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# New Impulse Acoustic Method for Testing and Estimating the Transversal Unevenness and Defectiveness of Filaments in Chemical Yarns

## Abstract

*The problem of testing the transversal unevenness of yarns is presented, and the methods used hitherto briefly revised. The development of the impulse-acoustic method and its basic principles are described, in view of the differences in the stretching diagrams of single fibres and yarns. Details of the test stand and the methods of preparing the samples are presented. In order to demonstrate the advantages of this method, tests on some selected samples of various kinds of chemical yarns are presented, as are the possibilities of applying the new method in science and industry.*

**Key words:** yarn irregularity, yarn's transversal unevenness, yarn stretching, stress-strain diagram, impulse-acoustic method.

## Introduction

The problems of unevenness and defectiveness of yarns and threads, and the influence of their irregularity characteristics on processing yarns, are as old as the textile industry itself. Therefore methods to control these indexes have been continually created and developed. Currently, the main methods of measuring the unevenness and defectiveness of yarns and threads are based on geometrical, mechanical and some physical irregularities of the objects in the longitudinal direction. There are two main groups of controlling methods [1, 2]:

- the detection of the longitudinal unevenness of yarns and threads in general, by measuring their linear density, mechanical characteristics, or other physical properties, and
- the observation of visible defects on the surface of filaments and yarns.

The best-known methods and measuring devices are based on the irregularity of dielectric properties (such as the Uster-Tester irregularity) and optical characteristics (cross-section irregularity and detecting local defects).

Since the beginning of the manufacture of chemical yarns, an additional problem of irregularity has arisen, namely the problem of the multifilament yarns' transversal irregularity (across their cross-section), i.e. the differences of properties and local defects of separate filaments in a multi-filament yarn (across the bundle of fibres). This kind of irregularity depends mainly on the as-spun yarn formation difference near the spinneret across the filaments bundle, and partly on yarn treatment at the technology stages after spinning. Dispersed impurities in the fibre-forming dope (melt or solution) and impurities in the spinning bath when using the wet-spinning process are additional causes of the transversal irregularity of filaments [3].

It should be emphasised that the longitudinal irregularity of chemical multifilament yarns is relatively low compared with twisted staple yarns and threads. This is determined by the relative stability in time of the fibre-formation process. Therefore the role of the transferral irregularity for chemical yarns is greater. A low transferral irregularity of filaments leads to high workability of the yarn processed, thus a high quality of textiles and thus of the goods manufactured [1,2]. The disturbances in the formation process decrease the quality of yarns, and lead to difficulties in the next yarn processing stages and deviations in the textile technology.

Thus cross-irregularity of multifilament chemical yarns is directly connected with the quality of the fibre formation process. Therefore testing this irregularity would

be a good method for estimating the formation stability, and would additionally serve as a test of the yarn's unevenness.

## Current methods of yarn irregularity tests and the new principles

The majority of traditional yarn test methods (determination of linear density, breaking characteristics and their unevenness, Uster-Tester control, visualisation of the outer defects etc.) yield only the longitudinal unevenness indexes, and do not permit information about other peculiarities of yarn unevenness to be obtained. These methods cannot show the differences in properties of separate filaments in the transversal direction of yarn or the presence of inner dangerous defects and weak segments of every filament, which would be the starting points of yarn rupture in processing.

Up to the present, simple methods for direct monitoring of the filaments' irregularity in multi-filament yarns in the transversal direction have existed. At present, the transversal irregularity can be estimated by the method of single-fibre breaking tests, which is analogous to those applied for staple fibre testing: a cut-out segment of yarn is divided to separate the fibres, and these are tested step by step. It is necessary to note that this test differs in principle from the initial yarn tests. The staple test method is not effective due to the possibility of incorrect sample separation, the structure of yarn destruction, the small lengths of the tested fibres, and additionally the very high labour capacity.

Therefore the need for a simple method to determine the transversal (inner) unevenness and defectiveness in the yarn has urgently arisen. Moreover, such a method would be especially advantageous for estimating the yarn formation control at the stage of as-spun yarn manufacture.

The first idea was to stretch a segment of yarn and to observe step by step the ruptures of separate filaments. This idea was developed on the basis of observations of load jumps, which could be detected during the yarn stretching at testing. A method was suggested of analysing the full deformation diagram, including its right-hand part after the maximum of the load value. The falling run of the right part of the curve, or a comparison of the two parts of the diagram (before and after the maximum of load) enables some information about the filaments' unevenness to be obtained [4 - 7]. However, in practice this method was not very sensitive.

Another method for detecting unevenness was to observe the moments of separate filament ruptures based on the detection of some physical effects at the place of break, for example electrical charges or sparks of light [8]. But these effects were also not very sensitive, due to the very small energy emissions and the screening effect of the neighbouring filaments.

Next, the idea of stretching untwisted yarn and indicating the acoustic impulses of every filament rupture based on the experience with the methods mentioned above was developed. The new impulse-acoustic method was elaborated for the transversal unevenness of yarns tested, and after some years was developed as an industrially applied variant. After long investigations it has been established that the most informative method involves the combination of the impulse-acoustic method with the full deformation diagram recorded during stretching, and detecting step by step the breaks of filaments until the rupture of the final filament and some of the yarn rupture.

### Acoustic estimation of solids and textiles destruction

The method of recording acoustic emission is widely used for testing and investigating breaking processes for mining rocks, metals and alloys, building materials, ceramics, plastics, composites and

other solids or block materials [9, 10]. Acoustic sound impulses during the formation and development of cracks in solids are registered and correlated with the destruction process. However for testing and investigating materials consisting of separate structure elements, in particular textile materials consisting of fibres, this method was not often used.

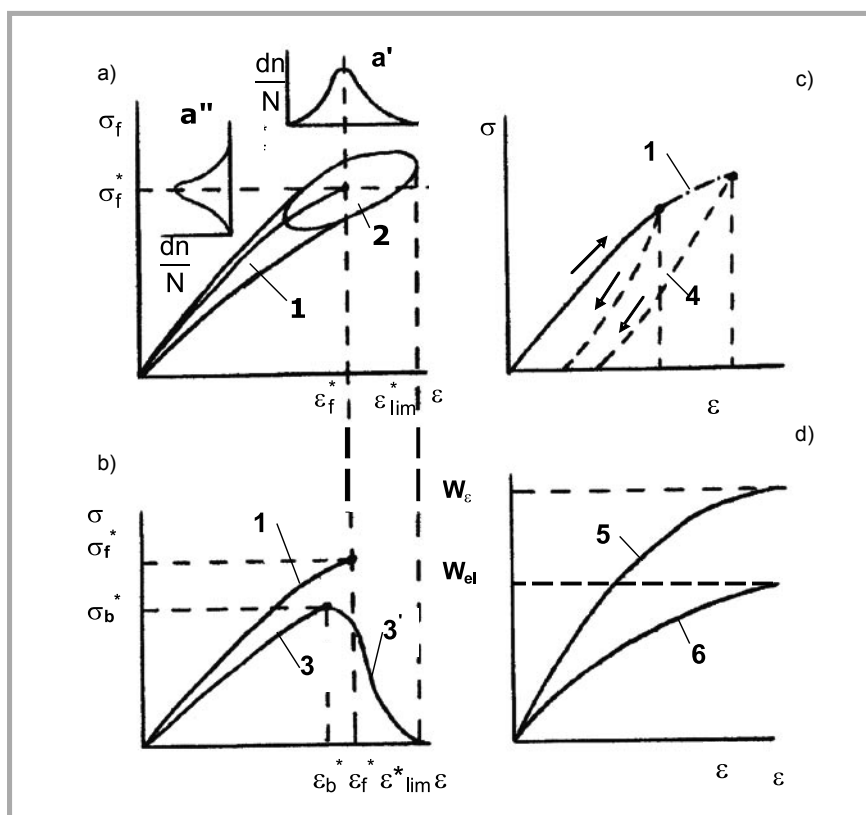
Only a few examples of applying this method for the mechanism of deformation and rupture processes of different textile products can be presented: twisted yarns, woven fabrics and nonwovens have been tested, but the method was not used for irregularity tests or chemical yarns' quality control [11 - 14]. Our previous acoustic investigations were also directed to the influence of yarns' structure, especially of twist, on the rupture mechanism [14].

It is apparent that the impulse-acoustic method can be useful for tests of chemical yarns. Later researchers have demonstrated the possibility of transforming this method into a method for monitoring the quality of multifilament chemi-

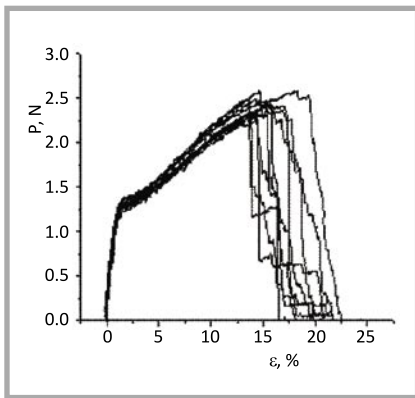
cal yarns, in particular for estimating the inner (transversal) unevenness and defectiveness of separate filaments. In the case of a multifilament yarn composed of chemical fibres, every acoustic impulse corresponds to the movement or destruction of any separate structural element (filament). Therefore the test results are correlated with the step-by-step process of yarn rupture.

### Principles of the new impulse-acoustic method of yarn quality control

The impulse-acoustic emission-recording method is based on stretching the untwisted multifilament structures (parallel fibres or bundles of filaments) and accumulating the filaments' deformation energy to rupture step by step the structural elements, i.e. the separate filaments. The deformation energy of every stretched filament comes free at rupture, and gives returning impulses owing to the contraction process. Therefore, at the moment of rupture, the energy of contraction is transformed into the energy of acoustic oscillation. These im-



**Figure 1.** Stretching diagram  $\sigma = f(\epsilon)$  of separate fibres (filaments) and their bundle (yarn), a) fibres diagram family, 1 – separate fibre middle diagram, 2 – dispersion area (ellipsis); a' – distribution of elongation at break  $\epsilon^*$ , a'' – distribution of strength  $\sigma^*$ ; b) fibres middle diagram (1) and unconnected bundle (3), 3' – right part of diagram; c) elastic recovery diagram before rupture point (4); d) fibre work of deformation  $W_\epsilon$  (5) and work of elastic recovery  $W_{el}$  (6).



**Figure 2.** Full stretching diagrams of viscose yarn (10 tests).  $P$  – load;  $\varepsilon$  – elongation.

pulses, their intensity, arrangement etc. are recorded, and produce the acoustic spectrum, which is the picture of deformation and the multi-element material destruction (of the multifilament yarn) at the time of its deformation. It therefore represents the picture of distribution of the yarn rupture; the impulse-acoustic spectrum is shown in the coordinates of deformation/impulse intensity [14 - 17]. The impulse acoustic spectrum consists of a series of separate impulses located at the axis of elongation or the time of deformation.

Great differences exist among the acoustic spectra of various yarns. The spectra differ in the impulse intensities and their positions in relation to the elongation. These data give an excellent reflection of individual filaments' breaking arrangements. Higher unevenness and defectiveness of yarn correspond to a broader width of the spectrum. The intensity and position of the first impulse, or a small group of impulses, give information about more defective filaments. It is necessary to stress that the information concerned with the first impulse is perceived only by the impulse-acoustic method. This information cannot be perceived in a standard stretching diagram such as that commonly carried out by dynamometric tests (load-deformation curve).

At present, together with the impulse-acoustic tests, a traditional load-deformation diagram is also recorded, as it was established that the best information and interpretation of the test results can be obtained by combination of the impulse-acoustic diagram spectrum with the full deformation diagram (up to the point of the yarn rupture). The acoustic spectrum and the full stress-strain curve both permit every impulse coordinate to be found.

## Diagram of yarn deformation to full rupture

Deformations of separate filaments and of the untwisted yarn are fundamentally different. They are presented on the scheme in Figure 1 (see page 37). The deformation of separate filaments creates a 'family' of stretching diagrams. The breaking points of separate filaments creates the area (surrounded by an ellipsis) of scattering (see Figure 1.a).

If some filaments are collected as a bundle (an untwisted yarn segment), their collective stretching creates a full deformation diagram (see Figures 1.b-d). The full deformation diagram of a bundle (yarn) consists of two parts; the left part of the load increasing to the point of the maximum stress value, and the right part of the load decreasing from maximum to the full breaking of the last filament. The right part of the diagram depends on the distribution of breaking points along the axis of elongation, and characterise the strength distribution for separate filaments during the rupture of the bundle step by step [14 - 17]. The shape of these two parts depends on the separate filament diagrams and the differences of their breaking characteristics. The scattering region of the filaments' rupture points is correlated with the right part of the diagram, and these both present the distribution of breaking characteristics (see Figure 1).

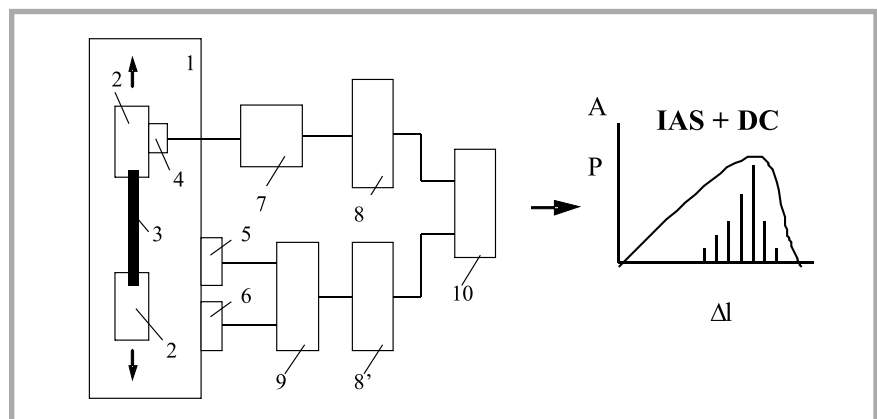
The differences in the filament structures which compose the yarn are usually small, because all the filaments in the yarn are identically formed and technologically treated. The defectiveness of

filaments depends on the fibre formation stability (the instabilities near the spinneret and the presence of defects that create the difference at the filament breaking points). It should be noted that the left part of the diagram shows small deviation (dependent on the yarn structure's unevenness) in comparison with the right part (dependent on the unevenness and defectiveness of the filaments in yarn). At the same time the position of the load maximum is about the same for the whole series of given yarns tests. All these peculiarities are shown for viscose multifilament yarn in Figure 2 as an example.

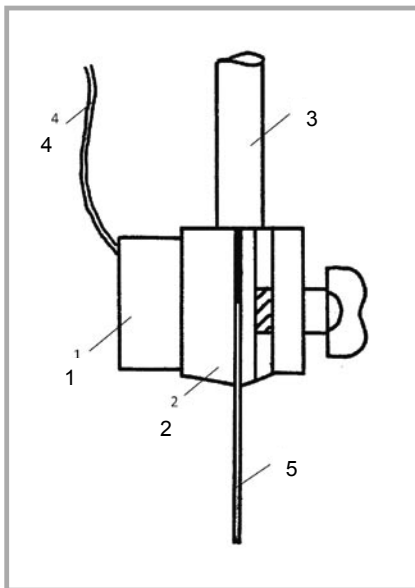
As has been shown by our previous investigations, the analysis of the right part of the diagram principally allows us to calculate the variation coefficient and other unevenness characteristics of filaments in the whole yarn [4 - 6]. It is possible because the majority of filament breaks correspond to the right part of the diagram. In reality, the analysis of the right part of the diagram to estimate unevenness is not easy, due to the difference in every yarn test, and especially due to very small load jumps over the separate filament destruction. Therefore the analysis of the diagrams' right part is available only in a small degree to determine the yarn unevenness and performance defectiveness tests. However, it is useful as a necessary addition to the impulse-acoustic spectrum analysis.

## Equipment for tests

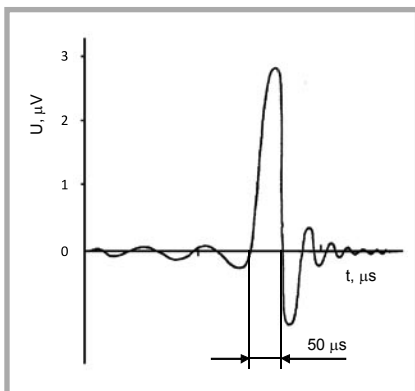
The testing device for the impulse-acoustic method consists of a low noise and vi-



**Figure 3.** Scheme of the testing device; 1 - Electronic dynamometer of FPZ 10/1 testing machine, 2 - Clamps, 3 - Sample, 4 - Acoustic sensor and amplifier, 5 - Load sensor, 6 - Deformation sensor; 7 - Amplitude detector; 8, 8' - Analogous-digital transformer (ADT), 9 - Commutator, 10 - Computer IAS + DC – impulse-acoustic spectrum and deformation curve;  $\Delta l$  – deformation;  $A$  – impulses amplitudes;  $P$  – load.



**Figure 4.** Clamp; scheme of sensor position; 1 - sensor; 2 - clamp; 3 - rod; 4 - connecting cable; 5 - sample (yarn).



**Figure 5.** Form of acoustic impulse corresponding to single filament rupture;  $U$  - amplitude of signal,  $t$  - time.

bration level electronic dynamometer with an additional acoustic system [14 - 17]. A scheme of the testing device is shown in Figure 3. The FPZ-10/1 Tiratest testing machine (dynamometer) from Thüringisches Prüfmaschinenwerk GmbH (Germany) was applied for our research. The measuring system includes standard deformation and load sensors and an additional acoustic measuring chain composed of a sensor, amplifier, and amplitude detec-

tor. The acoustic piezo-sensor is placed on the dynamometer clamp, as shown in Figure 4. The sensor and its amplifier are fastened by glue or a screw for good acoustic contact [18]. It is also possible to use other electronic dynamometers equipped with similar measuring systems.

Every filament break while stretching the yarn gives an acoustic returning impulse which is registered by the measuring system. The form of the acoustic signal is shown in Figure 5. All signals from the three sensors are sent to an analogue-digital transformer, and next to a computer for registration, processing and indication. The resulting information includes the impulse-acoustic spectrum combined with the full stretching diagram stored in the computer memory and visible on the monitor. According to the constant amplification factor, the height of each amplitude is proportional to the energy impulse returning from the filament ends. In this way, all the impulses of filament breaks as well as the full stretching diagram are reordered (see Figure 6).

It should be stressed that an appropriate sensitivity and minimal response time of the electronic system recording every impulse are necessary to separate each acoustic impulse while testing yarns consisting of a high number of filaments.

Standard and special software were applied to analyse the test results [19].

### Sample preparation and testing procedure

As a result of our investigations, a method of sample preparation and testing conditions was elaborated. The yarn samples are initially untwisted to zero twist; in this manner the bundle of parallel filaments is prepared. To fix the yarns, its ends are glued between two pieces of paper (with polyvinyl acetate glue, or another with a short drying time). The samples are conditioned at standard conditions (relative air humidity of  $65 \pm 2\%$  and tempera-

ture of  $20 \pm 2^\circ\text{C}$ ). The velocity of the clamp movement guarantees obtaining a time to sample break of  $20 \pm 2$  sec. If another procedure was necessary it would be used.

The selection of the clamping length is very important. After preliminary investigations, the optimal testing length was established within the range of 30 mm to 100 mm. This length should be correlated with the friction forces between filaments. If the friction between filaments is high, a short length is necessary. However, the best length for standard tests is 100 mm. The number of tests for one kind of sample should be 5 (or 10 in the case of filaments of high unevenness). This is enough for typical tests, and a higher number of tests is necessary only for investigation.

In order to prove the new method, additional tests of separate filaments by the staple test method were made. The samples were selected and prepared as segments of yarn. The same method was applied for standard tests of staple fibres by a clamping length of 10 mm. All these tests were compared with the results of the new impulse-acoustic method, and they confirmed its usefulness.

### Test objects - textile yarn samples

In order to demonstrate the advantages of the new method, the following selected impulse-acoustic tests and a full stretching diagram analysis were carried out for selected different kinds of chemical yarns: polypropylene (PP) 11.0 tex, viscose yarns of different manufacturing methods ('uninterrupted' (Visc-1) and 'interrupted' (Visc-2) viscose yarns), and polyester yarns of different linear density: 14.0 tex (PETF-1) and 27.8 tex (PETF-2). Normal mid-quality industrial yarn samples were used.

The properties of the standard tested yarns are shown in Table 1. Not only were standard tests with a clamping length of

**Table 1.** Tested yarns characteristics; \* at clamp length indicated (500 mm, 100 mm).

Yarn	Linear density, tex	Number of filaments	Tenacity*, cN / tex		CV (tenacity), % (*)		Elongation at break*, %		CV (elongation), %	
			500 mm	100 mm	500 mm	100 mm	500 mm	100 mm	500 mm	100 mm
Polypropylene	11.0	33	43.5	44.8	1.4	2.1	42.9	51.2	12.6	12.0
Viscose Visc-1	12.7	25	19.9	21.3	2.4	2.0	14.7	16.9	5.9	6.0
Viscose Visc-2	13.9	24	15.8	16.5	3.4	5.1	17.8	19.8	8.1	12.1
Polyester PETF-1	14.0	32	56.0	59.1	3.4	5.5	11.2	14.0	4.9	4.8
Polyester PETF-2	27.8	48	63.7	64.7	2.8	2.8	7.3	9.3	4.8	4.5

500 mm carried out, but also tests with a clamping length of 100 mm, which was applied in the impulse-acoustic tests.

### The testing results: Impulse-acoustic spectrogram and full deformation diagram of yarns

Figures 6a-f shows typical impulse-acoustic spectrograms combined with full stretching diagrams for the above-mentioned yarns of chemical fibres. The analysis of the impulse-acoustic spectrum enables us to understand the succession and picture of the multifilament yarn destruction. The position of every impulse on the elongation axis is summarised in the histograms (Figure 6), which correspond to all the acoustic spectra numbers of the tested yarn (10 tests).

It is necessary to note that in the case of large number of filaments in yarn (see for example Fig. 6f for high tenacity para-aramide PFTA yarn) and their low unevenness, the acoustic impulses are

joining in some groups. This depends on the sensitivity of the testing device.

The testing results permit us to estimate the following features of the destruction of multifilament chemical yarns, selected as mentioned above for filaments of high unevenness which are characterised by unevenness and defectiveness:

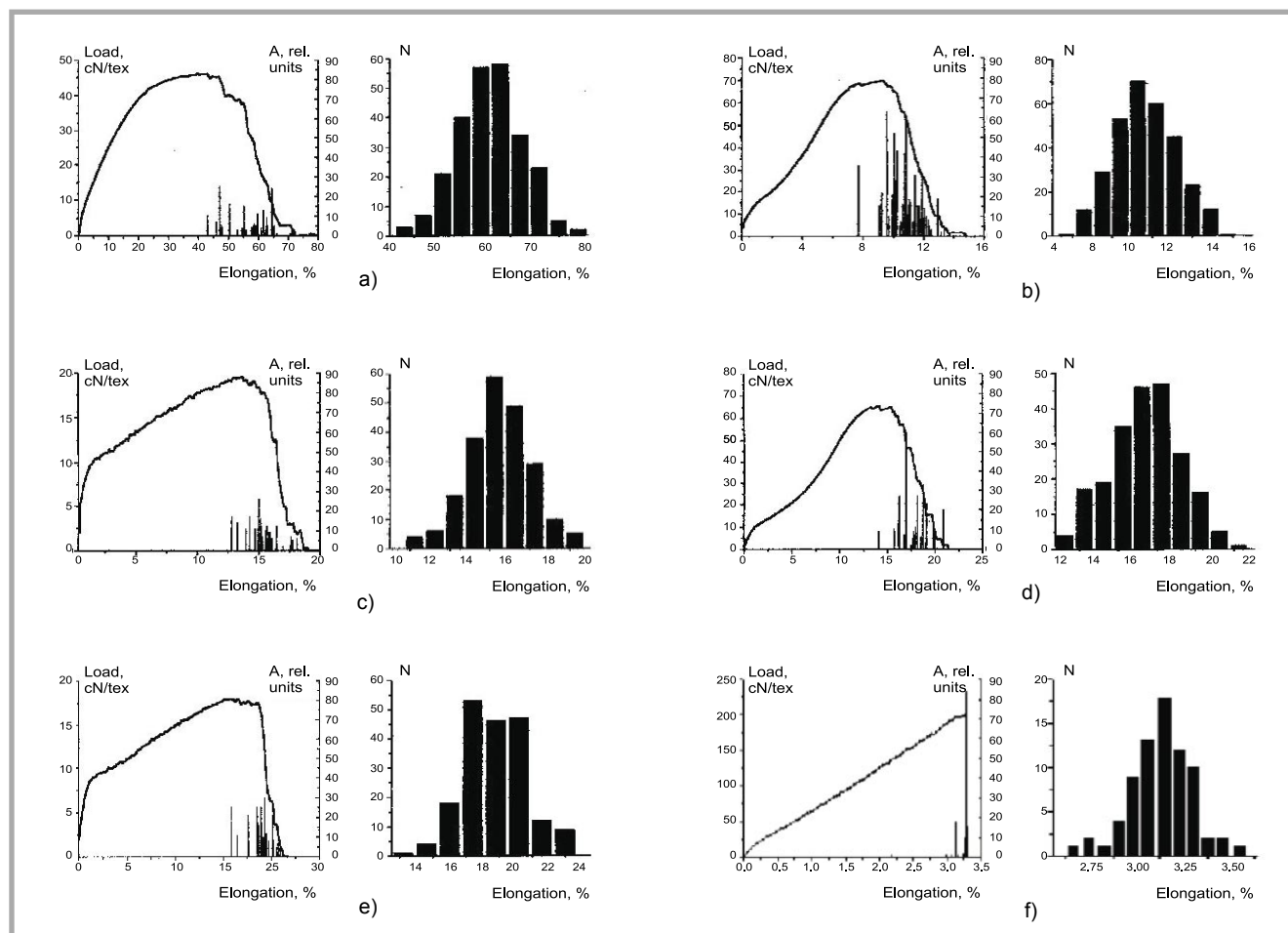
- elongation coordinate of the first impulse (or impulse group) and the related breaking load,
- elongation and load coordinates for every filament break,
- the width of the impulse-acoustic diagram,
- the position of the maximum, and the right part of the diagram in relation to the full elongation at break, and
- the irregularity characteristics of filaments in the tested yarn.

The results of the data processing are summarised in Table 2. In this table, the characteristics of unevenness for yarn as a whole are presented (by traditional tests with clamping length of 500 mm, and

tests with clamping length of 100 mm), separate filament unevenness by the impulse-acoustic method (clamping length of 100 mm) and some results of separate tests of short filament segments (cutting from yarn, clamping length of 10 mm). The data of the bundle tests corresponds to the coordinates of rupture points on the load-elongation curve (over each abscissa of the acoustic impulse).

The combination of the pictures presented in Figure 6 and the results of their processing shown in Table 2 give very interesting information about the transversal unevenness of each kind of yarn. It should be noted that the coordinates of rupture points can also be calculated by an additionally elaborated method [20].

The impulse-acoustic data, in combination with the full stretching diagram, permits more complete information about the yarn quality, its unevenness and defectiveness, to be obtained.



**Figure 6.** Impulse-acoustic spectrograms combined with full stretching diagrams (left) of yarns and histograms of elongation coordinates (right) for separate filaments; a – polypropylene yarn PP, b, c – viscose yarns Visc-1 and Visc-2, d, e – polyester yarns PETF-1 and PETF-2, f – Twaron (polyaramide), P – Load, cN/tex, A – Amplitude of impulses, relative units, N – Number of indexes.

**Table 2.** Estimation of unevenness of mechanical properties for multi-filament yarns.

Unevenness indexes		Clamp length, mm	Samples					
			PP	Visk-1	Visk-2	PETF-1	PETF-2	PFTA
Breaking characteristics of multifilament yarn	CV (tenacity), %	500	1.4	2.4	3.4	3.4	2.8	<b>4.8</b>
		100	2.1	2.0	5.1	5.5	2.8	<b>5.2</b>
	CV (elongation), %	500	12.6	5.9	8.1	4.9	4.8	<b>3.7</b>
		100	12.0	6.0	12.1	4.8	2.5	3.2
Breaking characteristics, corresponding step by step of filaments rupture	CV (tenacity), %	100	6.7	1.6	1.9	1.8	1.8	<b>3.7</b>
	CV (elongation), %	100	60.8	15.5	18.7	16.4	10.7	-
Breaking characteristics of separate filaments	CV (tenacity), %	10	5.5	7.5	9.8	8.4	6.8	9.6
	CV (elongation), %	10	22.4	16.5	12.5	13.7	13.8	-

## Results and perspective of the method's application and development

It is obvious that today's standard characteristics of yarns (linear density, breaking characteristic unevenness, variation coefficients etc.) are integral characteristics of yarn in the unevenness longitudinal direction as a whole, but they lack information about the inner-yarn transversal unevenness and defectiveness of filaments.

The new method elaborated for inner unevenness and defectiveness of multifilament chemical yarns tested according to the impulse-acoustic spectrum and the full stretching diagram analysis gives objective, important information about transversal irregularity, in addition to standard yarn testing and the longitudinal unevenness.

Due to the new elaborated method it is possible to estimate more of the full characteristics of the chemical yarns' quality, such as the probability of a filament breaking at a given percentage of elongation and the yarns' reliability with processing [21]. This method has already been applied to different kinds of yarn characterisation for the following purposes:

- estimation of the as-spun yarns' transversal unevenness as a characterisation of normal proceeding of yarn formation, or any disturbance in this process;
- comparison of yarns' formation stability at the different working places (different spinnerets) and their workability optimisation;
- estimation of yarns' quality at the separate stages of the given technology, or all their manufacturing stages;
- preliminary estimation of yarns' 'workability' (including longitudinal and transversal irregularity) in processing.

The suggested processing of results gives both the traditional integral characteristic of the yarns tested –(their variation coefficients etc.), and permits new characteristics to be obtained, such as the probability resource of yarn deformation work, a new characteristic of their 'workability' in processing.

The application of the impulse-acoustic method and the full stretching diagram analysis have no limitation for multifilament yarns. It was tested not only for the above-mentioned- of yarns, but also for nylon, para-aramides and other yarns.

All the data of the new method in combination with the standard testing results will be able to show the perfection of the manufacturing technology level, and will be able to help improve this technology. The impulse-acoustic method in combination with full stretching diagrams was applied additionally in industrial conditions for different kind of yarn formation and post-treatment, for example for viscose and para-aramide yarns at all stages of the technological process. Very useful results were obtained for different working places (spinnerets), and the treatment machines' workability could next be determined separately for every manufactured yarn. Then this data was applied for optimising the technology.

It should be emphasised that the preparation and testing of samples in order to obtain their unevenness and defectiveness is less time-consuming, characterised as it is by less time consumption by a factor of ten or more in comparison with the tests of separate filaments of a yarn by traditional tests (the segment of yarn as a staple test).

Some peculiarities of the methods presented occur by interpretation of the results for yarns or cables which consists of a very large number of filaments. The

cause of these peculiarities are friction between separate filaments, very small time intervals, and at the same distances between acoustic impulses on the chart. Therefore not only do separate filaments break, but also destruction of fibre groups is visible [15 - 17]. Nevertheless, also in this case the results give a picture which is useful for comparison of different samples of yarns and of their quality.

As a summary of the presented investigation, we can state that the new impulse-acoustic method of yarn testing, and especially combining it with the analysis of the full stretching diagram, is a new step in estimating the unevenness of separate filaments in yarns.

The principles described above have yielded very interesting information, based on rupture processes not only for chemical yarns but also for other fibrous structures. This therefore permit the destruction mechanism, the mechanical property irregularity and the presence of defects to be estimated [14, 22].

## Summary

- A new method was elaborated to determine the inner (transversal) unevenness of multifilament chemical yarns and its defectiveness in the yarn's cross-section by means of the impulse-acoustic spectrograms, both separately and in combination with an analysis of the full stretching diagram. This method was applied for different chemical yarns. There are no other methods of obtaining such information, including all the standard testing methods currently used.
- A system was created to realise this method (the registration and treatment of test results) the impulse-acoustic spectrograms in combination with analysing the full stretching diagrams, es-

pecially the right-hand side. Computer software was used to analyse the data.

## Conclusion

The results of the tests carried out permit us to estimate the inner (transversal) unevenness and defectiveness of different chemical yarns. This method is less time-consuming in comparison with the single-fibre (filament) testing, both considering the sample preparation and the testing procedure itself. The application of this method makes possible operative control and optimisation of chemical yarn production and processing technology, as well as improvement of the yarns' quality.



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