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ANALYSIS OF MEASUREMENT OF TEMPERATURE DEPENDENCE INSIDE RUBBER SAMPLE UNDER DYNAMIC HARMONIC LOAD

Šulc P., Pešek L., Bula V., Šnábl P., Cibulka J., Košina J.*

Abstract: *This work deals with the preparation and methodology of temperature measurement inside a rubber sample. In this paper, a rubber sample with temperature sensors is described and a description with a temperature measurement scheme under torsional dynamic stress with the possibility of measurement in a temperature chamber is proposed. Large torsional deformations are considered for harmonic torsional loads. The reason for these measurements is to determine the temperature dependence and sensitivity of the heat output parameters.*

Keywords: Heat flow, Temperature, Fourier equation, Heat conduction.

1. Introduction

Rubber-like materials are usually used as resilient machine elements, with different elastic, damping and also thermo-mechanical properties. For rubber materials unlike conventional structural materials under dynamic loading, a nonlinear time-varying behavior occurs due to the size of straining, creep, temperature and aging. Thermal together with mechanical time-variable loadings belong to one of the main causes of degradation of rubberlike materials. Therefore, we designed and built a device for dynamic torsion experiments on rubber samples with the possibility of placing in the temperature chamber Weiss T3 in our laboratory. The mechanical properties of rubbers were obtained on a phenomenological basis using continuum mechanics with respect to large deformations (up to 30 %). These mechanical rubber parameters were obtained from their identification by measuring the load torque, the angle of rotation of the test specimens for different harmonic loads and for different temperatures in the temperature chamber. Our aim is to show temperature dependence of deformation and dissipated energy of hard rubbers under torsional dynamic load (Pešek, 2007; Pešek, 2008; Šulc, 2012; Šulc, 2016; Šulc, 2017).

This paper deals with the preparation and methodology of temperature measurement inside a rubber sample. The reason for these measurements is to refine our temperature dependence of the tested parameters. Heat is shared between the sample and the environment in three basic ways, namely conduction, convection and radiation. Heat transmission is a portion of the specific internal energy from the first law of thermodynamics that crosses the boundaries of the body and is often considered only as a convective process expressed by the Fourier law. Generally, the heat transmission has a convective, dissipative and a part based on the bulk density of internal sources. The thermal processes in the rubber samples are quite complicated since in addition to the heat flow between the body and surroundings, heat is generated by transformation of dissipated mechanical energy, too.

Therefore, we proposed measuring the temperature dependence inside a rubber cylindrical sample with the possibility to deal with these stationary and non-stationary tasks by heat conduction and heat transfer to the surroundings. Using the energy balance equation of the sample where mechanical and thermal forms of energy take place simultaneously, we can evaluate the dissipated energy under dynamic loading of the sample, too.

* Ing. Petr Šulc, PhD., Ing. Luděk Pešek, CSc., Ing. Vitězslav Bula, Ing. Pavel Šnábl, Jan Cibulka, Ing. Jan Košina: Institute of Thermomechanics of the CAS, v. v. i., Dolejškova 1402/5, 182 00 Prague; CZ, sulc@it.cas.cz

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2. Experimental equipment and measurement procedure

The material to be examined is 85 Shore EPDM rubber. The sample has the shape of a cylinder with a diameter of 30 mm. The sample contains 3 temperature sensors made of type K thermocouples. Sample and sensors layout is shown in Fig. 1a. The sample is fixed to the torsion stand by means of chucks using steel clamping faces glued to both ends of rubber cylinder.

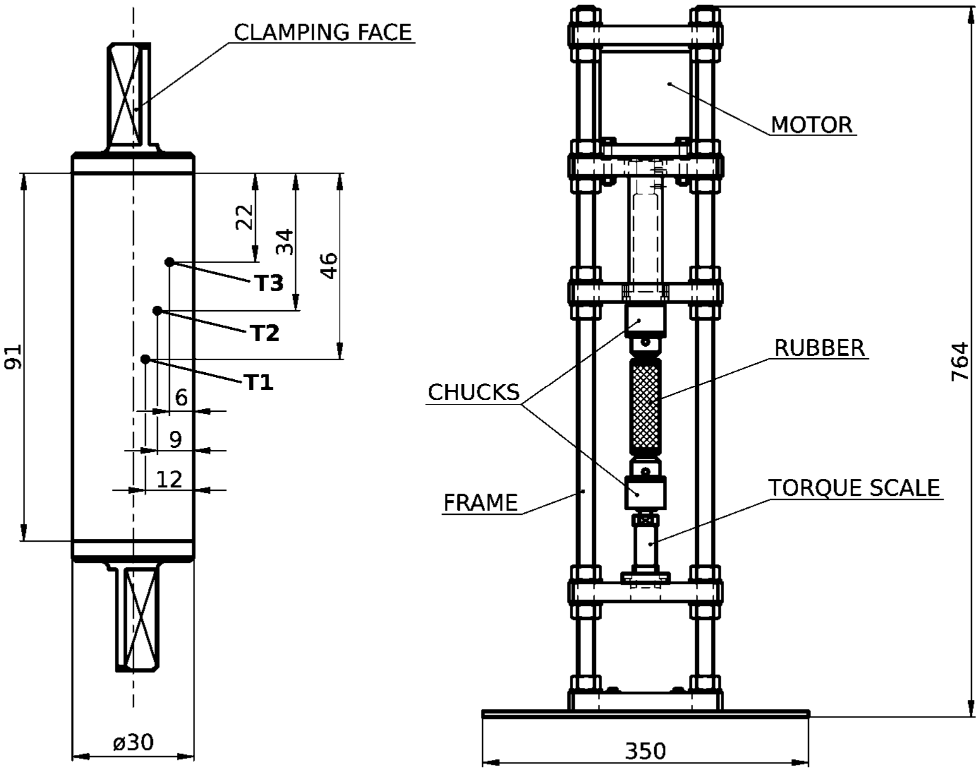

Fig. 1: a) Sample with 3 temperature sensors (on the left); b) torsion stend (on the right).

The torsion stend consists of a base frame on one side of which the servo motor TG drives TGN4-0510-10-320/T1XS4 is mounted. The motor twists a rubber sample over the chuck, which is connected via another chuck to a torque sensor attached to the other side of the base frame (Fig. 1b). The servo motor is powered by the Kollmorgen AKD-P00306-NBEC-E000 control unit. The torque sensor is realized by a load cell with strain gauges. The servo motor contains an encoder for measuring the actual rotation of the motor shaft.

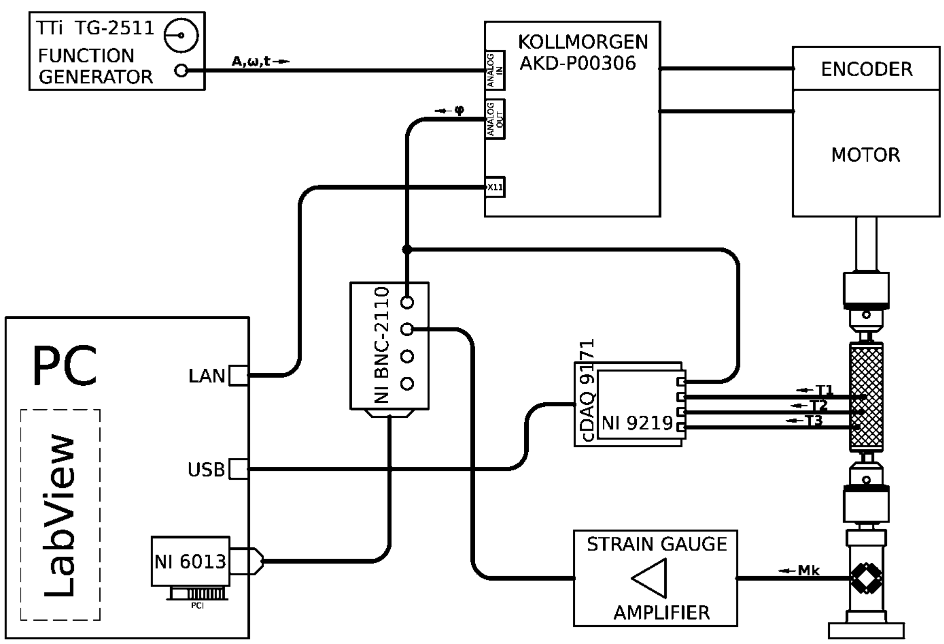

Fig. 2: Scheme of the experiment for measuring the displacement and the temperature.

The sample is loaded with a harmonic torque with amplitude of 1 to 10 Nm at a frequency of 2 to 5 Hz for a period of time of up to several tens of seconds. These parameters are set on the function generator, which supplies the control signal to the servo motor control unit. The controller setting mode is controlled by the Kollmorgen WorkBench software on the PC via the LAN Ethernet service port. The servo motor control unit provides the instantaneous angular rotation φ of the motor shaft from the encoder, which is also the angular deformation of the rubber sample. This angular rotation signal φ, together with the instantaneous load torque signal Mk from the torque sensor, is connected to the NI (National Instruments) BNC-2110 measurement break box and then connected to the NI 6013 measurement card connected to a PCI port on the PC. Three thermocouples located in the rubber sample are connected to a four-channel NI 9219 measuring card, which is attached to the NI cDAQ 9171 chassis connected to the USB port of the PC. The angular rotation signal of the motor shaft is connected to the fourth channel of this card. The signals from both cards are recorded on the PC using LabView software. Both measuring cards are connected to the PC via different ports (USB and internal PCI port) and at the same time each card records signals at different speeds. In order to check the synchronization of the recorded channels, the angular rotation signal of the motor shaft is split and recorded in parallel by both cards simultaneously - see Fig. 2.

3. Heat conduction equation

From the heat flow balance in the control volume for a non-stationary temperature field, we obtain a generally non-linear differential heat conduction equation, which can pass under certain assumptions into a linear heat conduction equation called the Fourier equation. If it is the stationary heat conduction, the time derivative of temperature is zero in this equation, where the temperature is therefore only a function of the coordinate. Non-stationary heat conduction problems lead to the solution of a partial differential equation, where coordinates and time are independent variables. Fourier's equation deals with both stationary and non-stationary heat conduction (Nožička, 1997, Šesták, 2004). General nonlinear differential equation of a non-stationary temperature field of a homogeneous isotropic solid body is based on the flow balance $\dot{Q}_{\mathrm{prod}} - \dot{Q}_{\mathrm{kond}} = \dot{Q}_{\mathrm{ak}}$ in the form

$$\mathrm{div}\left(\lambda\,\mathrm{grad}\,T\right) + \dot{q}_{\mathrm{prod}} = c_p \rho \frac{\partial T}{\partial \tau} \tag{1}$$

If there are c_p, ρ and λ constant in equation (1) then is called Fourier equation and has this shape

$$\frac{\partial T}{\partial \tau} = a\,\mathrm{div}\,\mathrm{grad}\,T + \frac{a}{\lambda}\dot{q}_{\mathrm{prod}}\left(\vec{r},\tau\right) \tag{2}$$

where $a = \dfrac{\lambda}{c_p \rho}$ $\left(\mathrm{m^2\,s^{-1}}\right)$ is the thermal conductivity. This equation has special cases of diffusion ($\dot{q}_{\mathrm{prod}} = 0$), Poisson ($\dot{q}_{\mathrm{prod}} \neq 0; \dfrac{\partial T}{\partial \tau} = 0$) and Laplace ($\dot{q}_{\mathrm{prod}} = 0; \dfrac{\partial T}{\partial \tau} = 0$) equations. The partial differential equations of heat conduction are completed by two boundary conditions:

a) initial and

b) boundary conditions (Dirichlet, Neumann and Fourier).

4. Conclusion

The aim of these measurements is to evaluate heat source due to dissipated energy in the rubber obtained from the heat flux density using the measured temperature dependences inside our sample at different diameters. We want to compare heat flows without a source and subsequently with a heat source in the form of torsion harmonic load of our cylindrical sample. The heat power that passes into the environment can be described by Fourier's law. Then we want to relate the heat power output with the dissipated power at harmonic load.

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