Hyperdeform Polymers Materials Vibration Analyses Set of Machines

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***Abstract*-** The hyperdeformable materials are increasingly being used in the construction of machines. It is a very diverse group of construction materials, which may include, among others: elastomers. The observed trends reflect the expectations of manufacturers, buyers and users on the properties of new polymer materials. Priority research are conducted in the field of cellular polyurethane elastomers. In this work, an analysis hyperdeformable properties of polymeric materials. The use of such a material is expanding, because of their advantages such as high durability, low density, high toughness, corrosion resistance factors influence the work (e.g., oils, concentrated acids, bases, alcohols) and the environment , (e.g., UV) in a wide range of operating temperatures. The development of applications affected by the availability of processing technology and the possibility of multiple processing.

***Keywords*:** Elastomers, Polymers foam, Oscillation, Large reversible deformation.

1. Introduction

The hyperdeformable materials are increasingly being used in the construction of machines, equipped with systems and energy dissipation units, such as buffers safety in cars or lifts (elevators), reducing or eliminating the effect of unwanted vibrations, for example, in automobile suspension systems - a set of shock absorbers suspension , air systems - the type of shimmy dampers, integrated energy and sound barriers used in road, parts of car seats and wheelchairs for people with impaired movement. It is a very diverse group of construction materials, which may include, among others: elastomers.

Very promising information about the work to produce new materials - called future materials by Elastogran BASF Gruppe (2002). The observed trends reflect the expectations of manufacturers, buyers and users on the properties of new polymer materials. Priority research are conducted in the field of cellular polyurethane elastomers by Bauer (1991).

The group of elastomeric materials include derivatives of natural and synthetic rubber and thermoplastic elastomers. Thermoplastic elastomers TPE (Polyester Thermoplastic Elastomer- TPE) are polymeric materials with high reversible relative deformation, just like vulcanized rubber, and the processing is performed by methods appropriate for thermoplastics characterize by Holden et al. (1996). There are conducted intensive research into new structures TPE - Balta et al. (2000) and Prowans et al. (2002).

Reversible deformation entropic rubber elastomers are responsible busy sections of rubber chains combined chemical nodes.Reversible elastic strain differ from the mechanism of elastic deformation and the consequent relaxation time. The term is meant elastic strain deformation resulting from the combined changes of interatomic distances and angles valence under the force of deformation. The elastic deformation is determined by straightening of the polymer chains in the form of their conformational equilibrium. Network nodes vulcanized rubber chemical and phase thermoplastic elastomers Hard constitute a point of reference deforming the flexible chains and directly affect the limit of plastic deformation. Thermoplastic elastomers are multiphase polymer systems. The polymeric material has the characteristics of a thermoplastic elastomer when:

— Consists of at least two phases (hard and soft) which differ considerably the glass transition temperatures (T_{g1}, T_{g2}) or glass transition temperature (T_g) and melting (T_m),

— A soft phase formed polymer chains (segment) with a high molecular mobility (Pożdżał et al. (1999)).

Thermoplastic elastomers provide the stabilization of the phase structure of the interfacial connections, which may be by covalent bonds, in the case of phase-separating block copolymers or physical interactions of various types in the case of polymer blends.

In this work, an analysis hyperdeformable properties of polymeric materials. The use of such a material is expanding, because of their advantages such as high durability, low density, high toughness, corrosion resistance factors influence the work (e.g., oils, concentrated acids, bases, alcohols) and the environment , (e.g., UV) in a wide range of operating temperatures. The development of applications affected by the availability of processing technology and the possibility of multiple processing.

2. Analytical Analyses

Analysis of the adoption of real hyper deformable material properties required in accordance with the conclusions of the paper by Osiński (1978) introduce the differential equation function for loading and unloading stages. The equations describing both steps are adopted polynomial functions (models of Moonneya-Rivlin and Yeoh) or exponential - Ogden models and its modifications.

For the analysis an equation for an oscillatory circuit to an elastic element made of an incompressible elastomer including the first member to develop (1):

$$m \cdot \ddot{x}[t] + k \cdot (x[t] + l - l^3 * (x[t] + l)^{-2}) = F[t], \tag{1}$$

where:

k – modulus (equal to the value of the constant C_{11}),

m   – mass of element.

It is also assumed that there is a viscous damping. The vibrations are described by the equation (2)

$$m \cdot \ddot{x}[t] + b \cdot \dot{x}[t] + k \cdot (x[t] + l - l^3 \cdot (x[t] + l)^{-2}) = F[t], \tag{2}$$

where:

b   – damping modules.

A equivalent range of work of elastomer in region of compression load was a input function (3):

$$F[t] = F \cdot \sin[\Omega * t] - F, \tag{3}$$

where:

Ω – the frequency of the exciting force,

$F(t)$ – variable during the forcing function.

For considerations adopted cellular elastomer of closed cell Cellasto. Material properties are defined using the experimental results presented in monograph by Żach (2013). After this transformation (4) were obtained (5÷6):

$$x[t] = A\sin[\Omega \cdot t] + B\cos[\Omega * t], \tag{4}$$

$$\dot{x}[t] = A\Omega\cos[\Omega \cdot t] - B\Omega\sin[\Omega \cdot t], \tag{5}$$

$$\ddot{x}[t] = -B\Omega^2\cos[\Omega \cdot t] - A\Omega^2\sin[\Omega \cdot t]. \tag{6}$$

After substitution(4÷6) do (2) obtained (7):

$$-(A\Omega^2\sin[\Omega \cdot t] + B\Omega^2\cos[\Omega \cdot t]) + \frac{b}{2m} \cdot (A\Omega\cos[\Omega \cdot t] - B\Omega\sin[\Omega \cdot t]) + 2\frac{k}{m}$$
$$\cdot \left(\frac{A\sin[\Omega \cdot t] + B\cos[\Omega \cdot t] + l}{l^2} - \frac{l^3}{(A\sin[\Omega \cdot t] + B\cos[\Omega \cdot t] + l)^2}\right) \qquad (7)$$
$$= \frac{F\sin[\Omega \cdot t]}{m}$$

Adopted marking:

$$c = \frac{2b}{m}, \omega_0{}^2 = \frac{k}{m}, \alpha = \frac{F_w}{m} \qquad (8)$$

where:

ω_0 — frequency wheel.

Equation (7) referred to the unit of mass takes the form (9):

$$-(A\Omega^2\sin[\Omega \cdot t] + B\Omega^2\cos[\Omega \cdot t]) + c * (A\Omega\cos[\Omega \cdot t] - B\Omega\sin[\Omega \cdot t]) + 2\omega_0{}^2$$
$$* \left(\frac{A\sin[\Omega \cdot t] + B\cos[\Omega * t] + l}{l^2} - \frac{l^3}{(A\sin[\Omega \cdot t] + B\cos[\Omega \cdot t] + l)^2}\right) \qquad (9)$$
$$= \alpha \cdot \sin[\Omega \cdot t]$$

Looking for solutions, according to the method of developing into a power series (small parameter) propose by Osiński (1986) and implement by Store et al. (1993), to a first approximation adopted solution (10):

$$-Al^3\alpha - A^2l^3\Omega^2 - B^2l^3\Omega^2 - \frac{1}{2}ABl^2\alpha\cos[\Omega \cdot t] + \frac{1}{4}A^3cl^2\Omega\cos[\Omega \cdot t] + \frac{1}{4}AB^2cl^2\Omega\cos[\Omega \cdot t]$$
$$+ Acl^4\Omega\cos[\Omega \cdot t] - \frac{3}{4}A^2Bl^2\Omega^2\cos[\Omega \cdot t] - \frac{3}{4}B^3l^2\Omega^2\cos[\Omega \cdot t]$$
$$- Bl^4\Omega^2\cos[\Omega \cdot t] + Al^3\alpha\cos[2\Omega \cdot t] + 2ABcl^3\Omega\cos[2\Omega \cdot t]$$
$$+ A^2l^3\Omega^2\cos[2\Omega \cdot t] - B^2l^3\Omega^2\cos[2\Omega \cdot t] + \frac{1}{2}ABl^2\alpha\cos[3\Omega \cdot t]$$
$$- \frac{1}{4}A^3cl^2\Omega\cos[3\Omega \cdot t] + \frac{3}{4}AB^2cl^2\Omega\cos[3\Omega \cdot t] + \frac{3}{4}A^2Bl^2\Omega^2\cos[3\Omega \cdot t]$$
$$- \frac{1}{4}B^3l^2\Omega^2\cos[3\Omega \cdot t] - \frac{3}{4}A^2l^2\alpha\sin[\Omega \cdot t] - \frac{1}{4}B^2l^2\alpha\sin[\Omega \cdot t] - l^4\alpha\sin[\Omega \cdot t]$$
$$- \frac{1}{4}A^2Bcl^2\Omega\sin[\Omega \cdot t] - \frac{1}{4}B^3cl^2\Omega\sin[\Omega \cdot t] - Bcl^4\Omega\sin[t\Omega]$$
$$- \frac{3}{4}A^3l^2\Omega^2\sin[t\Omega] - \frac{3}{4}AB^2l^2\Omega^2\sin[t\Omega] - Al^4\Omega^2\sin[\Omega * t] - Bl^3\alpha\sin[2\Omega * t]$$
$$+ A^2cl^3\Omega\sin[2\Omega \cdot t] - B^2cl^3\Omega\sin[2\Omega \cdot t] - 2ABl^3\Omega^2\sin[2\Omega \cdot t] \qquad (10)$$
$$+ \frac{1}{4}A^2l^2\alpha\sin[3\Omega \cdot t] - \frac{1}{4}B^2l^2\alpha\sin[3\Omega \cdot t] + \frac{3}{4}A^2Bcl^2\Omega\sin[3\Omega \cdot t]$$
$$- \frac{1}{4}B^3cl^2\Omega\sin[3\Omega \cdot t] + \frac{1}{4}A^3l^2\Omega^2\sin[3\Omega \cdot t] - \frac{3}{4}AB^2l^2\Omega^2\sin[3\Omega \cdot t]$$
$$+ 3A^2l\omega_0^2 + 3B^2l\omega_0^2 + 4l^3\omega_0^2 + \frac{3}{2}A^2B\cos[\Omega \cdot t]\omega_0^2 + \frac{3}{2}B^3\cos[\Omega \cdot t]\omega_0^2$$
$$+ 6Bl^2\cos[\Omega \cdot t]\omega_0^2 - 3A^2l\cos[2\Omega \cdot t]\omega_0^2 + 3B^2l\cos[2\Omega \cdot t]\omega_0^2$$
$$- \frac{3}{2}A^2B\cos[3\Omega \cdot t]\omega_0^2 + \frac{1}{2}B^3\cos[3\Omega \cdot t]\omega_0^2 + \frac{3}{2}A^3\sin[\Omega \cdot t]\omega_0^2$$
$$+ \frac{3}{2}AB^2\sin[\Omega \cdot t]\omega_0^2 + 6Al^2\sin[\Omega \cdot t]\omega_0^2 + 6ABl\sin[2\Omega \cdot t]\omega_0^2$$
$$- \frac{1}{2}A^3\sin[3\Omega \cdot t]\omega_0^2 + \frac{3}{2}AB^2\sin[3\Omega \cdot t]\omega_0^2 = 0$$

There was a significant non-linearity, which is characterized in that the amplitude does not reach an infinitely large value for the finite frequency by Żach (2013). With an increase in the amplitude of the resonance zone moves towards higher frequencies. Figure 1 contains a non-linear dependence of resonance frequency of the amplitude curve in the form of the core, obtained for foamed polyurethane structure Cellasto 550.

Fig. 1. Dependence of the non-linear natural frequency and the amplitude of the vibration sample chart

The results of numerical simulations show cyclical nature of the polymer structure.

3. Numerical Analyses

The effect of nonlinear damping, introduced under the thesis work of the previous chapters, pointing to the need for an individual description of the individual steps, ie loading and unloading. For this purpose, equation (2) was modified by introducing a record defining the attenuation values for the different phases of the individual element, in the form (11):

$$m \cdot \ddot{x}[t] + c1 \cdot \dot{x}[t] \cdot J[\dot{x}[t]] + c2 \cdot \dot{x}[t] \cdot J[-\dot{x}[t]] + k \cdot (x[t] + l - l^3(x[t] + l)^{-2}) = F[t] \qquad (11)$$

where:

$$J = \begin{Bmatrix} 1 & \dot{x} > 0 \\ 0 & \dot{x} \leq 0 \end{Bmatrix}$$ – zero ones function described the relation,

c_1, c_2 – the attenuation coefficients, wherein $c_1 \ll c_2$.

Presents the results of numerical simulations obtained for different operating conditions element: the nature of changes in displacement over time (figure 2): without damping (a) with damping (b), the asymmetric damping (c) for the assumed conditions: temperature +24°C and speed 17 mm/s and the velocity variation over time (figure 3):without damping (a) with damping (b), the asymmetric damping (c) for the assumed conditions, temperature −18°C and speed 50 mm/s.
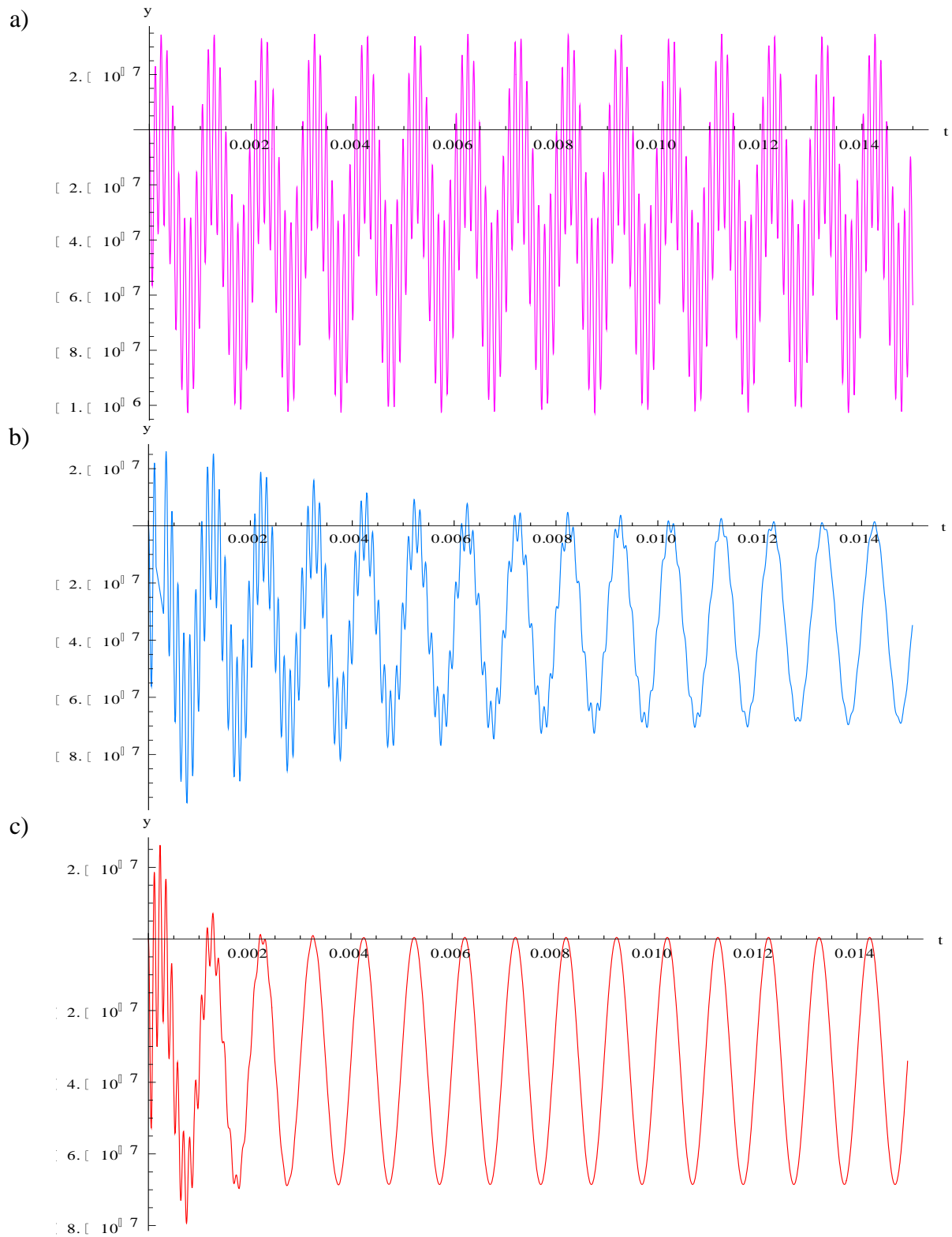
Fig. 2. The displacement in time for a steady state T= +24ºC i v=17 mm/s: (a) without damping, (b) with damping, (c) with unbalanced damping
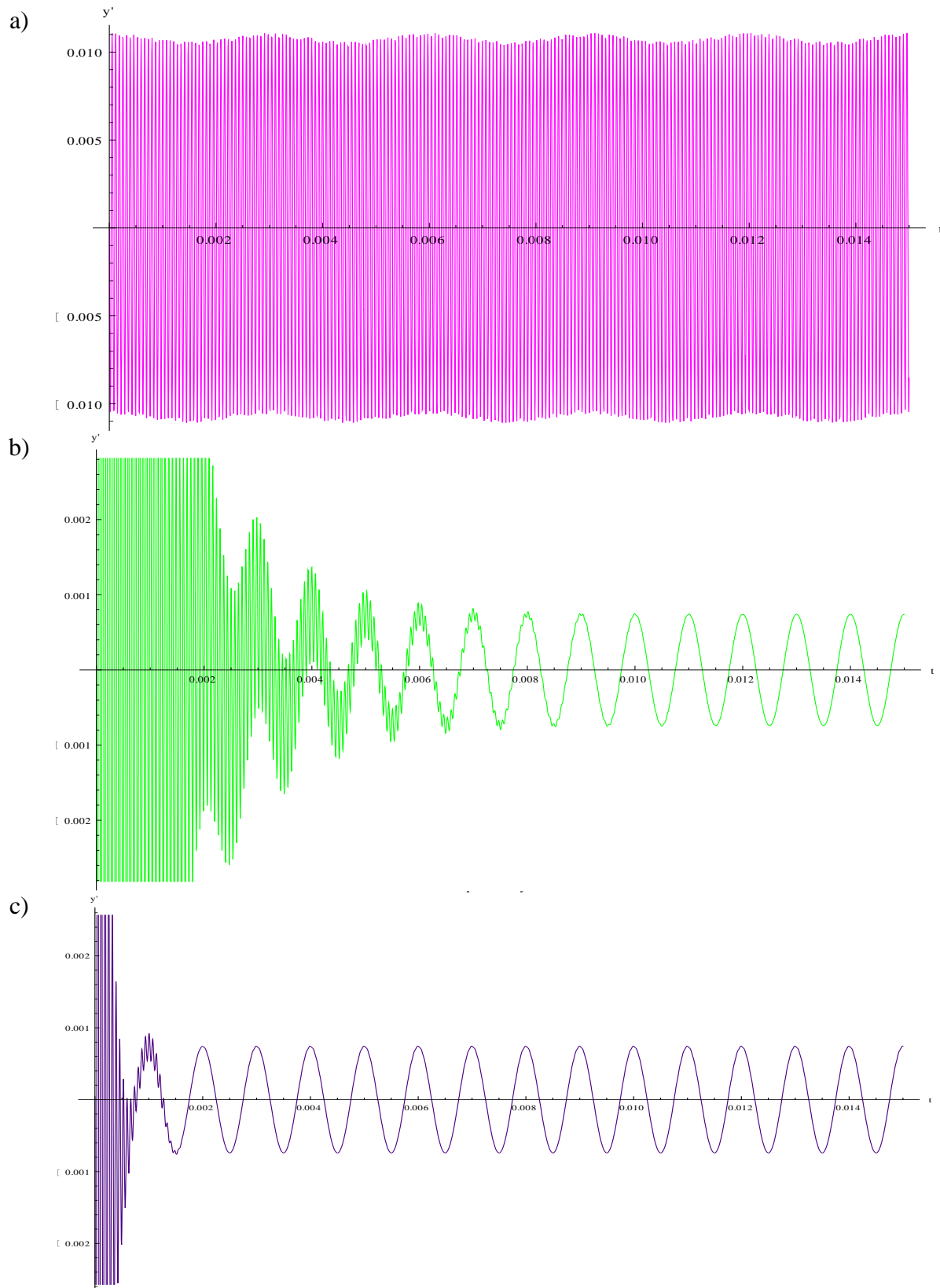
Fig. 3. Changing the speed in time for the agreed conditions T= −18 i v=50 mm/s: (a) without damping, (b) with damping, (c) with unbalanced damping

4. Conclusion

It has been shown that the behavior of the system constructed on the basis of the polymeric member, and in particular hyperdeformable material, such as polyurethane elastomer, is largely dependent on the temperature of the body, as well as the deformation speed. With decreasing temperature and increasing speed is a marked increase in vibration damping.

Compared to the responses obtained by means of numerical simulation for the elastomeric member. The results were obtained by considering a uniform description of attenuation for the whole process of deformation and defined as unbalanced individual to individual stages, including loading and unloading. It was found that the latter approach allows for solutions closer to the real, comparable with experimental results.

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