta}_j$, cross direction (effects $\hat{\alpha}_i$) and due to interaction are computed and compared with total sum of squares $s * M * N$. Statistical tests based on the F-criterion may be performed [2]. According to the results of testing of the null hypothesis H_0 ($\beta_i = 0$ or $\alpha_i = 0$) the statistical uniformity in the machine and cross direction can be accepted or not.

When eqn. (10) is considered as the special regression model, the diagonal elements of projection matrix have the same value [2]

$$H_{ij} = \frac{N + M - 1}{NM}$$

Outlying cells may be then detected by the standardized residuals

$$e_{Sij} = \frac{e_{ij}}{\sqrt{\sigma_R^2(1 - H_{ij})}}$$

where σ_R^2 is variance of error term estimated from residual sum of squares divided by corresponding degrees of freedom (NM-N-N). Roughly, if $e_{Sij} > 3$, the given cell is taken as an outlier.

2.3 Spatial autocorelation index

The spatial autocorrelation can be used for identification of association between values in neighboring cells. If the high values at one cell are associated with high values at neighboring cells the spatial autocorrelation is positive and when high values and low values alternates the spatial autocorrelation is negative. Lack of spatial autocorrelation means that there is no connection between cell values. The autocorrelation indices are simply cross products of spatial weights W_{ij} (connectivity or measures of contiguity between i-th and j-th cell) and some measures of proximity (distances between values P_i and P_j in the i-th and j-th cell). The original cell array P_{ij} is here replaced by the vector of length $n = N*M$ where P_{ij} are included row-wise. The spatial weights depends on the research question. Standard is so called kings case when neighborhood of adjacent eight cells to the i-th one have $W_{ij} = 1$ and other cells have $W_{ij} = 0$. [5].

Moran [4] introduced the measure I analogous to the conventional correlation coefficient suitable for ordinal ratio and interval data.

$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij} * (P_i - \bar{P}) * (P_j - \bar{P})}{\sum_{i=1}^{n}\sum_{j=1}^{n} (P_i - \bar{P})^2} \tag{13}$$

Symbol $\bar{P}$ denotes arithmetic mean. Like a correlation coefficient the values of I range from –1 to 1 , where 0 meaning random pattern.

Under normality assumption is the mean value $E(I)$ equal to

$$E(I) = -1/(n-1) \qquad (14)$$

and variance $D(I)$ is expressed in the form [5]

$$D(I) = \left(\frac{1}{S_0^2(n-1)} (b^2 S_1 - nS_2 + 3S_0^2) \right) - E(I)^2 \qquad (15)$$

The following variables in the variance equation are defined as

$$S_0 = \sum_i \sum_j W_{ij}$$

$$S_1 = \frac{\sum_i \sum_j (W_{ij} + W_{ji})^2}{2}$$

$$S_3 = \sum_i (W_{i\bullet} + W_{\bullet i})$$

where $W_{\bullet i}$ is i-th row and $W_{i\bullet}$ is i-th column mean. The z score is then in the form

$$z = \frac{(I - E(I))}{\sqrt{D(I)}} \qquad (16)$$

The random variable z has standardized normal distribution. If abs(z) > 2 is the assumption of spatial randomness rejected on the significance level 0.05.

3. EXPERIMENTAL PART

The chemically bonded (by the acrylate binder) nonwoven from viscose fibers (VS) was prepared. Starting lap of planar weight 60 g m^{-2} was created on the pneumatic web former. The lap consists of two types of viscose fibers mixed in the weight ratio 67/33 (VS 3,1 dtex/60 mm and 1,6 dtex/40mm). Binding acrylate (relative amount 20 %) was applied by padding. The qualitative visual appearance unevenness of final structure is clearly visible on the Fig 3.

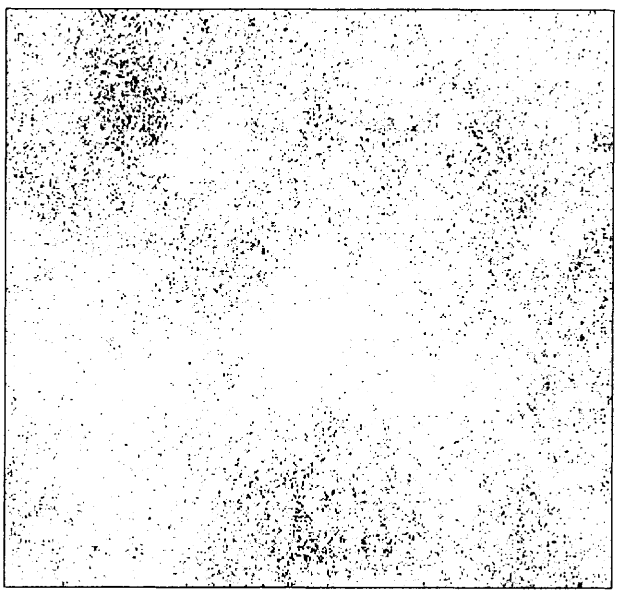

Fig. 3 Tested nonwoven structure

The rectangular samples of dimensions 100 x 100 mm (area A_j = 100 mm^2 and weight 6 mg) were cut for further analysis [3].

3.1 Subjective Visual Appearance

Subjective visual estimation of appearance is based on the evaluation of number of local maximal illumination L_m in individual mesh of defined rectangular net by the human eye. The maximal illumination corresponds to the spots without material.

The human eye is able to distinguish the spots of dimension higher than approximately the m = 0.5 mm By using of the microscope MEOFLEX (magnification 21 times) is lower bound of visible spots approximately equal to the 0.05 mm.

This subjective visual evaluation was used for above-mentioned nonwoven structure.

The microscope image of sample was divided to the net consisted of the 25 rectangular mesh (dimension 2 x 2 mm). The number of spots NE_{ij} in the ij-th mesh having maximal illumination was evaluated by the direct visual inspection [3].

The basic statistical characteristics of NE are:

- sample mean = 12.38 spots
- coefficient of variation CV_n = 15.78 %.

From the combination of six microscope images the areas of the same level of local numbers of white spots are shown graphically on the fig. 4.

From the fig. 4 the areas of the same level of white spots concentration are visible.

For creation of the smooth surface of white spots concentration the cubic bivariate spline smoothing technique has been used. The smoothed surface of NE for one image is shown on the fig. 5.

3.2 Application of the Image Analysis

Subjective visual evaluation of white spots number is very tedious and subjected by the errors. The image analysis system is suitable for objective visual

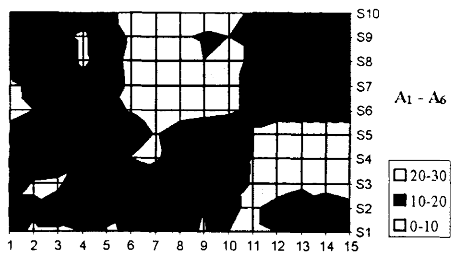

Fig. 4 Areas of the same levels of numbers of white spots.

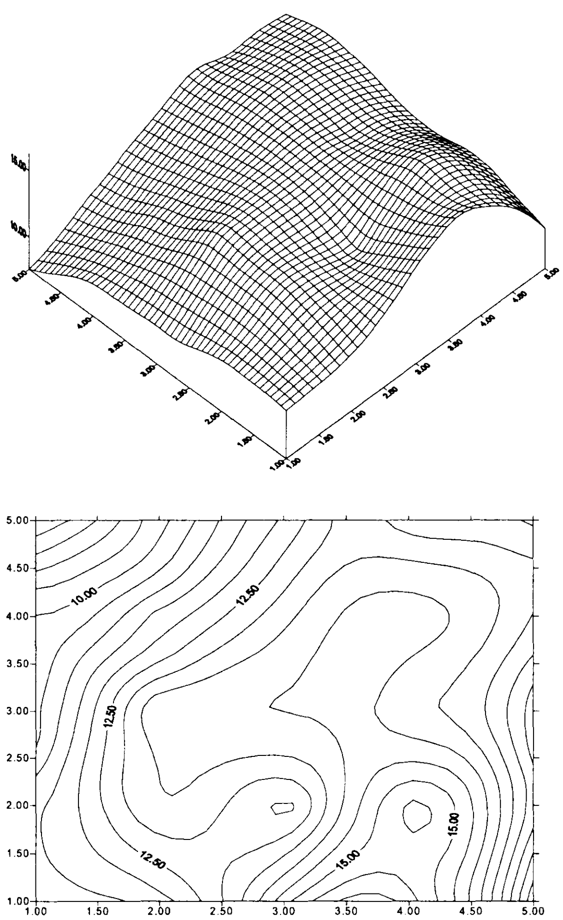

Fig. 5 Bivariate spline smoothed surface of *NE*

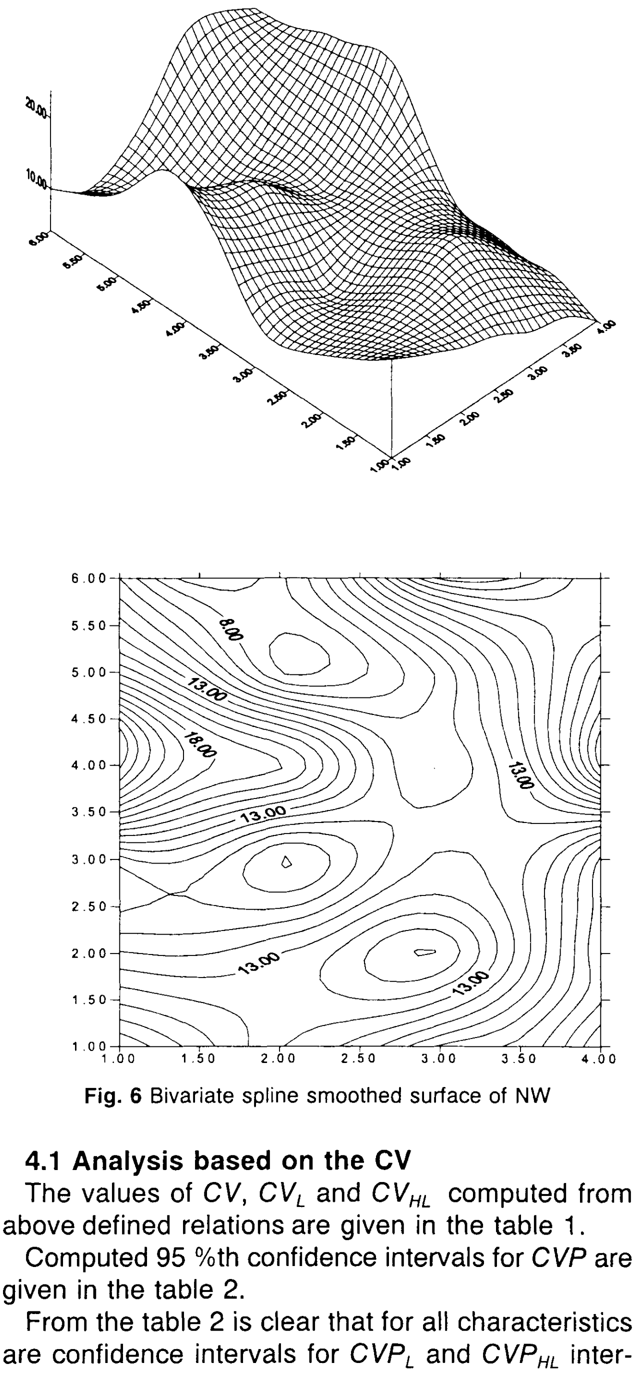

Fig. 6 Bivariate spline smoothed surface of NW

estimation. The system consists of microscope, CCD camera and personal computer has been used.

The treatments of digital images were made by the software LUCIA-M. This software is designed for analysis of the high color (3 x 5 bits) images having resolution of 752 x 524 pixels. The threshold value 62 (all gray patterns are converted to the black ones) has been chosen. The rectangular net dividing the image into equal cells has been defined by the same way as at subjective visual evaluation.

The following characteristics of appearance uniformity have been evaluated in each cell:

- number of white spots *NW,*
- relative porosity *AF.*

Bivariate spline smoothed surface of *NW* is shown on the fig 6 and for *AF* on the fig. 7.

From the surfaces of *NE*, *NW* and *AF* is possible to identify the local variation of these characteristics.

4. UNIFORMITY EVALUATION

Quantification of appearance uniformity has been realized by the analysis of coefficient of variation CV and analysis of variance ANOVA.

4.1 Analysis based on the CV

The values of CV, CV_L and CV_{HL} computed from above defined relations are given in the table 1.

Computed 95 %th confidence intervals for CVP are given in the table 2.

From the table 2 is clear that for all characteristics are confidence intervals for CVP_L and CVP_{HL} intersected The differences between coefficients of variation are therefore statistically insignificant.

The objective visual characteristics are closer that the subjective number of holes *NE* and objective number of white areas *NW*. This differences are probably due to higher resolution of image analysis system in comparison with human eye.

4.2 Analysis based on the ANOVA

Detailed results of ANOVA analysis computed by the ADSTAT package are presented for the characteristics ***Porosity AF*** only. For the *NE* and *NW* are summarized results of testing.

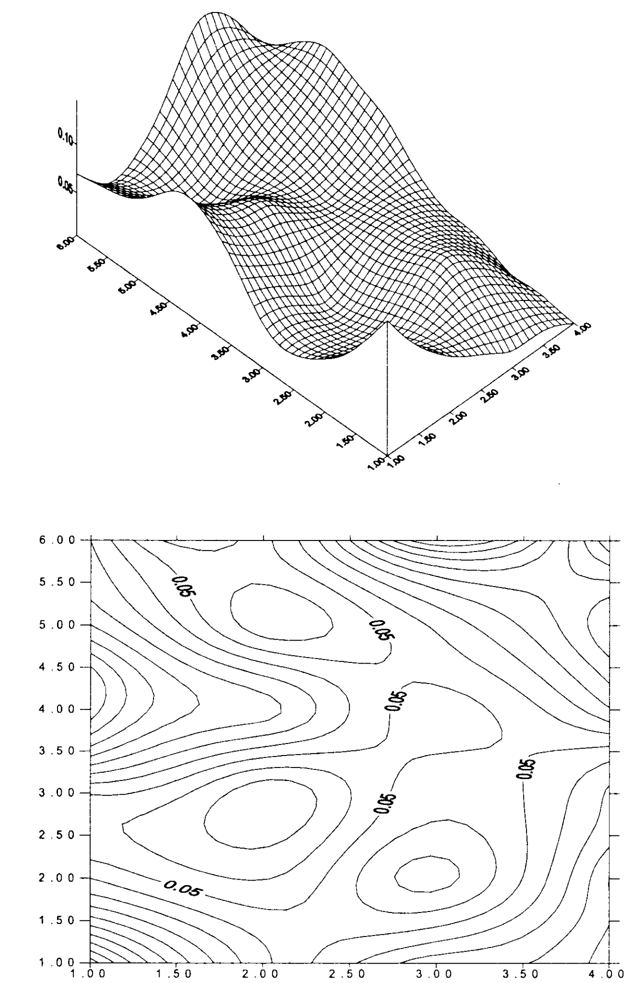

Fig. 7 Bivariate spline smoothed surface of *AF*

POROSITY *AF*

Basic characteristics are summarized in the table 3.

Computed characteristics for ANOVA model are:

Total mean = 6.3421E-02

Residual variance = 1.3626E–03

Tukey's one degree of non-additivity C = –8.3761.

In the table 4 is ANOVA table for full model with Tukey one degree of non additivity interaction.

Table 1 Coefficients of variation

Quantity	CV (total)	CV_L (machine direction)	CV_{HL} (transversal)
NE	0.1494245	0.0609795	0.1364155
NW	0.3944114	0.2029876	0.3381662
AF	0.5806934	0.2569274	0.520762

Table 2 Computed 95 %th confidence intervals for *CVP*

Quantity	CV_L (machine direction)	CV_{HL} (transversal)
NE	0.061±0.044	0.136±0.041
NW	0.203±0.150	0.338±0.109
AF	0.257±0.189	0.521±0.187

For variables *NE* and *NW* (number of white spots) are H_0 accepted on the significance level 0.95 as well. Therefore the ANOVA analysis leads to conclusion that the variability of *NE*, *NW* and *AF* in the cells are ***not statistically significant***.

4.3 Spatial autocorrelation index

The Moran's *I* and corresponding mean value $E(I)$ and variance $D(I)$ computed according relations from chap. 2.3 for the case of *NE* are given in the table 5.

The value of z exceeds the quantity 2 and therefore the random variation has to be rejected. The positive autocorrelation shows that the values of *NE* in adjacent cells are directly associated. The same results were obtained for *NW* and *AF* as well.

5. Conclusion

The proposed methods for visual irregularity evaluation can be used for light weight nonwovens without problems. Objective evaluation by the image analysis allows to identification a lot of other characteristics as the mean area of pores, objects with some gray levels etc. In further investigation this characteristics will be also used.

For evaluation of results both *CV* and ANOVA are suitable. The behavior of effects in the machine and cross directions computed by the ANOVA can be

Table 3 Means and Level Effects

Level	Fakctor A Mean	Effect	Level	Factor B Mean	Effect
1	0.09068	0.0272	1	0.0589	– 0.0045
2	0.04853	– 0.0148	2	0.0456	– 0.0177
3	0.06591	0.0025	3	0.0403	– 0.0231
4	0.04865	– 0.0147	4	0.0822	0.0188
			5	0.0736	0.0102
			6	0.0797	0.0163

Table 4 ANOVA Table

Source	Mean square	Testing criterion	Conclusion H_0 is	sig. level
A	0.00236	1.738	Accepted	0.205
B	0.00127	0.935	Accepted	0.488
AB	0.00013	0.097	Accepted	0.760
Residual	0.00136			
Total	0.00142			

Table 5 Spatial autocorrelation index for *NE*

Quantity	Moran
Indice	0.294
z	3.368
E(I)	– 0.0417
D(I)	0.00993

analyzed by the regression methods (trends, nonlinearitiers etc.). The spatial autocorrelation index I can be used for check of random variation of visual irregularity characteristics in cells.

ACKNOWLEDGEMENT

This work was supported by the Czech Grant agency Grant No. 106/99/1184 and research project of Czech Ministry of Education J11/98:244101113

6. REFERENCES

[1] Cherkassky A.: Surface Uniformity of Nonwovens, *Text. Res. J.* **68,** 242 (1998).

[2] Meloun M., Militky J., Forina M.: **Chemometrics for Analytical Chemistry**, Ellis Horwood, 1992.

[3] Klicka V.: Doctoral Thesis, TU Liberec 1998.

[4] Moran P.A.P.: Notes on continuous stochastic phenomena, *Biometrika* **37**, 17 (1950).

[5] Cliff A.D., Ord J.K.: **Spatial autocorrelation**, Pion, London 1973.

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COLOUR-APPEARANCE PHENOMENA – METAMERISM

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Research works at Laboratory Colour and Appearance Measurement at Department of Textile Materials, Textile Faculty Technical University of Liberec (LCAM DTM TF TU Liberec TF TUL) make for four dichroic ladders, comprising a set of samples and floater dyed with different dyes. These ladders have been used to examine metameric pairs of coloured samples.

Twelve observers were asked to select the sample from the ladder, which most closely matched the floater, the resulting pair being metameric.

The results indicated that colour-appearance models are slightly poor than colour-space CIELAB in statistical performance, when used to predict the visual data.

INTRODUCTION

If a piece of uniformly dyed cloth is divided into two parts, these will be seen to match in any light by any observer. The reflectance curves of the two portions will be identical and so will their tristimulus values *XYZ*. Where the reflectance curves are similar, i.e. for non-metameric pairs, good agreement is usually obtained between observers, between instruments and between visual and instrumental assessment of colour differences. In some instances, however, disagreement can be found in colour assessment of non-metameric pairs owing to differences in viewing geometry, differences in lustre, dichroism, fluorescence and discrepancies in colour-difference formulae.

Even when the reflectance curves of two samples are not identical, it is possible for an observer to see the specimens as a match under particular lighting conditions, say under Illuminant D65 in which case

$$X_1^{D65} = X_2^{D65},\ Y_1^{D65} = Y_2^{D65},\ Z_1^{D65} = Z_2^{D65} \qquad (1)$$

where $X_1^{D65}\ Y_1^{D65}\ Z_1^{D65}$ and X_2^{D65}, Y_2^{D65}, Z_2^{D65} are the tristimulus values of specimen 1 and specimen 2, respectively, under Illumination D65. However,

$$X_1^{(A,TL84,CWF...)} \neq X_1^{(A,TL84,CWF...)}$$
$$Y_1^{(A,TL84,CWF...)} \neq Y_1^{(A,TL84,CWF...)}$$
$$Z_1^{(A,TL84,CWF...)} \neq Z_1^{(A,TL84,CWF...)} \qquad (2)$$

simultaneously for other light sources (A, TL84, CWF...) and for other observers. Thus general agreement will not be obtained between different observers under a single light source nor will the pair be seen to be a match by one observer under different light conditions. This phenomenon is known as ***metamerism*** and two objects being matched are said to be a metameric pair.

Metamerism can cause difficulties in visual matching, in instrumental matching and in comparisons between the two. In visual matching of metameric pairs, agreement in matching and in degree of mismatching will not be obtained between even when all of the observers have normal colour vision.

As with non-metameric pairs, viewing geometry, specular reflection and dichroism have to be taken into account when dealing with metameric pairs.

Colour appearance phenomena and dichroic ladders:

Dichroic ladders were originally proposed for use as a test for defective colour vision and have proved to be most effective for this purpose. Garner tests, it is a name of test with dichroic ladder, is based on the use of metameric samples and groups observers according to their visual responses. Observers found to have "normal" colour vision by means of the Ishihara and Garner tests were required to position a "**float specimen – floater**" relative to series of samples. The floater was metameric to the series, whereas the member of series were non-metameric to one another and were

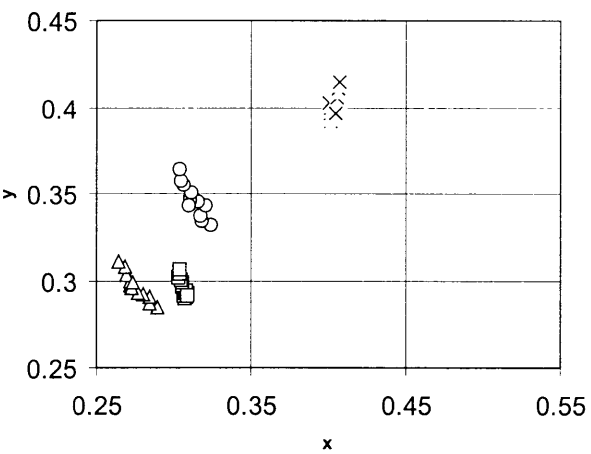

Fig. 1. Dichroic ladders in CIE x,y diagram under illumination D65

spaced at approximately equal visual intervals from each other. The fabric used to prepare the samples is dyed with mixtures of dyes that are colour constant, so that the colour appearance of the samples in the ladder changes by only a very small amount as the illuminant is changed. Floater is then prepared using different dyes chosen so that it is much less colour constant. In the colour vision test, the observer is asked to compare the colour of the floater with the colours of samples in the ladder that appears to be the closest visual match to the floater. The experiment is repeated under a different illuminant, and because the floater changes whilst the samples in the ladder remain colour constant, a different sample from the ladder will be chosen as the match.

EXPERIMENTAL

Initially, four dichroic ladders with their corresponding eight floaters (with poorly and strong metamerism), were prepared. All samples were prepared on 100% wool by application of the metal-complex (ladder). Floaters were also prepared on the same type of substrate by the application of mixtures levelling acid dyes. The wool fabric was steam pressed and mounted

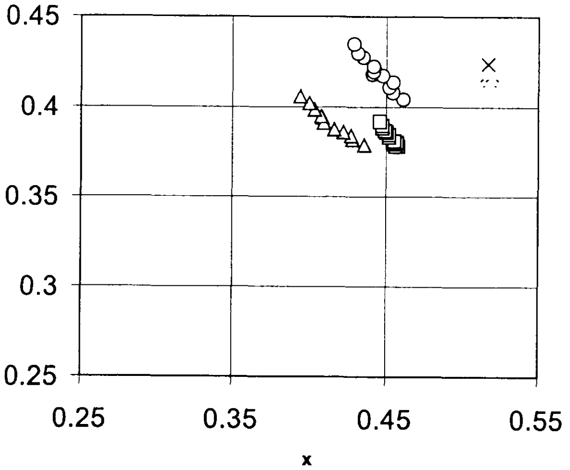

Fig. 2. Dichroic ladders in CIE x,y diagram under illumination A

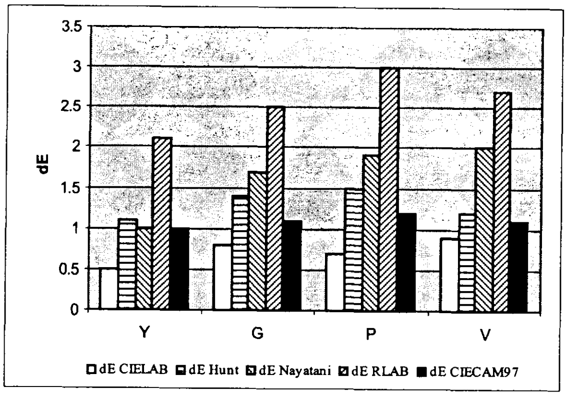

Fig.3 Relationship between color-appearance models and visual judgements

in four layers on grey card approximately 4 x 4 cm square.

The visual assessments of the four ladder and eight floaters were carried by a panel of 13 people, each of whom made five repeatable assessments under Illuminant D65, A, TL84 and CWF. Each observer was rated as possessing "normal" colour vision according to the Ishihara test for defective vision. All of the visual assessments were carried in a JUDGE II (Gretag Macbeth) colour matching cabinet. The assessments were made at an approximate distance of 40 cm from the samples corresponding to viewing angle of approximately 8°, when any particular sample of ladder was viewed.

Instrumental measurements of the floaters and the samples of the ladders were made using a Datacolor International Microflash 100d (d/8°) interfaced with computer. The software of the system (IRIS) allowed the measurement and storage to hard disc of the reflectance values, from which XYZ, L*a*b* values and other coordinate for CAM could be computed under the standard illuminants D65, A, TL84 and CWF.

CAM were was tested: Hunt96, Naytani, RLAB and CIECAM97.

RESULTS

Although this investigation was based only on a limited amount of data, certain important trends were identified.

The results of this data produced better correlation between the predicted matching samples and visually selected matching samples to the floater for model CIELAB, second was CIECAM97, afterwards Hunt, Nayatani and RLAB. Those results were probably occurred by very similar viewing condition as CIE standard viewing condition on which was CIELAB developed.

The measurement of observer metamerism is an excellent example of a situation in which the problem needs to be first completely addressed at the level of basic colorimetry. In other words, the observer variability in tristimulus values must first adequate specified before one need to be concerned about improvements that a colour appearance model could make.

REFERENCES

[1] Vik, M., Viková, M. : Relationship between colour-appearance models and visual judgements of textile dichroic ladders, The 5th Asian Textile Conference, Kyoto Research Park, Kyoto, Japan, September 30-October 2, 1999, s. 302

Acknowledgements

This work was supported by the Czech Ministry of Education Grant (grant No. PG99013) and research project of Czech Ministry of Education J11/98:244100003

DEPARTMENT OF TEXTILE AND FASHION DESIGN

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Eva Jandíková, ak. mal. (artist)
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Ing. Jaroslava Vaňová
Svatoslav Krotký, ak. mal. (artist)

Characteristics

The department was originally only part of the Department of knitting as this department was responsible for introducing of quite new study programmes – Textile and fashion design. It was in 1992. As independent body Department of textile fashion and design exists since 1997, after last great reorganisation of the faculty. Thanks to this activities the gap in textile oriented education was overcome and we can offer courses oriented both to art and technology.

Department has a very good links to other institution, first of all to Museum of North Bohemia, that deals as well with history of textile production.

Teaching activities

The department is responsible for comprehensive technical and artistic education, when the second part is devoted to the fabrics and textile products design and construction. The majority of teaching hours is devoted to development of students skill in studious, nevertheless the students should be aware about possibilities of their designs realisation in industrial conditions.

What is special in this study program? Extremely high number of the applicants. Usually only one of ten can be accepted.

Art activities

The department realises annually several exhibitions, some of them abroad. Although young, the department is becoming well known. One part of exhibitions presents the best students works either on graduates presentations in the Museum of North Bohemia or some competitions such as "Styl", "Smirnoff" etc., where they reached very good results. Some of the designs were practically used.

DEPARTMENT OF TEXTILE FINISHING

Teaching staff

Assoc. Prof. Ing. Miroslav Prášil, CSc., Head of Department

Prof. Ing. Jiří Kryštůfek, CSc.
Ing. Dagmar Machaňová
Doc. Ing. Jaroslav Odvárka, DrCs.
Ing. Rudolf Pastrnek
Ing. Jana Čandová
Ing. Petr Vlach
Ing. Mária Průšová

Characteristics

The department was formed in 1960 after foundation of the Textile Faculty. The first head of the department was Jiří Rais, Prof., M.Sc., Ph.D., whose scientific and pedagogical standards made the department to be generally recognised by the educated society.

At present time one professor, two associated professors and five assistants are employed at the department of Textile Finishing.

Teaching activities:

The department of Textile Finishing provides education in:

1. Bachelor of Science course
   Chemical Technology of Textile Finishing
2. Master of Science courses
   Textile Technology – specialisation Textile Finishing
   Chemical Textile Technology – specialisation Textile Chemistry
3. PhD Study

The studies are completed each year by approximately twenty students with specialisation at the master level and ten students with specialisation at the bachelor level.

Research activities

The scientific activities of the department are traditionally related to the chemistry of textile finishing.

1. Theory of dyeing – the problems of dyeing of microfibres, combination of substantive dyes, transition dyeing temperatures, optimising of time-temperature dyeing regime.
2. Theory of textile printing – the rheological problem of printing pastes, research of new means of printing and the ecological aspects of textile printing.
3. The theory of finishing – synergetic effects of individual components of the combination of finishing, programming of the resulting parameters of finishing using ternary diagrams, the behaviour of liquids at the fibre /0 liquid boundary, the behaviour of electrical charge on fibres and textiles.

International scientific co-operation

Foreign scientific co-operation has been developed with a number of colleges and universities. Together with the Bolton Institute and the University of Mansoura, we presented lectures at International conferences. Further, the department co-operates in the field of washing and textile drying with the State Textile Academy in Moscow and Hohenstein Institute, Germany.

Important publications

[1] Kryštůfek , J.: Low temperature Dyeing of Anionically Modified Polyester Shrink Fibres, Part II: Sorption of Carriers and Monitoring of further additives, Melliand Textilberichte 72, 1991, p. 58

[2] Odvárka, J., Schejbalová, H.: The effect of dispersing agents on the dyeing of polyester with a disperse dye, J. Soc. D. Col. 110, 1994, p. 30

[3] Prášil, M.: CAD/CAM systems in textile printing, Textilnaja promyšlenosť, 1995, N.4, p. 12

[4] Prášil, M., Dang, T. L.: Rheological behavior of disperse dye printing pastes, Vlákna a textil 3, 1996, p. 89

[5] Schejbalová, H., Odvárka, J. Záda,V. : Redispersity of disperse dyes containing polymeric dispersant, J. Soc. D. Col. 114, 1998, p.279

AN ALKALINE DYEING SYSTEM FOR POLYESTER

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The spinnability, tear lenght and surface oligomer content by polyester TESIL 22, 3,6 dtex sliver (woollen type) dyed by new alkaline and „classical" acid method in normal great production was tested. The expected significant decrease of surface oligomer content by alkaline dyed sliver was not proved, the spinnability is moderately improved.

Polyester fibers are generally dyed by disperse dyes in a weak acid bath (pH = 4,5–5,5), whereas the pretreatment and also aftertreatment (the reductive washing-off of the surface part of disperse dye) take place in alkali. Not before the last years several dyestuff-producers brought into being new types of alkali-resistant disperse dyes (the majority of „classical" disperse dyes – namely the azodyes – is reductively decomposed in alkaline medium).

This enables to realize the total dyeing technology in alkaline bathes. The details of published methods differ at the pH-optimum (mostly pH 9–10). Technology is then simplified and namely the effort and costs caused by moving from alkaline to acid (dyeing) and back to alkaline bath (final rinsing) can be reduced. The last alkali-reductive aftertreatment bath can be eliminated in majority of cases. The reproducibility of the resulting colour is improved and the problems caused by oligomers are minimised.

Just the dissolving of a considerable portion of the surface oligomer is one of the most important effects of polyester alkaline dyeing. Oligomers (total content approx. 2–3 % o.f.w.) migrate from the inside of fibre into the dye-bath namely by high temperature. The oligomer diffusion, desorption and dissolving processes are accelerated exponentially by temperature increase (normally are unmodificated or low modificated polyester fibre dyed 30–60 min. at 125–130 °C).

In the acid bath is oligomer solubility limited and therefore oligomers fall out by the final bath-cooling.

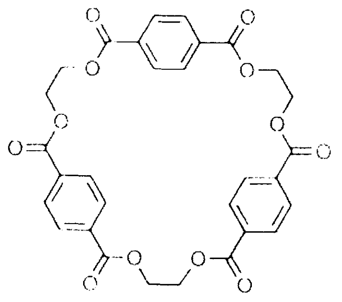

Fig. 1 Cyclic trimer at polyester

Oligomer crystallises on the fibre surface and also on the walls of apparatus now. The following water-rinsing can remove only the unessential part of the oligomer deposits. That applies namely to the cyclic type of oligomer (trimer) which forms the majority of oligomer. It crystallises very good. Melting point T_m = 14–16 °C.

Even this crystallised remnants on the fibre surface has the most negative influence on the spinning and other mechanical processes apart from the difficult clearing of the oligomer deposits in dyeing device.

The using of lubricant-agents, spinning oils and smoothness-rising auxiliaries brings mostly only partial solution of the bad spinning of polyester staple fibre.

In hot alkaline solutions a considerable oligomer-proportion solubilises by saponification of the ester bond. Theoretically surface of fibre could be partly decomposed in this way. We did not observed a weight last of the alkaline dyed fibres – pH about 10, but it seems to be unnegligible an idea that also the higher surface-smoothness (as an effect of the surface microlayer saponification) contributes to better spinnability besides the dissolving of surface oligomer by alkaline polyester dyeing.

Last but not least can the alkaline dyeing conditions prevent the redeposition of acrylic and others synthetic sizes which usually cannot be fully removed by prescour/desize. That's of great importance namely by microfibre polyester fabrics, which carry high quantities of wax, size and knitting oils. If dyeing is carried out in the acid region then these substances would be redeposited onto the fabric.

EXPERIMENTS

The spinnability, the tear lenght (cohesion) of sliver and the surface-oligomer content by the typically industrially dyed polyester sliver TESIL 22, 3,6 dtex (polyethyleneterephtalate modified by 0,1 % pentaerythritol, made in SILON j.comp., Planá n. Luž., CR) was tested.

Table 1 Properties of TESIL 22, 3,6 dtex, sliver dyed by different methods

dyeing method	colour	surface oligomer [%]	cohesion [m] (tear lenght)	var. coeficient [%]
acid bath	dark blue	1,20	66,2	8,9
(pH 5,5)	grey	0,82	67,6	5,2
alkaline bath	dark blue	1,32	49,0	21,7
(pH 9,8)	dark green	0,75	48,9	17,5
	brown	0,63	55,2	19,6
mass-dyed	dark blue	0,54	32,4	33,4
	black	0,26	32,9	31,9
undyed	–	0,18	36,0	33,5

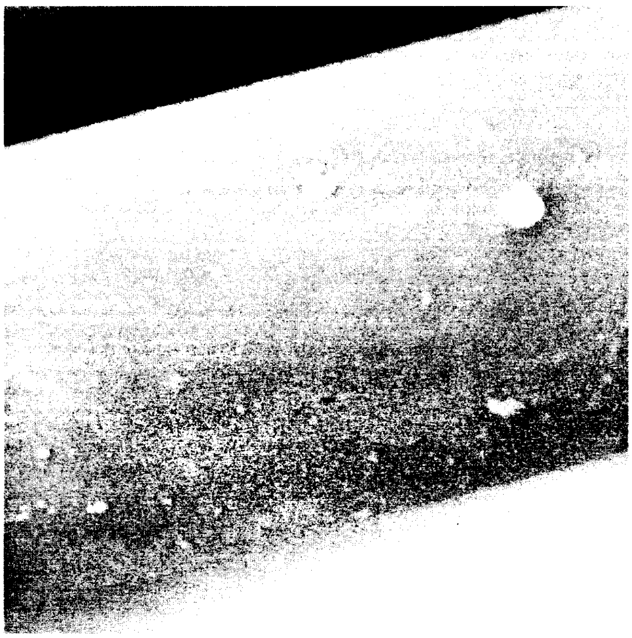

Fig. 2 TESIL 22 – Surface with oligomers

Polyester tow 3,6 dtex was teared before dyeing at the break converter (prod. Seydel), steamed (apar. Cloramatic 7, prod. Lagarde) and stretched (apar. GN5, prod. of NSC).

This variante were compared:

1 – dyed in acid bath (pH 5,5)
2 – dyed in alkaline bath (pH 9,8)
3 – mass-dyed by fibre producer
4 – undyed – for comparison.

By var. 1 and 2 were dyed 5 items (each 200 kg) on apar. YU 200 (prod. Vlněna, Brno, CR), liquor ratio 1 : 10. Dyestuffs: SERILENE (prod. Yorkshire, GB) – by var. 2 SERILENE ADS – alkali-resistant. The time-temperature schedule of dyeing was in both cases equal: start 60 °C – 30 min to 125 ° – 60 min by 125 ° – cooling on 90 °C – off and washing. The items of the „classical acid" dyeing var.1 were then standardly aftertreated in alkaline-reductive bath.

Analyses and methods: the surface oligomer were extracted by hot ethanol (30 min) and estimated by UV spectrophotometry by 242 nm.

The tear length (cohesion) on sliver [m] was found out at the strength tester Tiratest 2110.

The surface fibre picture was observed by electrone microscopy.

RESULTS

From table 1 stand to reason that – the tear length (cohesion) of the alkaline dyed polyester sliver is inexpressive lower than by the acid dyed one. Also the decrease of the surface oligomer-content is similarly inexpressive. The microscopic obsevation confirms only unessentialy less deposit of crystalic substances on fibre surface (Figure 2).

Tear lenght-values of the undyed and mass dyed polyester fibre were not reached.

There is also an inconvenient aspect „against good spinnability" by the alkaline dyed sliver: the several times greater variation coefficient of cohesion in comparison with „acid dyeing".

In spite of the not too conductive observations for the meaning of the alkaline dyeing method, the monitoring of the dyed (and others compared) items by further processing indicates an intermediate improving – namely by spinning – by the alkaline dyed polyester sliver in comparison with the mild acid dyed one.

CONCLUSION

It was not proved the theoretically expected elimination of surface oligomer content by dyeing of TESIL 22 polyester sliver from alkaline bath (pH 9,8; 125 °C, 60 min) in normal industrial production. The further sliver processing is moderately improved.

Acknowledgements: The authors would like to thank the co-workers of TEXTILANA 01, Liberec for their help by observation and testing of production and Mr. Ing. Radovan Kubrt (now: Rieter j. comp. Ústí n. Orl., CR) for full experiments realized by his diploma – work.

REFERENCES

WALLES,F.– KÜHN,R.: Melliand Textilber. *80* (Oct.1999), p. 834

KRYŠTŮFEK,J. – STUDNIČKOVÁ,J. – KUBRT,R.: Zpravodaj STCHK *31* (March 2000), p. 5

GRIESSER,W.: Textilveredlung *31* (1996), No 9/10, p. 201

IMAFUKU,H.: J. Soc. D. Col. *109* (Nov.1993), p. 350