STRUCTURAL—MECHANICAL AND THERMOPHYSICAL PROPERTIES OF MODIFIED POLYVINYL CHLORIDE

N. A. Bordyuk, Yu. N. Bestyuk,
V. I. Nikitchuk, and B. S. Kolupaev

UDC 678.743.22.046.01

On the basis of a systematic investigation of the viscoelastic properties of polyvinyl chloride filled with waste from mineral fertilizer and phosphoric acid production in the form of highly dispersed phospho-gypsum, the specific heat is calculated and the energy of interaction of the structural elements of the system matrix is determined, together with the effective thermal conductivity coefficient, with allowance for energy dissipation by the elements of the structure.

A model experimental approach to the study of general physicochemical problems of the structure and properties of filled polymer systems requires an in-depth analysis of the changes in their energy spectrum and the nature of the kinetic effects under the influence of the ingredients [1]. The main difficulty in investigating the vibrational motion of the structural organization in compositions is the need to solve the molecular physics problem of controlling the stereochemical characteristics of individual subsystems capable of changing shape and in different conformations aggregating into structural elements of higher order [2]. All this is known to be of practical as well as theoretical interest in connection with the investigation of energy transfer processes in these systems under the influence of a mechanical or temperature field [3].

The present research is devoted to the investigation of the effect of structural modification on the dissipative energy losses and the spectral distribution density of the kinetic elements of polyvinyl chloride (PVC) filled with phospho-gypsum (PG). We investigated systems based on PVC MW 1.4×10^5 with a Fikentscher constant of 65 obtained by suspension polymerization and purified by reprecipitation from solution. As fillers we used commercial PG with the composition: $CaSO_4 \cdot 2H_2O$ — 75-79%; H_2O (free) — 18-22%; P_2O_5 — 0.97-1.8%; F — 0.8-1.0%; SiO_2 — 0-0.5%. The predominant particle fraction was crystals 10 to 40 microns in size. The initially highly dispersed PG was dried at T = 373 K, and then after mechanical mixing with PVC, compositions were obtained in the T—p regime [4]. The temperature and concentration dependence of the density ρ of the PVC compositions and the longitudinal v_ℓ and shear v_t strain rates at 0.4 MHz were determined by the method described in [5].

The real parts of the moduli (E', μ', K') were determined in accordance with [5] using the known values of v_ℓ and v_t, the investigation frequency ω and the corresponding absorption coefficients α_ℓ and α_t.

It was found that even at a filler content of 0.1-0.3% by vol. the experimental values of ρ for the PVC compositions differ from those calculated in accordance with the additive component contribution rule. A "plateau" corresponding to a PG content of 5-10% by vol. is observed on the density-filler content $\rho - \varphi$ curve. A further increase in the PG content of the system leads to an increase in ρ.

On the filler concentration range 0.1-1.0% by vol. the density of the polymer matrix ρ_M also differs from the system density (Fig. 1). When $\varphi = 7.0\%$ by vol. a maximum of ρ_M is observed, while on the filler concentration range 8-20% by vol. ρ_M decreases, which points to a loosening of the matrix.

The change in the ρ_M of PVC systems under the influence of a filler also finds expression in a change in their viscoelastic properties. As follows from Table 1, the change in the viscoelastic properties of the composition is sharpest on the filler content range from 0.1 to

---

D. Z. Manuil'skii State Pedagogical Institute, Roven'. Translated from Inzhenerno-fizicheskii Zhurnal, Vol. 60, No. 6, pp. 987-994, June, 1991. Original article submitted June 15, 1990.

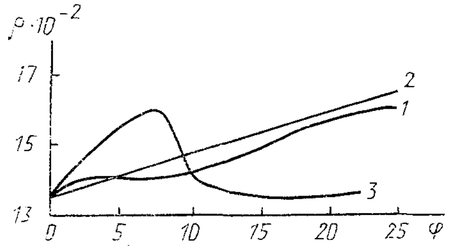

Fig. 1. Concentration dependence of the density of PVC systems: 1) PVC+PG (experiment); 2) PVC+PG (additivity); 3) PVC+PG (matrix density). ρ, kg/m³; φ, % by vol.

0.5% by vol. This points not only to a decrease in the mobility of the segments of the macromolecules and supermolecular formations of the PVC but also to structural changes affecting the PVC in the boundary layers [1, 4]. With further increase in the PG content φ of the PVC competing effects associated with the increased polymer fraction in the boundary layer and the stiffening of the structural elements of the polymer are observed.

In order to be able to predict the viscoelastic properties of PVC compositions we calculated them using various methods and models [3, 6-9]. An analysis of the results obtained (Table 1) shows that on the range of filler contents φ from 0 to 0.1% by vol. the most satisfactory agreement between experiment and theory is obtained using the two-component Einstein model [8], while on the interval 0.5-5.0% by vol. the self-consistent field method [6, 7] and the micromechanical theory [8] give the best results. When $\varphi \geq 5.0\%$ by vol. the theoretical calculations considered do not give satisfactory agreement with experiment.

Starting from the values of v_ℓ and v_t we calculated the characteristic frequency spectrum of the PVC systems (ω_D^ℓ, ω_D^t) in accordance with the relations

$$\omega_D^l = \frac{(6\pi^2 N)^{1/3}}{V^{1/3}} v_l; \quad \omega_D^t = \frac{(6\pi^2 N)^{1/3}}{V^{1/3}} v_t. \tag{1}$$

As follows from the data of Table 2, as the filler concentration varies, so do the values of ω_D^ℓ and ω_D^t. Thus, on the filler concentration range 0.5-1.0% by vol. a maximum of the longitudinal frequencies is observed, while the value of ω_D^t increases on the concentration interval from 2.0 to 20.0% by vol. A comparison of calculated values of ω_D^ℓ and ω_D^t for filled PVC and the calculated spectrum for the initial polymer shows that they are somewhat higher for the system PVC+PG. This points to a stiffening of the polymer structure under the influence of the highly dispersed PG as a result of the formation of a dipole—dipole bond between the structural elements of the PVC and the active centers of the filler [4].

Knowing ω_D^ℓ and ω_D^t, we can determine the elastic moduli of these elements of the system as a function of the filler concentration. For this purpose we will consider the quasi-lattice formed by a linear chain of the type ABAB..., in which two different elements with masses M_A and M_B ($M_A < M_B$) alternate [10]. We will assume that the simple linear lattice of type A is formed by the group CH_2 ($M_A = 23.284969 \times 10^{-27}$ kg) and that of type B by CHCl ($M_B = 80.463721 \cdot 10^{-27}$ kg). If it is assumed that the structural elements are bound together by quasi-elastic forces with elastic constant β and the length of the unit cell is equal to d, then for longitudinal vibrations the solution of the secular equation of the type

$$\left| \frac{M}{(M_A M_B)^{1/2}} \Phi_{A,B} - M\omega^2 \delta_{A,B} \right| = 0, \tag{2}$$

where $\Phi_{A,B}$ is the A—B interaction potential, has the form:

$$\omega(k) = \left[\frac{\beta}{M_A M_B} \{M_A + M_B \pm (M_A^2 + M_B^2 + 2M_A M_B \cos(dk)^{1/2}\} \right]^{1/2}. \tag{3}$$

TABLE 1. Viscoelastic Properties of the System PVC+PG

φ, vol %	Experiment			Einstein's equation			Self-consistent field equation			Micromechanical theory			$E'=14,4\mu_1'\psi(\varphi)$; $\mu'=6,75\mu_1'\psi(\varphi)$, $K'=5,62\mu_1'\psi(\varphi)$		
	$E'\cdot10^{-9}$	$\mu'\cdot10^{-9}$,	$K'\cdot10^{-9}$,	$E'\cdot10^{-9}$,	$\mu'\cdot10^{-9}$,	$K'\cdot10^{-9}$,	$E'\cdot10^{-9}$,	$\mu'\cdot10^{-9}$,	$K'\cdot10^{-9}$,	$E'\cdot10^{-9}$,	$\mu'\cdot10^{-9}$,	$K'\cdot10^{-9}$,	$E'\cdot10^{-9}$,	$\mu'\cdot10^{-9}$,	$K'\cdot10^{-9}$,
	Н/м^2														
0,1	7,43	1,55	5,35	7,16	1,45	5,20	7,88	1,70	5,61	7,89	1,71	5,61	0,071	0,02	0,02
0,3	7,64	1,37	5,81	7,19	1,46	5,23	7,84	1,68	5,61	7,84	1,70	5,59	0,09	0,04	0,03
0,5	7,81	1,43	5,91	7,23	1,47	5,25	7,82	1,66	5,60	7,83	1,70	5,58	0,13	0,06	0,05
1	7,80	1,61	5,65	7,32	1,49	5,32	7,75	1,62	5,58	7,78	1,69	5,55	0,21	0,10	0,08
2	7,76	1,62	5,61	7,50	1,52	5,45	7,61	1,58	5,53	7,65	1,66	5,47	0,36	0,17	0,14
3	7,62	1,58	5,51	7,68	1,56	5,58	7,49	1,47	5,50	7,53	1,64	5,42	0,52	0,24	0,20
5	7,45	1,70	5,19	8,03	1,63	5,84	7,23	1,44	5,31	7,30	1,60	5,27	0,77	0,36	0,30
10	7,57	2,02	4,87	8,93	1,81	6,49	6,49	1,30	4,76	6,74	1,50	4,93	1,46	1,17	0,57
20	9,52	2,66	5,97	10,71	2,18	7,79	5,78	1,03	4,41	6,54	1,31	4,32	4,90	2,30	1,91

<u>**Remark**</u>: $\overline{E}_1'$ and μ_1' are the moduli of the initial PVC, $\psi(\varphi)=\frac{\pi}{16\sqrt{2}}\,\frac{\varphi^{2/3}}{1-\varphi^{1/3}}$.

TABLE 2. Concentration Dependence of the Viscoelastic and Thermophysical Properties of PVC+PG

φ, vol. %	v_l,	v_t,	Θ_D^l,	Θ_D^t,	$\omega_D^l\cdot10^{-13}$,	$\omega_D^t\cdot10^{-13}$,	β,	$\varkappa_1$,	$\varkappa_2$,	$U'\cdot10^{21}$,	$U_1\cdot10^{20}$,	$U_2\cdot10^{20}$,	U, kJ/mole
	m/sec		K		Hz		N/m			J			
0	2310	1040	162	73	2,114	0,952	4,04	0,13	0,46	4,79	0,08	0,73	45,9
0,1	2350	1070	165	75	2,155	0,980	4,20	0,14	0,48	4,98	0,08	0,76	47,4
0,3	2390	1005	168	71	2,194	0,923	4,35	0,13	0,43	5,16	0,08	0,68	47,5
0,5	2400	1025	168	72	2,203	0,941	4,38	0,13	0,45	5,19	0,08	0,71	48,1
1	2390	1085	168	76	2,204	1,000	4,39	0,15	0,50	5,21	0,09	0,79	49,3
2	2370	1080	167	76	2,192	0,999	4,34	0,15	0,50	5,15	0,09	0,79	48,9
3	2320	1120	162	78	2,115	1,020	4,04	0,15	0,52	4,79	0,09	0,82	47,1
5	2300	1095	163	78	2,141	1,020	4,14	0,15	0,52	4,91	0,09	0,82	47,8
10	2270	1170	164	84	2,150	1 105	4,18	0,18	0,61	4,96	0,10	0,97	50,1
20	2460	1290	182	107	2,386	1,250	5,14	0,23	0,79	6,10	0,13	1,25	60,7

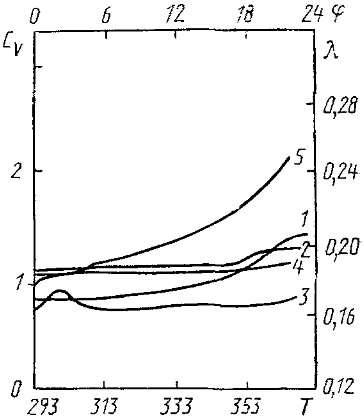

Fig. 2. Temperature and concentration dependence of the C_V and λ of PVC systems. Temperature dependence of the C_V of the system PVC+3%PG: 1) experiment; 2) theory. Concentration dependence of the C_V of the system PVC+PG: 3) experiment; 4) theory. Concentration dependence of the λ of the system PVC+PG: 5) theory. C_V, kJ/(Kg·K): λ, W/(m·K); T, K; φ, % by vol.

Assuming that the A and B lattices as a whole vibrate relative to each other (cos(dk) = 1) and $\omega_{max}(k) = \omega_D^l$, we obtain

$$\beta = \frac{(\omega_D^l)^2 M_A M_B}{2(M_A + M_B)}\,. \tag{4}$$

Since the transverse vibrations are determined by the flexibility of the chain and are realized at the expense of the deformation of the valence angles, the resulting force obeys Hooke's law. In this case let the elastic constant be equal to κ ; then

$$\omega(k) = \left(\frac{16\varkappa}{M}\right)^{1/2} \sin^2\left(\frac{kd}{2}\right). \tag{5}$$

Assuming that $\omega_{max}(k) = \omega_D^t$, we find

$$\varkappa = \frac{(\omega_D^t)^2 M}{16}\,. \tag{6}$$

Calculating in accordance with equations (4) and (6), we obtain the dependence of the quasi-elastic constants on the loading of the PVC with the filler PG. An analysis of the dependence of β on φ shows that on the filler concentration range 3-5% by vol. the values of β are observed to decrease, while on an interval of the order of 20% by vol. they increase sharply. It should be noted that over the entire filler concentration range the constant of quasi-elastic interaction between $CH_2{-}CHCl$ groups is higher than for the initial PVC. A comparison of the quasi-elastic constants of transverse interaction of the structural units of the system shows that in the case of interaction of the types H—H($\varkappa_1$) and H—Cl($\varkappa_2$) the value $\varkappa_1 < \varkappa_2$, and on the filler concentration interval 0.3-20.0% by vol. $\varkappa_2$ is observed to increase, especially on the range 5-20%. The constant $\varkappa_1$ varies only slightly. Consequently, the introduction of filler in amounts of the order of 1.0% by vol. or more leads to a strengthening of the crosslinks in the system.

Analyzing the temperature dependence of $\beta, \varkappa_1$, and $\varkappa_2$, we conclude that an increase in the temperature of the PVC composition leads to a decrease in the values of the quasi-elastic interaction constants and hence to a decrease in the interaction between the structural elements of the system.

Considering that the interaction between the atoms along the main chain of the macromolecule is equal to $F = \beta x$, the energy of the quasi-elastic component in the longitudinal direction will be equal to $U' = \beta x^2/2$ and in the transverse direction to $U_1 = \varkappa_1 x_1^2/2$ and

TABLE 3. Temperature Dependence of the Viscoelastic and Thermophysical Properties of the System PVC+3%PG

T, K	v_l,	v_t,	$\omega_D^l \cdot 10^{-13}$,	$\omega_D^t \cdot 10^{-13}$,	Θ_D^l,	Θ_D^t,	β,	$\varkappa_1$,	$\varkappa_2$,	$U' \cdot 10^{20}$,	$U_1 \cdot 10^{20}$,	$U_2 \cdot 10^{20}$,	$U_0 \cdot 10^{20}$,	U, kJ/mole
	m/sec		Hz		K		N/m			J				
293	2320	1120	2,115	1,020	162	78	4,04	0,15	0,52	4,79	0,09	0,82	1,213	47,1
298	2250	1100	2,053	1,004	157	77	3,81	0,15	0,51	4,52	0,09	0,81	1,234	45,5
303	2190	1080	1,999	0,986	153	75	3,61	0,14	0,49	4,28	0,08	0,78	1,254	43,7
308	2120	1050	1,935	0,958	148	73	3,38	0,13	0,46	4,01	0,08	0,73	1,275	41,6
313	2060	1030	1,880	0,940	144	72	3,19	0,13	0,44	3,78	0,08	0,70	1,296	40,0
318	2000	1020	1,825	0,931	140	71	3,01	0,13	0,44	3,57	0,08	0,70	1,317	38,8
323	1910	1010	1,743	0,922	133	70	2,74	0,12	0,43	3,25	0,07	0,68	1,337	36,7
328	1830	995	1,670	0,908	128	69	2,52	0,12	0,41	2,99	0,07	0,65	1,358	34,9
333	1800	970	1,643	0,885	126	68	2,44	0,11	0,39	2,89	0,06	0,62	1,379	33,7
338	1740	940	1,588	0,858	121	66	2,28	0,11	0,37	2,70	0,06	0,59	1,400	32,5
343	1680	920	1,533	0,840	117	64	2,12	0,10	0,35	2,51	0,06	0,55	1,420	31,0
348	1610	900	1,468	0,821	112	63	1,95	0,10	0,34	2,31	0,06	0,54	1,441	29,8
353	1570	860	1,432	0,785	109	60	1,85	0,09	0,31	2,19	0,05	0,49	1,461	28,5
358	1530	810	1,396	0,739	107	56	1,76	0,08	0,27	2,09	0,05	0,43	1,482	27,3

$U_2 = \varkappa_2 x_2^2/2$. Assuming that $x \approx d$, where d is the interatomic spacing, which is equal to 1.54 Å for C—C and 1.08 and 1.78 Å for H—H and H—Cl respectively, we determine U', U_1, and U_2. As the calculations show, the interaction energy U_1 is unimportant as compared with U' and U_2 ($U'/U_1 \approx 50$; $U_2/U_1 \approx 10$). Taking into account the thermal motion of the structural elements, we find its energy as $U_0 = i/2\ kT$. Then the total energy of the interacting structural elements is equal to

$$U = U_0 + U' + U_1 + U_2 = \frac{i}{2} kT + \frac{\beta x^2}{2} + \frac{\varkappa_1 x_1^2}{2} + \frac{\varkappa_2 x_2^2}{2}. \tag{7}$$

The results obtained (Tables 2 and 3) show that the interaction energy of the system depends on the PG concentration and temperature. At a filler content of 1-2% by vol. U has a maximum, and on the interval $\varphi \geq 10\%$ by vol. is observed to grow strongly. An analysis of the temperature dependence shows that as the temperature rises, the interaction energy decreases, and its temperature dependence can be controlled by means of the PG content.

Starting from the data on the propagation velocity of an ultrasonic wave in the system, we will determine the thermophysical properties of the PVC composition.

For this purpose we divide the spectral distribution density into two components [5]:

$$\rho(\omega) = \rho_l(\omega) + 2\rho_t(\omega), \tag{8}$$

where

$$\rho_l = \frac{V}{2\pi^2 v_l^3}\,\omega^2 \text{ and } \rho_t = \frac{V}{2\pi^2 v_t^3}\,\omega^2,$$

and normalize each part on N:

$$\int_0^{\omega_D^l} \rho_l(\omega)\,d\omega = N, \quad \int_0^{\omega_D^l} \rho_t(\omega)\,d\omega = N.$$

Then the specific heat (C_V) can be determined as

$$C_V = Nk\,D\left(\frac{\Theta_D^l}{T}\right) + 2Nk\,D\left(\frac{\Theta_D^t}{T}\right), \tag{9}$$

where

$$\Theta_D^l = \frac{\hbar(6\pi^2 N)^{1/3} v_l}{kV^{1/3}}; \quad \Theta_D^t = \frac{\hbar(6\pi^2 N)^{1/3} v_t}{kV^{1/3}}$$

are the characteristic Debye temperatures.

The calculations show that as the temperature rises, the Θ_D^ℓ and Θ_D^t of the PVC systems tend to decrease. Typically, over the entire temperature range investigated $\Theta_D^t < \Theta_D^\ell$. Furthermore, it should be noted that θ_D^ℓ and θ_D^t are also functions of the filler concentration in the system. On the range 10-2% by vol. PG the quantities θ_D^ℓ and θ_D^t vary by 18 and 23 K respectively.

As follows from the data presented in Fig. 2, on the interval 290-370 K the C_V values of the PVC systems calculated from relation (9) are close to the experimental values. The C_V of the system varies only slightly as the filler concentration increases on the interval investigated. This also finds confirmation in the experimental dependence of C_V on φ.

We will calculate the thermal conductivity of the poler system taking into account the fact that the structure of an amorphous polymer is a set of subsystems of constantly increasing complexity, statistically distributed in the system relative to the heat flux, energy being exchanged between them by contact heat conduction. We assume that the heat transfer is associated with the transfer of energy along the main valence chain of the micromolecule by longitudinal phonons, with velocity v_ℓ, and by energy exchange between side-chain atoms or groups of atoms and between neighboring macromolecules attributable to transverse phonons with velocity v_t [11, 12].

We assume that the polymer matrix is homogeneous and isotropic, that there are no internal heat sources, and that the time of action of the temperature field on the system investigated $t \ll \tau_i$, where τ_i is the finite lifetime of the structures investigated; then the effective thermal conductivity coefficient of the structural subsystem can be determined in accordance with the heat balance equation

$$C_V \rho V = \frac{2\sqrt{\lambda_l C_V \rho}}{\sqrt{\pi}} \sqrt{\tau} S, \tag{10}$$

where S is the cross section of the subsystem, and τ is the time taken by the system to reach equilibrium temperature. Solving equation (10) and using the rules of transition from subsystem to system [13], we obtain

$$\lambda_l = \frac{\pi}{12} C_V \rho v_l l, \tag{11}$$

where ℓ is the mean free path for longitudinal phonons. Considering that in the propagation of thermal energy each structural subsystem is characterized by the dissipative energy losses (Q_t) associated with the side groups or branches of the macromolecules, we determine the thermal conductivity in this direction (λ_t) as [12]:

$$\lambda_t = \frac{\rho v_t C_V a}{8}, \tag{12}$$

where a is the effective cross section of the subsystem.

On the basis of relations (11) and (12), the thermal conductivity coefficient of flexible-chain amorphous polymers and their systems will be:

$$\lambda = C_V \rho \left(\frac{\pi}{12} v_l l + \frac{a v_t}{8} \right). \tag{13}$$

An analysis of the results obtained shows that the calculated values of the thermal conductivity and the experimental data are in satisfactory agreement. Only on the filler concentration interval 5-20% by vol. is the value of λ observed to increase (Fig. 2).

The properties of PVC can be controlled by using waste from phosphoric acid and (or) mineral fertilizer production in the form of high-dispersity phospho-gypsum.

NOTATION

v_ℓ and v_t are the longitudinal and shear strain rates; ω is the investigation frequency; ρ is the density; α_ℓ and α_t are the longitudinal and shear wave absorption coefficients; E', μ', and K' are the real parts of the longitudinal, shear, and compression moduli; ω_D^ℓ and ω_D^t are the characteristic Debye frequencies for the longitudinal and shear waves; U is the total energy of the interacting elements; $\rho(\omega)$ is the spectral distribution density; $D\left(\frac{\Theta_D^l}{T}\right)$ and $D\left(\frac{\Theta_D^l}{T}\right)$ are Debye functions; C_V is the specific heat; and λ is the thermal conductivity coefficient.

LITERATURE CITED

1. Yu. S. Lipatov (ed.), Physcicochemistry of Multicomponent Polymer Systems, Vol. 1, Filled Polymers [in Russian[, Kiev (1986).
2. Z. P. Shul'man, B. M. Khusid, E. A. Zal'tsgendler, et al., "Thermal processes and reaction kinetics of oligomeric compositions," Minsk (1988) (Preprint, Institute of Heat and Mass Transfer, Academy of Sciences of the Belorussian SSR).
3. L. N. Novichenok and Z. P. Shul'man, Thermophysical Properties of Polymers [in Russian], Minsk (1971).
4. Yu. S. Lipatov, N. A. Bordyuk, O. M. Voloshin, and B. S. Kolupaev, Plast. Massy, No. 8, 30-32 (1988).
5. B. S. Kolupaev, Relaxation and Thermal Properties of Filled Polymer Systems [in Russian], S. Ya. Frenkel' (ed.), Lvov (1980).

6. I. A. Chaban, Akust. Zh., No. 1, 102-110 (1965).
7. B. S. Kolupaev, B. P. Dem'yanyuk, B. I. Muka, and N. A. Bordyuk, Kompozits. Polimer. Materialy, No. 23, 20-23 (1984).
8. J. A. Manson and L. H. Sperling, Polymer Blends and Composites, Plenum Publ., N.Y. (1976).
9. T. Ya. Kinus, A. V. Roze, and I. G. Zhigun, Statistical Testing Methods for Reinforced Plates [in Russian], Yu. M. Ternopol'skii (ed.), Riga (1972).
10. B. Wunderlich and G. Bauer, Heat Capacity of Linear Polymers [Russian translation], Moscow (1972).
11. B. S. Kolupaev and N. A. Bordyuk, Vysokomolek. Soedin., Ser. A, 23, No. 7, 1499-1504 (1981).
12. B. S. Kolupaev, N. A. Bordyuk, and Yu. S. Lipatov, Kompozits. Polimer. Materialy, No. 19, 3-7 (1983).
13. L. D. Landau and E. M. Lifshitz, Elasticity Theory, Pergamon Press (1987).

DAMPING OF THE MECHANICAL VIBRATIONS OF A PIEZOELECTRIC ELEMENT BY SENSITIVE COATINGS

V. E. Savchenko

UDC 551.508.8.082.73:519.2

A method of calculating the viscoelastic properties of moisture-sensitive polymer films deposited on the piezoelectric element of a quartz resonator is proposed.

In quartz atmospheric humidity sensors that employ the energy measuring principle the role of moisture-sensitive element is played by thin polymer films deposited on the piezoelectric element of the quartz resonator [1, 2]. The change in the damping properties of the polymer film as a result of the sorption of water vapor from the air leads to a change in the dissipation of the mechanical energy of the quartz resonator and its equivalent electrical resistance. Sensors of this kind have been called dissipative quartz mechanical energy transducers (DQMET).

The sensitivity of DQMET to a nonelectric quantity such as atmospheric humidity depends on the damping capacity of the sensitive coatings deposited on the piezoelectric element of the quartz resonator and its dependence on the parameter being monitored. The output parameter of the DQMET is its equivalent resistance R [3]:

$$R = K_0 \eta_f \Delta_f, \tag{1}$$

where K_0 is the conversion coefficient of the piezoelectric element, ohm·sec/kg, and η_f and Δ_f are the viscosity, Pa·sec, and thickness, m, of the sensitive film.

The viscosity of the film (internal friction) varies with the parameter monitored, for example the humidity of the air, affecting the dissipation of the elastic vibration energy of the piezoelectric element and causing a corresponding change in the equivalent resistance of the quartz resonator. If the viscosity of the sensitive polymer is too great, there will be a decrease in its damping capacity expressed in a decrease in the equivalent resistance of the DQMET with increase in viscosity, which limits the range of application of expression (1). In our opinion, this effect is attributable to relaxation processes in the polymer film.

For DQMET intended to serve as atmospheric humidity sensors it is proposed to use a polyamide (Kapron, nylon-6) coating [2]. We will consider the variation of the damping properties of a polyamide filament with relative humidity when vibrations are excited in the filament at a frequency of 100 Hz. Figure 1 shows the loss modulus $E'' = \omega\eta$ and the modulus of elasticity E' of the filament as functions of the relative humidity ϕ [4]. The loss modulus has a maximum at 60% relative humidity. With further increase in humidity the loss modulus decreases. We will explain this effect from the standpoint of relaxation theory.

Ivanov Scientific-Research Experimental-Design Machine-Building Institute. Translated from Inzhenerno-fizicheskii Zhurnal, Vol. 60, No. 6, pp. 994-999, June, 1991. Original article submitted May 5, 1990.