Acoustical properties of the wool felt

Anatoli Stulov* **and Dmitri Kartofelev**†

*†Institute of Cybernetics at Tallinn University of Technology
Akadeemia tee 21, 12618 Tallinn
ESTONIA
e-mail of corresponding author†: dima@cs.ioc.ee
Oral Presentation Preferred

ABSTRACT

The propagation of longitudinal deformation waves through a felt material is investigated. The felt made of wool is a very miraculous substance indeed. Almost two hundred years this material is used for piano hammer manufacturing. The piano hammer felt is a unique and indispensable coating matter of wooden mallets. Experimental testing of piano hammers, which consist of a wood core covered with several layers of compressed wool felt demonstrates, that all hammers have a hysteretic type of the force-compression characteristics, which are essentially nonlinear [1, 2]. A main dynamic feature of the felt is that the slope of the force-compression characteristic is strongly dependent on the rate of loading. These phenomena require that the felt made of wool is a microstructured material possessing history-dependent properties, i.e. a material with memory. The nonlinear hereditary models of the felt that are in a good agreement with experimental data were presented in [2, 3]. The four-parameter hereditary model of the felt was derived in the form

$$F(u(t)) = F_0\left[u^p(t) - \frac{\varepsilon}{\tau_0}\int_0^t u^p(\xi)\exp\left(\frac{\xi - t}{\tau_0}\right)d\xi\right]. \tag{1}$$

Here $F(u)$ is the acting force and u is the felt compression. The instantaneous stiffness F_0 and compliance nonlinearity exponent p are the elastic parameters of the felt, and hysteresis amplitude ε and relaxation time τ_0 are the hereditary parameters.

According to this model and experimental data, the duration of contact between the hammer and the string decreases with increasing of the striking velocity of the hammer. This means that the speed of the deformation wave, traveling from the contact point to the hammer kernel and back, increases with the growth of its amplitude.

To consider the longitudinal deformation waves propagation through a wool felt material, the constitutive equation of the felt was chosen in a form

$$\sigma(\epsilon) = E_d\left[\epsilon^p(t) - \frac{\varepsilon}{\tau_0}\int_0^t \epsilon^p(\xi)\exp\left(\frac{\xi - t}{\tau_0}\right)d\xi\right], \tag{2}$$

which corresponds to the hammer felt model. Here σ is the stress, $\epsilon = \partial u/\partial x$ is the strain, u is the displacement, and E_d is the dynamic Young's modulus.

By introducing the new nondimensional variables U, x, and t, and using the equation of motion, and constitutive equation (2) the third order nonlinear partial differential equation was derived

$$\frac{\partial}{\partial x}\left(\frac{\partial U}{\partial x}\right)^p - \frac{\partial^2 U}{\partial t^2} + \frac{\partial^2}{\partial x\partial t}\left(\frac{\partial U}{\partial x}\right)^p - \delta\,\frac{\partial^3 U}{\partial t^3} = 0\,. \tag{3}$$

This nondimensional equation describing the wave propagation in the felt material has only two independent nondimensional parameters: parameter of nonlinearity p, and $\delta = 1 - \varepsilon$.

Equation (3) is studied numerically by using a finite difference method. A bell-like pulse propagation is considered, and the influence of values of parameters p and δ on the changing of the pulse form is analyzed.

A relationship between the speed of deformation wave and its amplitude is obtained. The solution of the linear problem is also considered, and the rate of the wave attenuation in the felt material is estimated.

REFERENCES

[1] A. Stulov. Hysteretic model of the grand piano hammer felt. *J. Acoust. Soc. Am.*, **97**, 2577–2585, 1995.

[2] A. Stulov. Experimental and computational studies of piano hammers. *Acta Acoustica united with Acoustica*, **91**, 1086–1097, 2005.

[3] A. Stulov. Dynamic behavior and mechanical features of wool felt. *Acta Mechanica*, **169**, 13–21, 2004.