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Characterization of Material Viscoelasticity at Large Deformations

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Abstract:
Mechanical properties of various technological materials at large deformations are proposed to characterize by means of some generalized parameters obtained at large oscillation strains but not related to any definite rheological equations. The base for the analysis is the Lissajous-Bowditch figures in two coordinate systems – "stress – deformation" and "stress derivative with respect to the phase angle – deformation." An area of the first of these figures provides the well known integral estimation of dissipative losses in the deformation cycle while the second one presents the new integral measure of the matter's elasticity. The correlation between the proposed integral estimations of the "averaged" dynamic modulus and the values found in using Fourier and Chebyshev series was demonstrated. This integral method was applied for three suspensions of various types. The obtained results allowed for viewing the type of non-linearity: pseudo-plasticity or dilatancy, stiffening or softening, as functions of deformation.

Key words:
viscoelaticity, non-linearity, large strain, suspensions

1 INTRODUCTION

Measuring viscoelastic properties of various technological materials, including colloid systems, gels, polymeric compositions (solutions, melts, multicomponent mixtures) and so on in periodic oscillations is one of the most important and widely used methods of their characterization. This method allows us to find relaxation modes of matter in very wide frequency-temperature ranges [1, 2]. According to the basic relationships of linear viscoelasticity [2 – 4], results of these measurements are related to the relaxation spectrum of a matter and allow us to calculate stress vs. deformation dependencies at any loading mode. The theory of viscoelasticity in its classical version relates to the range of low deformations and stresses strictly proportional to deformations at any time, though different versions of non-linear generalization of the theory are also known [5]. During the last decade, the interest for measuring non-linear viscoelastic properties of different matters by creating large amplitude oscillatory strain (LAOS) increased sharply.

It is necessary to stress that speaking about large deformations, two phenomena different by their physical sense are meant [6, 7]. Firstly, large (in comparison with one) deformations lead to geometrical non-linearity. In this case, the region of amplitudes corresponding to linear behavior may appear rather wide, especially for rubbery materials. Secondly, large deformation (or more exact, large stresses) can lead to physical non-linearity. It consists in rupture of the structure of a matter. This is characteristic, e.g. for suspensions where the inherent structure is built from hard and rigid dispersed particles. In this case, non-linear behavior is observed already at low (in comparison with one) deformations and develops rather abruptly.

Different approaches to treating the results of LAOS experiments have been proposed and discussed in current publications. The most evident approach consists in estimating non-linear material properties are analyzed as though they would be measured in a linear region. Then the values of storage and loss modulus are used and just these parameters are given by the software of industrial devices [8 – 11]. It is evident that it is unacceptable because these values are not adequate and insufficient for characterization of the properties of a sample. Then the rather evident approach to treating non-linear data in LAOS consists in the presentation of a non-linear response via the Fourier series (e.g. [12 – 18]):

$$\sigma(\gamma_o,\omega,t)=\gamma_o\sum_{n=1}^{N}\left[G_n^{'}sin(n\omega t)\right]+i\left[G_n^{''}cos(n\omega t)\right] \quad (1)$$

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