USE OF THE VIBTEX VIBRATION SYSTEM FOR TESTING TEXTILES

Petr Tumajer[1], Petr Ursíny[1], Martin Bílek[2], Eva Moucková[1]

[1]Technical University of Liberec, Faculty of Textile Engineering, Department of Textile Technologies
[2]Technical University of Liberec, Faculty of Mechanical Engineering
Studentská 2, 461 17 Liberec 1, The Czech Republic
E-mail: petr.tumajer@tul.cz, petr.ursiny@tul.cz, martin.bilek@tul.cz, eva.mouckova@tul.cz

Abstract:

Principal objective of this paper is a description of a special testing device (VibTex). This device allows testing of textile materials (threads, samples of fabrics, etc.) during cyclical stress at a high frequency. Control of the VibTex allows harmonic and non-harmonic elongation of the textile samples. Results of the tests with harmonic elongation can be used for calculations of the dynamic characteristics of textile samples. In the final part of the paper, values of the dynamic modulus and loss angles are determined at frequencies of 10 Hz and 100 Hz for various yarns.

Key words:

Dynamic characteristic, cyclical stress, mechanical properties, testing device, VibTex.

Introduction

Textile materials and products made of these materials are exposed to varied load regimes [1]. The load regime of finished products made of textile materials is determined by the manner of their use; meanwhile, the load regime of textile materials during their processing is determined by technological processes. The deformation properties of finished textile products often determine and limit the use of these products in certain areas. The deformation properties of textile materials influence the technological process itself, as well as the quality of the finished product. A typical example is the technological process of weaving. In the second half of the past century, the output of weaving machines increased considerably [2]. Around the turn of the century, this trend changed, i.e. the output of weaving machines has stagnated or decreased. One possible reason for this standstill in the increase in output may be the deformation properties and behaviour of textile materials in the weaving process. During weaving, the textile material (thread, fabric) is loaded cyclically, at a relatively high frequency [3], [4]. Some products made of textile materials are exposed to cyclical or dynamic load in their use, too, e.g. safety belts, straps, ropes, liquid and air filters, artificial tendons, etc. The principal objective of this paper is a description of a special testing device (VibTex). This device allows testing of textile materials (threads, samples of fabrics, etc.) during cyclical stress at a high frequency. Control of the VibTex allows harmonic and non-harmonic elongation of textile samples. The tests with the non-harmonic elongation can be used for simulations of the stress of textile materials during various technological processes [5] or for simulations of the stress on some textile products. The results of the tests with harmonic elongation can be used for calculations of the dynamic characteristics of textile samples (the dynamic modulus and its real and imaginary parts, hysteresis, phase shifts between elongation and force, etc.). Values of the dynamic modulus and loss angles determined at frequencies of 10 Hz and 100 Hz for various longitudinal textiles are mentioned in the final part of this paper.

VibTex: Use of a vibration system for testing of textiles

The standard appliances used for testing of textiles do not enable an experimental analysis of their deformation properties in the necessary range of frequencies and clamping lengths [6]. Therefore, in the frame of the project GAR 01/09/

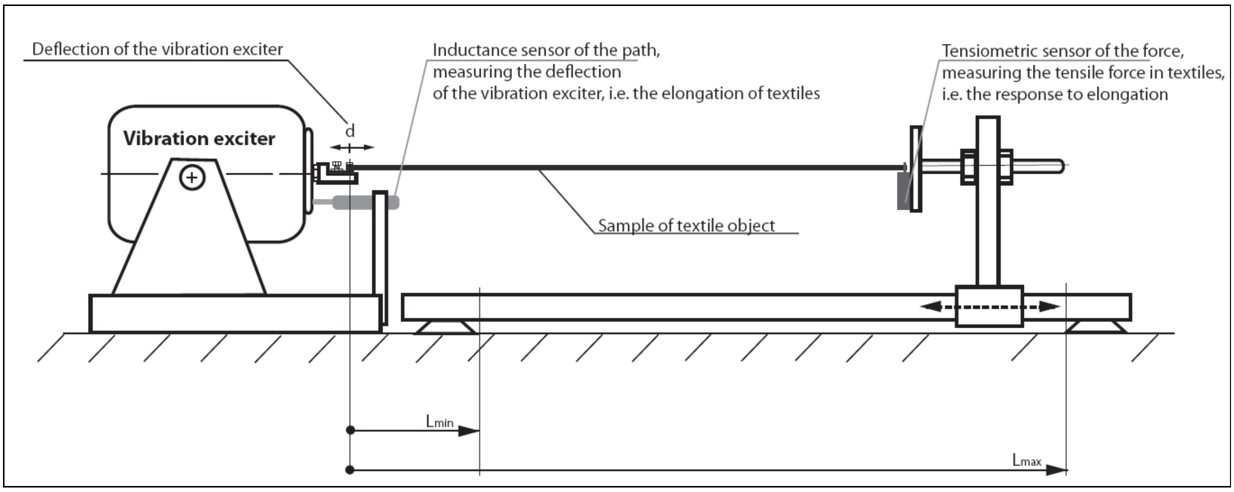

Figure 1. Principle of the VibTex equipment

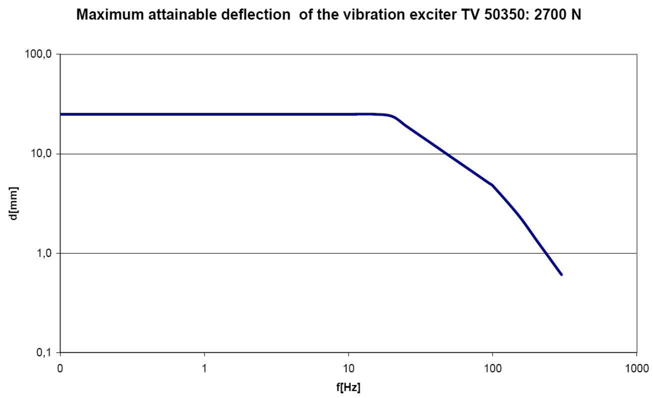

Figure 2. Dependence of the maximum attainable deflection (elongation of the textile object) on frequency

0466, special equipment (VibTex) has been constructed which is able to test textiles at a wide range of clamping lengths (from 30 cm to 160 cm) [7]. An electromagnetic vibration system serves as the basis of this equipment, which is able to extend textiles at varied frequencies, and a tensiometric sensor, measuring the tensile force in the textiles (response to elongation, see Figure 1).

The vibration sensor is employed as an exciter, generating periodic (cyclical) elongation of the textiles. The range of attainable frequencies at the maximum elongation of textiles is determined by the employed type of vibration system. Figure 2 shows the dependence of the maximum attainable deflection (elongation of textiles) on the frequency for the type installed in the VibTex equipment: TV 50350: 2700 N (manufacturer: TIRA).

From the diagram, it follows that at the maximum required elongation of the textile object (25 mm), it is possible to work with frequencies up to 15 Hz, at 10 mm with frequencies up to 40 Hz, at 4 mm with frequencies up to 100 Hz and at 1 mm with frequencies up to 200 Hz.

Manner of control of the vibration exciter and measuring of tensile force

The vibration system consists of a dual channel control unit VR 8500 (manufacturer: Vibration Research Corporation), which allows for the control of the vibration exciter in compliance with the required course of acceleration. For these reasons, an acceleration sensor must be installed on the vibration exciter, bringing the signal of this sensor to the first channel of the control unit. The signal of the inductance sensor is brought to the other channel of the control unit . By means of a power cord, the control unit is interconnected with a standard computer (operating system Windows XP), equipped with the software VibrationVIEW. This software is supplied together with the control unit, and it allows for defining the required time dependence of acceleration of the vibration exciter. In our case, the programme VibrationVIEW contains two modules (see Figure 3):

1. **System Check**, enabling a fast realisation of tests with a harmonic course of elongation for the given frequency and amplitude of acceleration. In this case, the required amplitude of acceleration also determines the amplitude of the velocity and the amplitude of the deflection:

$$a(t) = -D_a.\omega^2.\sin(\omega.t) \quad (1a)$$

$$v(t) = D_a.\omega.\cos(\omega.t), \quad (1b)$$

$$d(t) = D_a.\sin(\omega.t), \quad (1c)$$

where *a* stands for acceleration, *v* for the velocity and *d* for the deflection of the vibration exciter. The symbol D_a stands for the amplitude of deflection of the vibration exciter, ω for angular frequency and *t* for time.

2. **Field Data Replicator (FDR)**, enabling realisation of tests with an arbitrary periodic course of elongation. Fourier series can be employed here for expressing the time dependence of various periodic functions.

The VibTex equipment also includes an eight-channel data logger MGCplus (manufacturer: Hottinger Baldwin Messtechnik). The signal from the tensiometric sensor is brought to the fifth channel of this logger, and the signal from the inductance sensor is brought to the sixth one. In the configuration for linear textiles (see Figure 5), it is possible to perform measurements of tensile forces up to the value 5 N, and in the configuration for flat textiles, up to the value of 200 N. By means of a power cord, the data logger is also interconnected with the computer, which is equipped with the service programme HBM Setup Assistant (see Figure 4). In this programme, it is possible to visualise the time dependence of the deflection of the vibration exciter, which determines the elongation of textiles (exciting function) and the time dependence of the tensile force in textiles (response), and to export these values to a text file with ASCII coding. In the majority of cases, the recorded data are measured in the time interval of 1 sec., with a sampling frequency of 19200 Hz.

Figure 3. Windows of the programme VibrationVIEW (module System Check and module FDR)

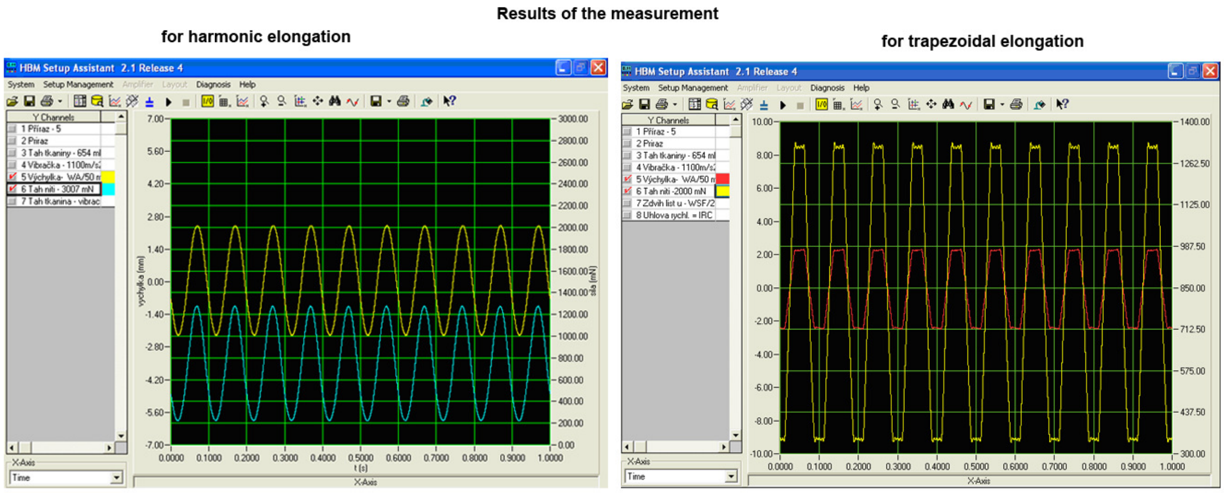

Figure 4. Visualisation of measured data in the window of the programme HBM Setup Assistant (results of measuring with harmonic and trapezoidal elongation)

The VibTex equipment allows for adjusting the required pre-loading in the textile sample by means of adjusting screws, integrated in the holder of the tensiometric sensor. The required climatic conditions (temperature and relative humidity) are maintained during the tests by means of an air conditioning unit and an air humidifier. The relative humidity can be regulated in the range of 40 - 60%. The temperature can be regulated in the range 16 - 27OC. A complete layout of the equipment VibTex is shown in Figure 5.

Consequently, the VibTex equipment enables the realisation of experimental tests of varied textiles, and the analysis of their dynamic and mechanical properties in a wide range of frequencies. Therefore, the equipment can perform very well while determining the dynamic modulus of rigidity and loss angles in a wide range of frequencies.

4. Manner of determining dynamic and mechanical properties of textiles based on the results

For determining the dynamic moduli of rigidity of textiles, it is necessary to perform experimental measurements with a harmonic course of deflection of the vibration exciter *d(t)*:

$$d(t) = D_a . \sin(\omega . t) \tag{2}$$

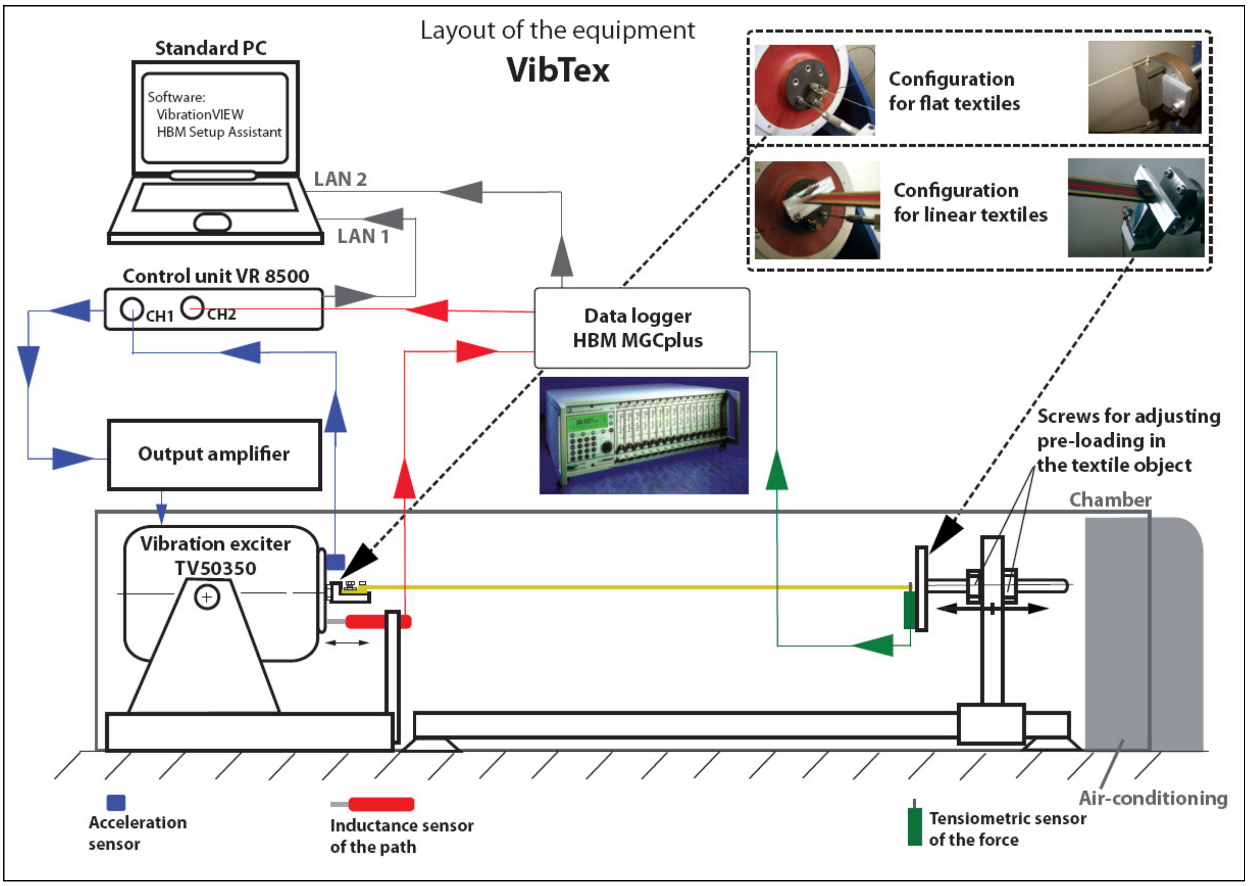

Figure 5. Layout of the VibTex equipment

Table 1. Basic characteristics of the VibTex equipment

Required max. elongation of textiles	Range of possible frequencies of elongation
25 mm	from 5 to 15 Hz
10 mm	from 5 to 40 Hz
4 mm	from 5 to 100 Hz
1 mm	from 5 to 200 Hz
Range of clamping lengths of textiles	from 30 to 160 cm
Maximum tensile force in textiles	5 N for linear textiles / 200 N for flat textiles

where:
D_a - amplitude of deflection of the vibration exciter [mm],
ω – angular frequency [rad/sec] defined as:

$$\omega = 2.\pi / T \quad (3)$$

T - period [sec] defined as:

$$T = 1/f \quad (4)$$

f - frequency [Hz].

This course of deflection of the vibration exciter generates a harmonic course of elongation (l(t) in the pre-loaded textile object:

$$\Delta l(t) = D_a.[1+\sin(\omega.t)] = \frac{\Delta L_{\max}}{2}.[1+\sin(\omega.t)] \quad (5)$$

where ΔL_{max} is a maximum elongation of the textile object [mm] defined as:

$$\Delta L_{\max} = 2.D_a \quad (6)$$

The elongation serves as an exciting function, provoking a response in the form of a harmonic course of the tensile force *Q(t)* in the textile object:

$$Q(t) = Q_P + Q_a[1+\sin(\omega.t+\delta)] = Q_P + \frac{\Delta Q_{\max}}{2}.[1+\sin(\omega.t+\delta)] \quad (7)$$

where:
Q_P - pre-loading in the textile object [mN],
Q_a - amplitude of the response, i.e. of the tensile force [mN],
δ - mutual phase displacement between the exciting function and the response ($\delta < 0$), i.e. the loss angle [rad],
ΔQ_{max} - maximum change of the tensile force [mN] defined as:

$$\Delta Q_{\max} = 2.Q_a \quad (8)$$

The time dependence of the deflection of the vibration exciter d(t), elongation of the textile object (exciting function) Dðl(t) and tensile force in the textile object (response) Q(t) are shown diagrammatically in Figure 6. Figure 7 shows the dependence of the tensile force on the elongation of textiles, and the symbol H here stands for hysteresis, i.e. the dissipation of energy in the textile object during one period.

From equation (5) it follows that the elongation of a textile object (exciting function) can be expressed as the sum of two terms:

$$\Delta l(t) = \Delta l_K + \Delta l_H(t) \quad (9)$$

where the first term Δl_K:

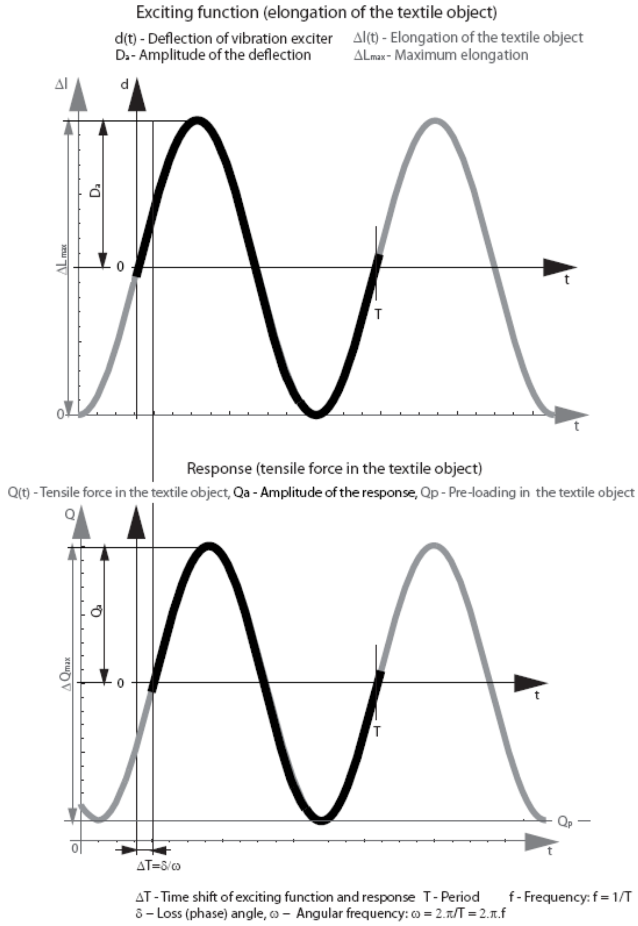

Figure 6. Time dependence of elongation of the textile object (exciting function) and tensile force (response)

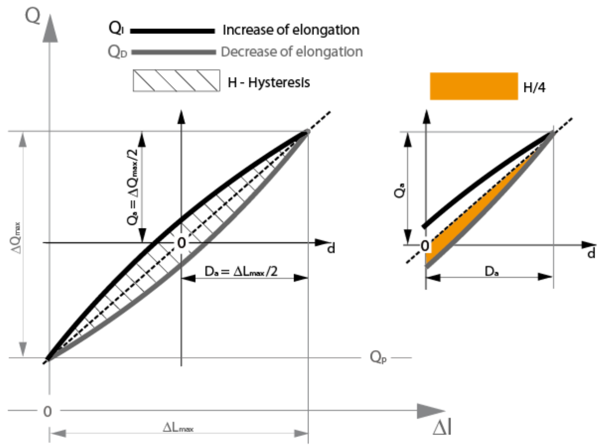

Figure 7. Dependence of tensile force on elongation

$$\Delta l_K = D_a = \frac{\Delta L_{\max}}{2} \quad (10)$$

stands for the elongation component, which is constant over time (not dependent on time) and the second term $\Delta l_H(t)$:

$$\Delta l_H(t) = D_a.\sin(\omega.t) = \frac{\Delta L_{\max}}{2}.\sin(\omega.t) \quad (11)$$

stands for the variable component of elongation, which changes harmonically with time.

From equation (7) it follows that the tensile force in the textile object (response) can be expressed as the sum of three terms:

$$Q(t) = Q_P + Q_a + Q_H(t) \qquad (12)$$

where the first term Q_P stands for the pre-loading in the textile object, which is constant over time (not dependent on time). The second term Q_a also stands for the component of tensile force which is constant over time. The third term of the expression (12) $Q_H(t)$ stands for the variable component of the tensile force which changes harmonically over time:

$$Q_H(t) = Q_a.\sin(\omega.t + \delta) = \frac{\Delta Q_{\max}}{2}.\sin(\omega.t + \delta) \qquad (13)$$

Dynamic (complex) module of rigidity

The dynamic modulus of rigidity C is established as the ratio of the amplitude of variable component of the response $Q_H(t)$ and the amplitude of the variable component of the exciting function $\Delta l_H(t)$:

$$C = \frac{Q_a}{D_a} = \frac{\Delta Q_{\max}}{\Delta L_{\max}} \qquad (14)$$

where C is dynamic, i.e. the complex module of rigidity [N/m].

Loss angle (phase displacement)

The loss angle is expressed by the energy in one quarter of the period, i.e. in the time interval from 0 to $T/4$, in which the textile object is extended by the value $L_{1/4}$. One quarter of the period can be expressed by the following relation, employing equation (3):

$$T/4 = \frac{\pi}{2.\omega} \qquad (15)$$

and the energy in one quarter of the period W is given by the following integral:

$$W = \int_0^{L_{1/4}} Q_H.d\Delta l_H = \int_0^{\frac{\pi}{2.\omega}} Q_H.\frac{d\Delta l_H}{dt}.dt = \int_0^{\frac{\pi}{2.\omega}} Q_a.\sin(\omega.t + \delta).D_a.\omega.\cos(\omega.t).dt =$$

$$= \frac{1}{4} Q_a.D_a.[2.\cos(\delta) + \pi.\sin(\delta)] = Q_a.D_a.\left[\frac{\cos(\delta)}{2} + \frac{\pi.\sin(\delta)}{4}\right] \qquad (16)$$

From relation (16) it follows that the energy in one quarter of the period W can be expressed by the sum of two terms:

$$W = W_S + W_L \qquad (17)$$

The first term expresses the storage energy W_S:

$$W_S = \frac{1}{2} Q_a.D_a.\cos(\delta) \qquad (18)$$

and the second term the loss energy W_L, i.e. the dissipation of energy in the textile object during one quarter of the period:

$$W_L = \frac{\pi}{4} Q_a.D_a.\sin(\delta) \qquad (19)$$

From the measured values, we calculate the dissipation of energy (hysteresis H) during one period:

$$H = \int_0^{\Delta L_{\max}} Q_I(\Delta l).d\Delta l - \int_0^{\Delta L_{\max}} Q_D(\Delta l).d\Delta l, \qquad (20)$$

where:
Q_I - tensile force at an increase of elongation,
Q_D - tensile force at a decrease of elongation.

In our case, the above integral (20) is solved numerically (by the rectangular method), and subsequently, the dissipation of energy is calculated during one quarter of the period: $H/4$. The dissipation of energy in one quarter of the period is expressed by relation (19), and therefore, the following equation must be valid:

$$\frac{\pi}{4}.Q_a.D_a.\sin(\delta) = \frac{1}{4} H \qquad (21)$$

From equation (21), we express the loss angle δ:

$$\delta = \arcsin\frac{H}{\pi.Q_a.D_a} \qquad (22)$$

and employing relations (6) and (8), we can express this angle by means of hysteresis H, maximum elongation of the textile object ΔL_{max} and maximum change of the tensile force in the textile object ΔQ_{max}, namely by the following equation:

$$\delta = \arcsin\frac{4.H}{\pi.\Delta Q_{\max}.\Delta L_{\max}} \qquad (23)$$

Elastic and loss modules of rigidity

The elastic module of rigidity C_{Re} constitutes the real component of the dynamic (complex) module of rigidity C (see Figure 8), and it is the measure of ideal resistance to mechanical stress, coincident with the stressing phase:

$$C_{\mathrm{Re}} = C.\cos(\delta) \qquad (24)$$

where C_{Re} is the elastic module of rigidity, i.e. the real component of the dynamic modulus [N/m].

The loss module of rigidity C_{Im} constitutes the imaginary component of the dynamic (complex) module of rigidity C, and it is the measure of mechanical losses during one period, phase-displaced by the value $\pi/2$:

$$C_{\mathrm{Im}} = C.\sin(\delta) \qquad (25)$$

where C_{Im} is the loss module of rigidity, i.e. the imaginary component of the dynamic modulus [N/m].

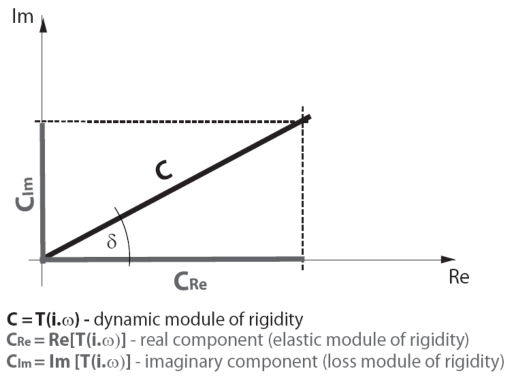

Figure 8. Dynamic modulus of rigidity, its real and imaginary components

VibTexSoft: Software for processing of measured data and calculation of mechanical & dynamic properties of textiles

For the purpose of statistical processing, a series of tests with various sections of the concerned textile object is performed in the majority of cases. The output of the measurement is a

Table 2. Example of results in a table processor

Measuring number	Clamping length [mm]	Maximum elongation [mm]	Minimum force [mN]	Maximum force [mN]	Dynamic modulus [N/m]	Loss angle [°]	Elastic module [N/m]	Loss module [N/m]
1	530	4,70	236	1263	218	5,5	217	21,1
2	530	4,71	176	1169	211	6,2	210	22,8
3	520	4,71	197	1189	211	6,1	209	22,4
4	520	4,70	236	1242	214	5,8	213	21,7
5	520	4,71	182	1160	208	6,0	206	21,7
6	520	4,69	214	1197	209	5,8	208	21,3
7	520	4,70	210	1225	216	6,0	215	22,4
8	530	4,67	201	1193	212	5,9	211	21,8
9	520	4,69	202	1211	215	6,0	214	22,5
10	520	4,70	213	1213	213	6,1	212	22,6
Average v.	523	4,70	207	1206	213	5,9	212	22,0
St. dev.	5	0,01	20	32	3	0,2	3	0,6
Conf. int.95%	3	0,01	12	20	2	0,1	2	0,4

Table 3. Measurement conditions

Frequency of elongation: 10 Hz					
Material of yarn	Maximal elongation [mm]	Clamping length [mm]		Preload [mN]	
	Average value	Average value	95% confidence interval	Average value	95% confidence interval
PL	4,6	493	(492 ; 494)	196	(184 ; 208)
CO	4,6	493	(492 ; 494)	210	(195 ; 225)
PP	4,7	523	(520 ; 526)	207	(195 ; 219)
VI	2,7[1]	496	(494 ; 498)	166	(153 ; 179)
Frequency of elongation: 100 Hz					
Material of yarn	**Maximal elongation [mm]**	**Clamping length [mm]**		**Preload[2] [mN]**	
	Average value	**95% confidence interval**	**95% confidence interval**	**Average value**	**95% confidence interval**
PL	3,0	492	(491 ; 493)	398	(383 ; 413)
CO	3,0	494	(493 ; 495)	405	(396 ; 414)
PP	3,0	498	(497 ; 499)	466	(448 ; 484)
VI	3,1	499	(497 ; 501)	479	(456 ; 502)

Note1: In this case, a lower value of maximal elongation was set due to the limited range of the tensile strength sensor for longitudinal textiles (5 N). At higher values of maximal elongation, the sensor range crossed.
Note2: At a frequency of 100 Hz, it was necessary to set higher preload values due to the elimination of transverse oscillations of the yarn.

Table 4. Values of dynamic modulus and loss angle for individual yarns

Frequency of elongation: 10 Hz				
Material of yarn	Dynamic modulus [N/m]		Loss angle [°]	
	Average value	95% confidence interval	Average value	95% confidence interval
PL	273	(261 ; 285)	5,0	(4,9 ; 5,1)
CO	465	(443 ; 487)	6,0	(5,9 ; 6,1)
PP	213	(211 ; 215)	6,0	(5,9 ; 6,1)
VI	987	(921 ; 1053)	4,5	(4,3 ; 4,7)
Frequency of elongation: 100 Hz				
Material of yarn	**Dynamic modulus [N/m]**		**Loss angle [°]**	
	Average value	**IS 95%**	**Average value**	**95% confidence interval**
PL	297	(291 ; 303)	7,6	(7,4 ; 7,8)
CO	513	(496 ; 530)	9,6	(9,3 ; 9,9)
PP	280	(275 ; 285)	9,3	(9,0 ; 9,6)
VI	1211	(1178 ; 1244)	7,4	(7,1 ; 7,7)

group of files in text format (with ASCII coding), and these files contain three columns of real numbers. The first column contains time, the second one the deflection of the vibration exciter and the third one the tensile force.

In the frame of the project GAR 01/09/0466, the software VibTexSoft has been developed, which facilitates the processing of individual groups of files and the calculation of the dynamic and mechanical properties of textiles. This application was written in the language Java. Therefore, it can run on any operating system which contains the component JRE (Java Runtime Environment). The only input to be submitted by the user is the value of the elongation frequency of textiles. All calculations are then run automatically, and the application compiles a table containing the following values: maximum elongation of the textile object [mm], minimum force (pre-loading) in the textile [mN], maximum force in the textile object [mN], dynamic (complex) module of rigidity [N/m] calculated in accordance with relation (14), the loss angle [°] calculated in accordance with relation (23), elastic module [N/m] calculated according to relation (24) and the loss module [N/m] calculated according to relation (25) for all individual measurements. The compiled table can be imported into a routine table processor, and the calculated values can be statistically processed there. In Table 2, an example of the programme output is shown.

Experiment and results of a test with specific textile objects

Using the VibTex device, the experimental measurement of longitudinal textiles was performed gradually. The following yarns were used: 100% PL yarn of fineness 25 tex x 2; 100% CO yarn of fineness 20 tex x 2; 100% PP yarn of fineness 25 tex x 2; 100% VI yarn of fineness 25 tex x 2. Measurements were done at 22°C and at a relative humidity of 40%. For each yarn, 10 measurements were done. The conditions for the measurements are shown in Table 3.

Measured values were processed by means of the VibTexSoft programme. The results (values of dynamical modulus and loss angle for individual textile materials are shown in Table 4. The values in Table 4 show that changing the frequency of elongation from a value of 10 Hz to a value of 100 Hz increases the dynamic modulus and loss angle for all tested textile materials. At a frequency 10 Hz, the upper limit of the confidence interval of the dynamic modulus and loss angle was lower in all cases than the lower limit of the confidence interval of these values at a frequency of 100 Hz. Therefore, the increase in dynamic modulus and loss angle with a change in the frequency of elongation from 10 Hz to 100 Hz is statistically significant. This phenomenon is probably due to the rheological properties of the tested yarns (see previous work in [8] and [9]).

Conclusion

In this paper, a special testing device called VibTex, which allows testing of textile materials during cyclical stress at a high frequency, was introduced. The dynamic characteristics (for example dynamic modulus and its real and imaginary parts, hysteresis, phase shifts between elongation and force, etc.) can be calculated from the results of this measuring device by means of the specially designed VibTexSoft software. Within the experiment, ply yarns of various raw materials were cyclically elongated up to predefined maximal elongation at different frequencies of elongation (10 Hz and 100 Hz) with the VibTex device. The dynamic modulus of rigidity and loss angles of rigidity of the tested yarns were compared. Changing the frequency of elongation from a value of 10 Hz to a value of 100 Hz, the dynamic modulus and loss angle increased for all the tested textile materials. This phenomenon is probably due to the rheological properties of the tested yarns.

Acknowledgement

This work was supported by research project No. 101/09/0466 by the Grant Agency of the Czech Republic.

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