Petr Tumajer,
Petr Ursíny,
***Martin Bílek,**
Eva Moučková

Faculty of Textile Engineering,
Technical University of Liberec,
Studentská 2, 461 17 Liberec, Czech Republic,
E-mail: petr.tumajer@tul.cz
petr.ursiny@tul.cz
eva.mouckova@tul.cz

***Faculty of Mechanical Engineering,**
E-mail: martin.bilek@tul.cz

Research Methods for the Dynamic Properties of Textiles

Abstract
This paper is concerned with a theoretical description of the dynamic properties of textiles and their experimental analysis. In the theoretical section of the paper, the dynamic properties of textiles are described based on rheological models. To describe their dynamic characteristics, the Laplace transformation has been employed. The experimental section of the paper describes special equipment - VibTex and the possibilities of its use in the experimental analysis of the dynamic properties of textiles. The experimental section includes a description of the manner of determining the dynamic properties of textiles based on the results of measurement.

Key words: *dynamic properties, rheological model, Laplace transformation, experiment, cyclical stress.*

Introduction

The mechanical properties of textiles are important both from the point of view of their processing in a technological process and their use in the form of final products [1]. The absence of an exact mathematical description of the deformation characteristics of textiles makes it difficult to analyse their behaviour in various stressing and loading regimes.

The issue of the influence of dynamic loading on the rheological properties of textile materials during their processing is dealt with in work [2], where a study of the influence of the dynamic loading of threads in the sewing process on their rheological properties is presented. Work [3] describes an experimental investigation of the visco-elastic properties of textiles under dynamic conditions using the longitudinal resonance vibration method on a special installation. The possibilities of modelling the pulsators as well as the characteristics of cyclic longitudinal impact loads on threads are presented in work [6].

This paper is concerned with a theoretical description of the dynamic properties of textiles and their experimental analysis.

Theoretical modelling of the dynamic properties of textiles

Rheological models and their description using the L-transformation

Rheological models comprising elastic and viscous elements can be described generally by a system of linear differential equations with constant coefficients, using the Laplace transformation for a theoretical description of dynamic properties [4, 6]. The mutual relation between the response F (tensile force in the textile object) and the exciting function x (elongation of the textile object) can then be expressed by means of response equations of the following type:

$$F(p) = T(p) \cdot x(p) \qquad (1)$$

where: $F(p)$ stands for the Laplace transform of the response; $T(p)$ is the transfer of the rheological model to an operator form, $x(p)$ - the Laplace transform of the exciting function, and p is the Laplace operator (complex parameter) [5].

The Laplace transform $Y(p)$ of function $y(t)$ is defined by the following integral:

$$Y(p) = \int_0^\infty y(t) \cdot e^{-p \cdot t} \cdot dt \qquad (2)$$

and the relation for unilateral Fourier transformation by the following integral [5]:

$$Y(\omega) = \int_0^\infty y(t) \cdot e^{-i \cdot \omega \cdot t} \cdot dt \qquad (3)$$

From equations (2) and (3), it follows that their right sides agree accurately on the condition of the pure imaginary variable p:

$$p = i.\omega \qquad (4)$$

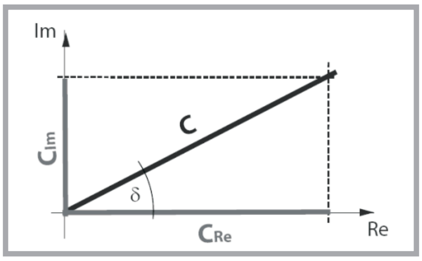


Figure 1. *Dynamic module of rigidity, its real and imaginary components; $C = T(i \cdot w)$ - dynamic module of rigidity, $C_{Re} = Re[T(i \cdot w)]$ - real component (elastic module of rigidity), $C_{Im} = Im[T(i \cdot w)]$ - imaginary component (elastic module of rigidity)*

In our case, we will use this property to express the frequency responses (dependencies of dynamic modules on frequency) and phase shifts (dependencies of loss angles on frequency) of individual rheological models [8]. If we express response $T(p)$ in an operator form, the frequency response $T(i.\omega)$ is defined as well, using the relation (4).

If we decompose the frequency response $T(i.\omega)$ to its real $\mathrm{Re}[T(i.\omega)]$ and imaginary $\mathrm{Im}[T(i.\omega)]$ components (***Figure 1***), we can express the dynamic module of rigidity $C(\omega)$ by the following relation:

$$C(\omega) = \sqrt{\left(\mathrm{Re}\left[T(i.\omega)\right]\right)^2 + \left(\mathrm{Im}\left[T(i.\omega)\right]\right)^2} \qquad (5)$$

and the mutual phase shift between the exciting function and the response (the loss angle) by the following relation:

$$\delta = arctg \frac{\mathrm{Im}\left[T(i.\omega)\right]}{\mathrm{Re}\left[T(i.\omega)\right]} \qquad (6)$$

When compiling operator equations of rheological models, we use the Laplace transform of the function $y(t)$:

$$L\{y(t)\} = Y(p) \qquad (7)$$

and the Laplace transform of the first derivative of function $dy(t)/dt$ for the zero initial condition:

$$L\left\{\frac{dy(t)}{dt}\right\} = p.Y(p) \qquad (8)$$

As an example, we will introduce here the so-called three-membered rheological model, produced from a combination of two elastic elements, G_0 and G_1, with viscous element b_1 in such a way that elastic element G_0 is coupled in parallel with a pair of elements, G_1 and b_1, arranged in series (see ***Figure 2***).

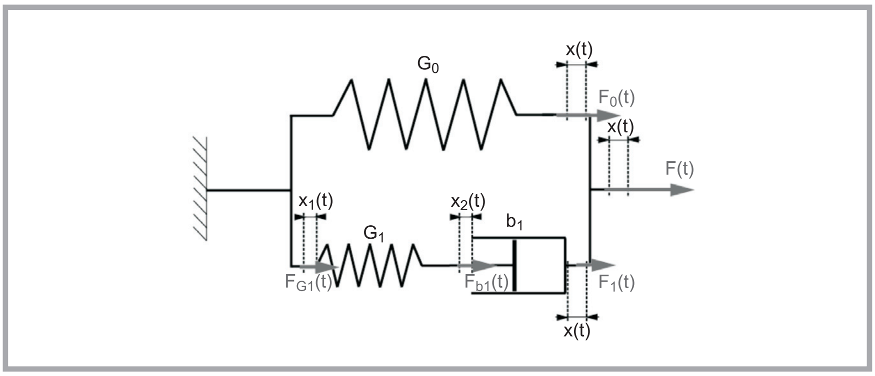


Figure 2. *Three-membered rheological model.*

Three-membered rheological model

For this model we shall compile a system of equations in an operator form characterising the response equation, the frequency response and its real (elastic module of rigidity) and imaginary (loss module of rigidity) components. Using ***Equation 5***, it is then possible to express the dependence of the dynamic module on the frequency, and using ***Equation 6*** - the dependence of the phase shift (loss angle) on the frequency, thus establishing the dynamic characteristics of the rheological model concerned. Furthermore, we established values of the rigidity modules and loss angles for very low frequencies (static values), i.e. for $\omega \to 0$, and values for high frequencies, i.e. for $\omega \to \infty$.

Equations for the time	Equations in an operator form	
$F_0(t) = G_0.x(t)$	$F_0(p) = G_0.x(p)$	(9)
$F_{G1}(t) = G_1.x_1(t)$	$F_{G1}(p) = G_1.x_1(p)$	(10)
$F_{b1}(t) = b_1.\frac{dx_2(t)}{dt}$	$F_{b1}(p) = b_1.p.x_2(p)$	(11)
$x(t) = x_1(t) + x_2(t)$	$x(p) = x_1(p) + x_2(p)$	(12)
$F_1(t) = F_{b1}(t) = F_{G1}(t)$	$F_1(p) = F_{b1}(p) = F_{G1}(p)$	(13)
$F(t) = F_1(t) + F_2(t)$	$F(p) = F_1(p) + F_2(p)$	(14)

$$F(p) = \left[G_0 + \frac{b_1.p}{1 + \frac{b_1}{G_1}.p} \right].x(p) = \left[\frac{G_0.\left(1 + \frac{b_1}{G_1}.p\right) + b_1.p}{1 + \frac{b_1}{G_{.1}}.p} \right].x(p) = T(p).x(p) \quad (15)$$

$$T(i.\omega) = \frac{G_0.\left(1 + \frac{b_1}{G_1}.i.\omega\right) + b_1.i.\omega}{1 + \frac{b_1}{G_1}.i.\omega} = G_0 + \frac{b_1.i.\omega.\left(1 - \frac{b_1}{G_1}.i.\omega\right)}{\left(1 + \frac{b_1}{G_1}.i.\omega\right)\left(1 - \frac{b_1}{G_1}.i.\omega\right)} = G_0 + \frac{\frac{b_1^2}{G_1}.\omega^2 + b_1.\omega.i}{1 + \left(\frac{b_1}{G_1}\right)^2.\omega^2} =$$

$$= G_0 + \frac{\frac{b_1^2}{G_1}.\omega^2}{1 + \left(\frac{b_1}{G_1}\right)^2.\omega^2} + \frac{b_1.\omega.i}{1 + \left(\frac{b_1}{G_1}\right)^2.\omega^2} \quad (16)$$

$$C(\omega) = \sqrt{\left[G_0 + \frac{\frac{b_1^2}{G_1}.\omega^2}{1 + \left(\frac{b_1}{G_1}\right)^2.\omega^2} \right]^2 + \left[\frac{b_1.\omega}{1 + \left(\frac{b_1}{G_1}\right)^2.\omega^2} \right]^2} =$$

$$= \sqrt{G_0^2 + \frac{2.G_0.\frac{b_1^2}{G_1}.\omega^2.\left[1 + \left(\frac{b_1}{G_1}\right)^2.\omega^2\right] + \frac{b_1^4}{G_1^2}.\omega^4 + b_1^2.\omega^2}{\left[1 + \left(\frac{b_1}{G_1}\right)^2.\omega^2\right]^2}} \quad (19)$$

Equations 9, 10, 11, 12, 13, 14, 15 and 16.

The response equation obtained by eliminating $x_1(p)$, $x_2(p)$, $F_{G1}(p)$, $F_{b1}(p)$, $F_1(p)$ and $F_0(p)$ from the system of ***Equations 9*** to ***14*** is as ***Equation 15***:

Frequency response set-up by substituting (4) into transfer $T(p)$ see ***Equation 16***.

Real component of the frequency response (elastic module of rigidity):

$$\mathrm{Re}[T(i.\omega)] = G_0 + \frac{\frac{b_1^2}{G_1}.\omega^2}{1 + \left(\frac{b_1}{G_1}\right)^2.\omega^2} \quad (17)$$

Imaginary component of the frequency response (loss module of rigidity):

$$\mathrm{Im}[T(i.\omega)] = \frac{b_1.\omega}{1 + \left(\frac{b_1}{G_1}\right)^2.\omega^2} \quad (18)$$

Dynamic module obtained using equation (5), i.e. the dependence of the dynamic module on the frequency see ***Equation 19***.

Module for low frequencies, i.e. $\omega \to 0$ (static module of rigidity):

$$\lim_{\omega \to 0}[C(\omega)] = G_0 \quad (20)$$

Module for high frequencies, i.e. $\omega \to \infty$:

$$\lim_{\omega \to \infty}[C(\omega)] = G_0 + G_1 \quad (21)$$

The loss angle (dependence of phase shift on frequency) obtained using ***Equation 6***:

$$\delta = arctg \frac{b_1.\omega}{G_0.\left[1 + \left(\frac{b_1}{G_1}\right)^2.\omega^2\right] + \frac{b_1^2}{G_1}.\omega^2} \quad (22)$$

Loss angle for low frequencies, i.e. $\omega \to 0$:

$$\lim_{\omega \to 0}[\delta(\omega)] = 0 \quad (23)$$

Loss angle for high frequencies, i.e.

$\omega \to \infty$:

$$\lim_{\omega \to \infty} [\delta(\omega)] = 0 \qquad (24)$$

Figure 3 shows the dynamic characteristics of the three-membered rheological model. The upper graph represents the dependence of dynamic module *C* on the frequency ω (see the ***Equation 19***), and the lower graph represents the dependence of the loss angle δ (the phase shift between the force and the elongation) on the frequency ω (see ***Equation 22***). Booth curves are created for these parameters: G_0 = 100 N/m, G_1 = 100 N/m and b_1 = 10 N.s/m.

In the area of low frequencies, the dynamic module of rigidity of the three-membered rheological model is determined by the rigidity of the elastic element G_0 (see ***Equation 20***), and with an increasing frequency, it increases up to value G_0+G_1 (see ***Equation 21***). The loss angle (the phase between the force and elongation) is approximately zero in the areas of both low and high frequencies (see ***Equations 23*** and ***24***), increasing only in the "transition" area, i.e. in the area where the dynamic module of rigidity is changing. These theoretical results show the influence of the elongation frequency on deformation properties, i.e. the dynamic module and loss angle.

The above manner of describing dynamic characteristics is universal, and it can be employed for a description of any rheological model.

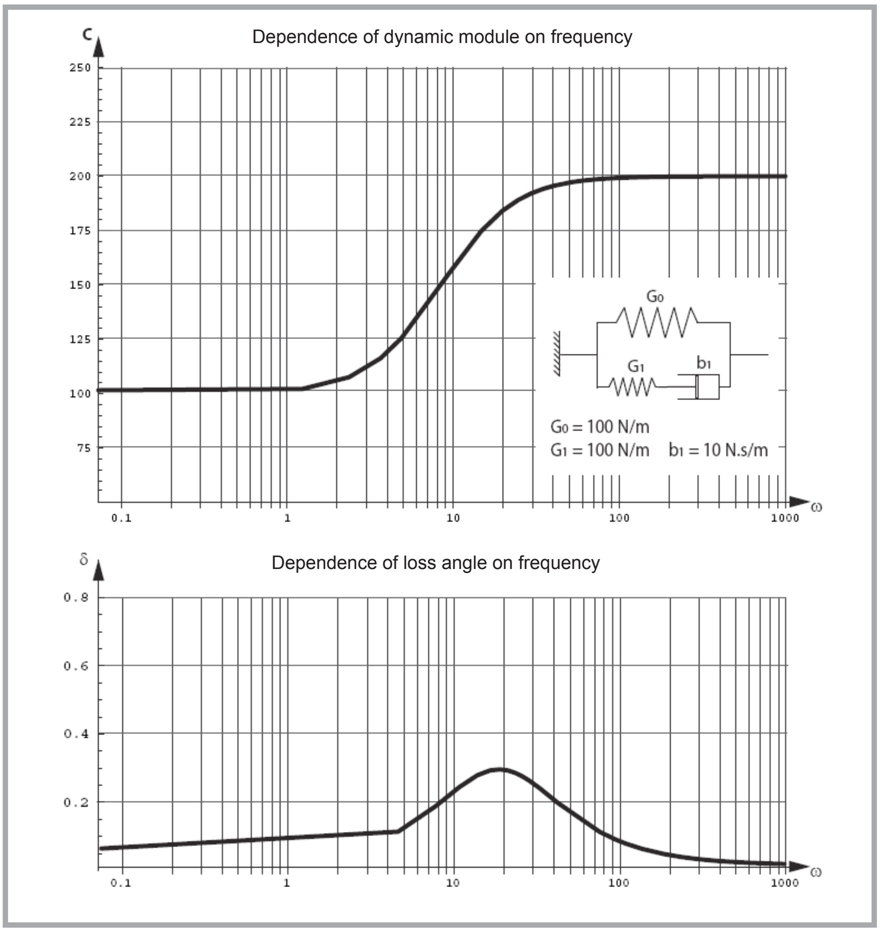
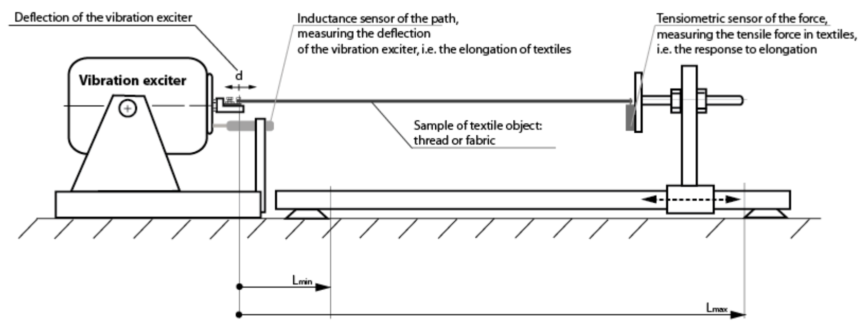


Figure 3. *Dynamic characteristics of the three-membered rheological model.*

Experimental part

The dynamic properties of textiles were analysed in an experimental form as well [6]. Experimental analysis allows to find a suitable rheological model for the textile object concerned and to compile a corresponding mathematical description of its dynamic properties.

The standard appliances for testing textiles do not enable an experimental analysis of their deformation properties in the range of frequencies and clamping lengths necessary [10]. Therefore, within the framework of project GAČR 01/09/0466, special equipment (VibTex), schematically shown in ***Figure 4***, was constructed which is able to test textiles in a wide range of clamping lengths (a detailed description is given in [7]). A electromagnetic vibration system was used as the basis of the equipment so as to able to extend textiles at varied frequencies, as well as a tensiometric sensor to measure the tensile force in the textiles (response to elongation). An inductance sensor was fastened to the vibration exciter, measuring the elongation of the textiles (exciting function).



Basic characteristics of VibTex equipment:

Max. elongation of textiles required	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

Figure 4. *Principle of VibTex equipment.*

VibTex equipment allows to adjust the pre-loading required in the textile sample by means of adjusting screws, integrated in the holder of the tensiometric sensor.

The VibTex also allows the realisation of tests with a harmonic course of the

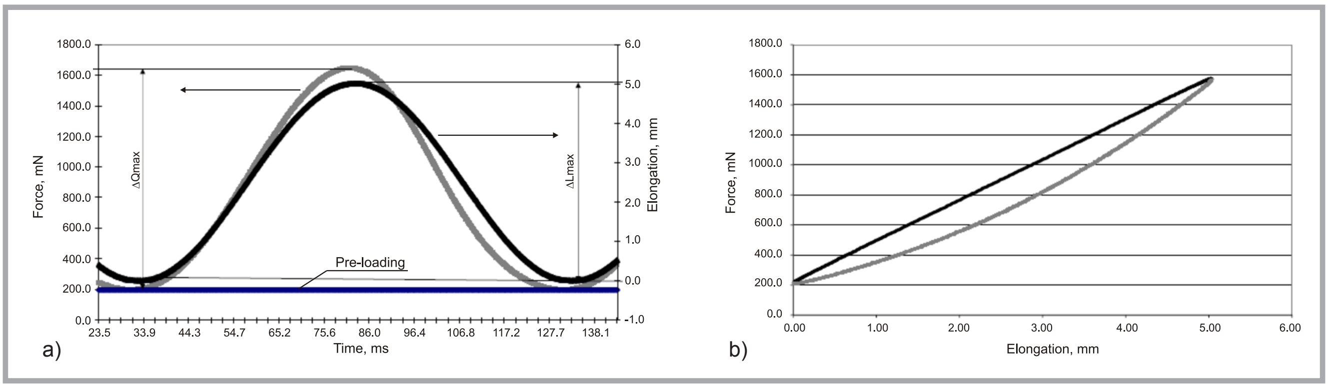


Figure 5. Example of the result of a test with harmonic elongation: frequency 10 Hz, maximum elongation - 5 mm; a) time dependence of the force and the elongation, b) dependence of the force on the elongation.

elongation for a given frequency and amplitude of acceleration, or tests with an arbitrary periodical course of elongation [9]. We can also record values of the elongation (exciting function) and the force (response function) in the textile object during the tests and calculate the dynamic characteristics of the textile object from these values.

Manner of determining the dynamic properties of textiles based on the results of measurements

To determine the dynamic modules of the rigidity of textiles, it is necessary to realise experimental measurements with a harmonic course of deflection of the vibration exciter *d(t)*:

$$d(t) = D_a \cdot \sin(\omega \cdot t) \tag{25}$$

D_a – amplitude of deflection of the vibration exciter in mm,

ω – angular frequency in rad/sec,

$$\omega = 2 \cdot \pi / T \tag{26}$$

T – period in sec,

$$T = 1/f \tag{27}$$

f – frequency in Hz.

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

$$\Delta l(t) = D_a.[1 + \sin(\omega.t)] = \frac{\Delta L_{\max}}{2}.[1 + \sin(\omega.t)] \tag{28}$$

ΔL_{max} – maximum elongation of the textile object in mm,

$$\Delta L_{max} = 2 \cdot D_a \tag{29}$$

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:

$$Q(t) = Q_P + Q_a [1 + \sin(\omega.t + \delta)] = Q_P + \frac{\Delta Q_{\max}}{2}.[1 + \sin(\omega.t + \delta)] \tag{30}$$

Q_P – pre-load in the textile object in mN,

Q_a – amplitude of the response, i.e. of the tensile force in mN,

δ – mutual phase displacement between the exciting function and the response, i.e. the loss angle in rad,

ΔQ_{max} – maximum change of the tensile force in mN,

$$\Delta Q_{max} = 2 \cdot Q_a \tag{31}$$

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

From ***Equation 28*** it follows that the elongation of a textile object (exciting function) can be expressed as the sum of two terms:

$$\Delta l(t) = \Delta l_K + \Delta l_H(t) \tag{32}$$

where the first term Δl_K:

$$\Delta l_K = D_a = \frac{\Delta L_{\max}}{2} \tag{33}$$

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

$$\Delta l_H(t) = D_a.\sin(\omega.t) = \frac{\Delta L_{\max}}{2}.\sin(\omega.t) \tag{34}$$

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

From ***Equation 30*** it follows that the tensile force in the textile object (response) can be expressed as the sum of three terms:

$$Q(t) = Q_P + Q_a + Q_H(t) \tag{35}$$

where the first term Q_P represents pre-loading in the textile object, which is constant in time (not dependent on time), the second term Q_a - the component of the tensile force, which is constant in time, and the third term of the expression (35) $Q_H(t)$ represents the variable component of the tensile force, which changes harmonically with the time:

$$Q_H(t) = Q_a.\sin(\omega.t + \delta) = \frac{\Delta Q_{\max}}{2}.\sin(\omega.t + \delta) \tag{36}$$

Dynamic (complex) module of rigidity:

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

$$C = \frac{Q_a}{D_a} = \frac{\Delta Q_{\max}}{\Delta L_{\max}} \tag{37}$$

C – dynamic, i.e. complex module of rigidity in N/m.

Loss angle (phase shift between the force and elongation):

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

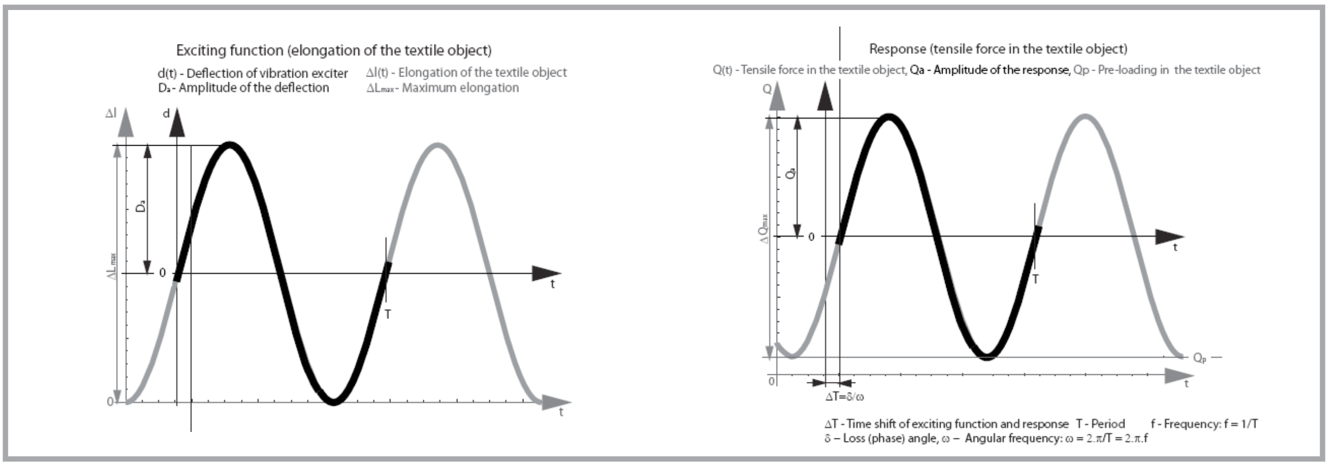


***Figure 6.** Time dependence of the elongation of the textile object (exciting function) and tensile force (response).*

expressed by the following relation, employing equation (26):

$$T/4 = \frac{\pi}{2.\omega} \qquad (38)$$

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

$$W = \int_0^{L_{1/4}} Q_H . d\Delta l_H = \int_0^{\frac{\pi}{2.\omega}} Q_H . \frac{d\Delta l_H}{dt} . dt =$$

$$= \int_0^{\frac{\pi}{2.\omega}} Q_a . \sin(\omega.t + \delta)\, D_a . \omega . \cos(\omega.t) . dt = \qquad (39)$$

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

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

From relation (39) it follows that the energy in one quarter of the period W can be expressed by the sum of two terms:

$$W = W_S + W_L \qquad (40)$$

Here the first term expresses the storage energy W_S:

$$W_S = \frac{1}{2} Q_a . D_a . \cos(\delta) \qquad (41)$$

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:

$$W_L = \frac{\pi}{4} Q_a . D_a . \sin(\delta) \qquad (42)$$

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

$$H = \int_0^{\Delta L_{max}} Q_I(\Delta l) . d\Delta l - \int_0^{\Delta L_{max}} Q_D(\Delta l) . d\Delta l, \qquad (43)$$

where:

Q_I - tensile force during an increase in elongation,

Q_D - tensile force during a decrease in elongation.

In our case, the above integral (43) is solved numerically (by the rectangular method), and subsequently the dissipation of energy during one quarter of the period is calculated - $H/4$. The dissipation of energy in one quarter of the period is expressed by relation (42), and therefore the following equation must be valid:

$$\frac{\pi}{4} . Q_a . D_a . \sin(\delta) = \frac{1}{4} H \qquad (44)$$

From equation (44), we express the loss angle δ:

$$\delta = \arcsin \frac{H}{\pi . Q_a . D_a} \qquad (45)$$

and employing relations (29) and (31), we can express this angle by means of the hysteresis H, the maximum elongation of the textile object ΔL_{max}, and by the maximum change in the tensile force in the textile object ΔQ_{max} using the following equation:

$$\delta = \arcsin \frac{4.H}{\pi . \Delta Q_{max} . \Delta L_{max}} \qquad (46)$$

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, and it is a measure of the ideal resistance to mechanical stress, coincident with the stressing phase (see ***Figure 1***):

$$C_{Re} = C \cdot \cos(\delta) \qquad (47)$$

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

The loss module of rigidity C_{Im} constitutes the imaginary component of the dynamic (complex) module of rigidity C, and it is a measure of mechanical losses during one period, phase-displaced by the value π/2 (see ***Figure 1***):

$$C_{Im} = C \cdot \sin(\delta) \qquad (48)$$

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

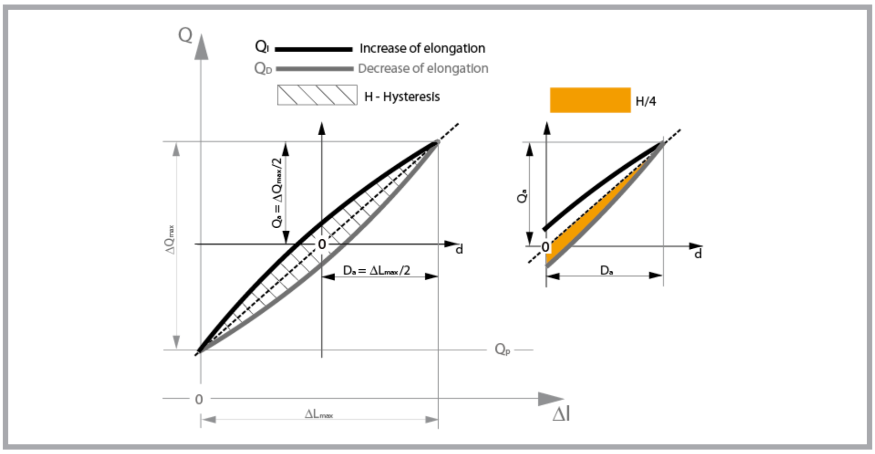


***Figure 7.** Dependence of the tensile force on elongation.*

Table 1. Results of a test at an elongation frequency of 10 Hz and 100 Hz.

Elongation frequency, Hz	Measuring number	Clamping length, mm	Maximum elongation, mm	Force, mN		Dynamic module, N/m	Loss angle, °	Module, N/m	
				minimum	maximum			elastic	loss
10	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
	Mean	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. 95%	3	0.01	12	20	2	0.1	2	0.4
100	1	495	3.05	457	1287	272	9.1	268	43.1
	2	495	3.05	481	1351	285	8.8	282	43.7
	3	500	3.02	494	1355	285	9.3	282	45.9
	4	495	3.01	437	1290	283	9.6	279	47.1
	5	496	3.03	486	1352	286	9.4	282	46.5
	6	497	2.97	470	1283	274	10.2	270	48.6
	7	499	2.98	414	1218	270	9.4	266	43.9
	8	500	2.98	451	1265	274	9.4	270	44.5
	9	500	2.98	450	1278	278	9.4	274	45.4
	10	500	3.01	514	1392	291	8.7	288	44.0
	Mean	498	3.01	466	1307	280	9.3	276	45.3
	St. dev.	2	0.03	30	53	7	0.4	7	1.8
	Conf. 95%	1	0.02	18	33	5	0.3	5	1.1

For the purpose of statistic processing, a series of tests with various sections of the textile object concerned was realised in the majority of cases. The output of the measurements is a group of files in text format (with ASCII coding) containing three columns of real numbers. The first column contains the time, the second one the deflection of the vibration exciter, and the third one the tensile force. Within the framework of project GAČR 01/09/0466, the program VibTexSoft was generated, which facilitates the easy processing of individual groups of files and the calculation of the dynamic properties of textiles using ***Equations 37, 43, 46, 47*** & ***48***. The output of VibTexSoft is a table which includes the following values: the maximum elongation of the textile object in mm, the minimum force (pre-loading) in the textile in mN, the maximum force in the textile object in mN, the dynamic (complex) module of rigidity in N/m, the loss angle in deg, the elastic module in N/m and the loss module in N/m for all individual measurements. The table compiled can be imported into a routine table processor, and there the values calculated can be processed statistically.

Results of a test with a specific textile object

- As an example, we shall introduce here the results of a test with a specific linear textile object (thread):Fineness T = 25 tex × 2, 100% PP
- Ply twist: 439 m^{-1}, 95% confidence interval: (432; 446), number of measurements1): 30
- Mass irregularity CV = 8.69%, 95% confidence interval: (8.57; 8.81), number of measurements2): 5.

The test was carried out at frequency 10 Hz and 100 Hz. The results are shown in the ***Table 1***:

Results for a frequency of 10 Hz, a clamping length of 523 ± 3 mm, a preload of 207 ± 12 mN and a maximum elongation of 4.7 mm:

- Dynamic module of rigidity: 213 ± 2 N/m
- Loss angle (phase shift): 5.9 ± 0.1°
- Elastic module: 212 ± 2 N/m
- Loss module: 22.0 ± 0.4 N/m.

Results for a frequency of 100 Hz, a clamping length of 498 ± 1 mm, a preload of 466 ± 18 mN and a maximum elongation of 3.0 mm:

- Dynamic module of rigidity: 280 ± 5 N/m
- Loss angle (phase shift): 9.3 ± 0.3°
- Elastic module: 276 ± 5 N/m
- Loss module: 45.3 ± 1.1 N/m.

Conclusion

The results of the experimental measurements present the principle of the employment of VibTex equipment in the analysis of the dynamic properties of textiles and in establishing the dynamic modules of rigidity and loss angles at a certain frequency of elongation. We can see that the values of the dynamic modules and loss angles are different at 10 Hz and 100 Hz, i.e. these values increase with the elongation frequency. This behaviour of textile material is probably due to their rheological properties. The characteristics of VibTex equipment facilitate the realisation of the tests described above in a wide range of frequencies, and the results can be used for the verification of rheological models for specific textile materials. Currently, theoretic-experimental methodology for the creation of the frequency characteristics (see figure 3) of the deformation properties of textiles, the design of appropriate rheological models and the determination of their input parameters is being formulated. This methodology will be published in following papers.

Editorial note

1) *Measuring equipment: Zweigle KG Reutlingen D310, direct method, pre-loading: 250 mN.*
2) *Measuring equipment: Uster Tester IV-SX, measuring velocity: 400 m/min, time of measuring: 1 min*

Acknowledgment

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

References

1. *Morton W. E., Hearle, J. W. S.: Physical properties of textile fibres, Manchester & London, The Textile Institute, Butterworths, 1962.*
2. *Gersak J., Gotlih K., Zunic Lojen D., Rudolf A.; Influence of dynamic loading on rheological properties of textile material, International Journal of Clothing Science and Technology, Vol. 10, No. 6, 1998, pp. 60-62.*
3. *Vlasenko V., Kovtun, S., Arabuli, A., Bereznenko, S.; Application of the longitudinal resonance vibration method for an investigation of a textile's visco-elastic properties Vlakna a Textil, Vol. 14, No. 2, 2007, pp. 11-14.*
4. *Nosek S.; Straining of various linear textile bodies in generalized drawing fields, mainly in warps on looms, Book of proceedings, Conference Textile Science, pp. 125-138, Technical University of Liberec, Czech Republic, 1998.*
5. *Rektorys K. at all: Přehled užité matematiky – 2.díl, 720 pages, Prométheus, 2009, ISBN 978-80-7196-180-2.*
6. *Snycerski M.; The pulsator - a generator of cyclic longitudinal impact loads to simulate weaving conditions for warp yarn, Fibres and Textiles in Eastern Europe, Vol. 5 No. 4(19), 1997, pp. 65-67.*
7. *Tumajer P., Bílek M., Strašáková P.; Mutual action force between weaving machine and textile material, Book of proceedings, X. International Conference on the Theory of Machines and Mechanisms, 2.9 - 4.9.2008, pp. 665-670, Technical University of Liberec – Department of Textile Machines Design, Liberec, Czech Republic, 2008, ISBN 978-80-7372-370-5, UT ISI:000259441500108.*
8. *Bílek M., Tumajer P.; Behaviour of textiles under high frequency stress, Acta Universitatis Cibiniensis, Vol. LVIII, 2009, pp. 8-13, „ Lucian Blaga“ University of Sibiu, Romania, ISSN 1583-7149.*
9. *Ursíny, P., Bílek, M., Tumajer, P., Moučková, E.: Simulation des Textilmaterialverhaltens während des Webprozesses, Sammelbuch des Vortrages, 12. Chemnitzer Textiltechnik-Tagung Innovation mit textilen Strukturen, pp. 314 – 321, 30.9.-1.10.2009, Technische Universität Chemnitz, Germany, 2009, ISBN 978-3-9812554-3-0.*
10. *Tumajer, P., Ursíny, P., Bílek, M., Moučková, E.: Influence of stress frequency on deformation properties of threads, Proceedings of Texsci 2010 (CD-Book of Full Textes), 7th International Conference Textile Science TEXSCI 2010, p. 55, Technical University of Liberec, Liberec, Czech Republic, 2010., ISBN 978-80-7372-638-6.*

Received 14.12.2010 Reviewed 08.04.2011