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WYZNACZANIE CHARAKTERYSTYK MATERIAŁOWYCH MIESZKA GUMOWO-KORDOWEGO SPRZĘGŁA PNEUMATYCZNEGO

Streszczenie: W artykule przedstawiono metodę wyznaczania charakterystyk materiałowych mieszka gumowo-kordowego, stanowiącego wyposażenie sprzęgła pneumatycznego. Opracowano w tym celu model dyskretny mieszka przy użyciu metody elementów skończonych (MES). W celu określenia parametrów materiału mieszka przeprowadzono jego próby wytrzymałościowe. Charakterystyki materiałowe mieszka sporządzono, wykorzystując tzw. zależność Mooney'a-Rivlina, stosowaną w przypadku materiałów silnie odkształcalnych, a więc silnie nieliniowych. W artykule zaprezentowano wyniki badań mieszka, stanowiącego wyposażenie różnicowego sprzęgła pneumatycznego z autoregulacją.

Słowa kluczowe: połączenie pneumatyczne oraz elastyczne, właściwości materiału

DEFINING OF MATERIAL CHARACTERISTICS FOR FLEXIBLE ELEMENT IN PNEUMATIC FLEXIBLE COUPLING

Summary: This paper deals with to describe the material properties of rubber-cord elastic element necessary for assessment of pneumatic-flexible element by means of Finite Element Method (FEM). For solution of deformation and stress analysis of pneumatic-flexible member is necessary to create a computer model. Here it is necessary to identify and define the material properties of the investigated pneumatic-flexible element. With regard to elasticity of rubber it is necessary for solution of tasks of deformation and stress analysis by help of pneumatic-flexible element to consider in the program the non-linearity of material and solve the non-linear task by means of FEM. Time curves are used for description of history of loading in the FEM program.

Keywords: pneumatic flexible coupling, elasticity, material properties, elasticity material.

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1. Introduction

For solution of deformation and stress analysis of pneumatic-flexible element by means of the Finite Element Method (FEM) it is necessary to create a computer model. Here it is necessary to determine and define the material properties of investigated rubber-cord elastic element. With regard to the elasticity of rubber which differs from elasticity of ideal crystalline substances it is necessary at calculation by means of FEM to consider the material non-linearity and precisely define the material properties of flexible element. The mechanical properties of rubbers are described by a mathematical model, which is not based on the molecular structure.

2. Differential pneumatic flexible coupling with autoregulation

In the field of minimization of torsional vibration, by which is assured the appropriate tuning of torsional vibrations of mechanical system the attention of authors is presently concentrated on development and application of pneumatic-flexible couplings, i.e. pneumatic tuners of torsional vibrations [1]. For correct design of coupling it is necessary to know the properties of couplings in more detail. Generally it can be said that the flexible coupling is characterised by strength, operational and dilatational properties [2]. At determination of dilatational properties it is necessary to focus on deformation criteria of flexible elements of the coupling, in case of pneumatic – flexible couplings from deformation criteria of pneumatic-flexible element (bellows).
The problem is solved for pneumatic-flexible element of differential pneumatic flexible coupling with autoregulation. The basic principle of activity is protected by patent [2].

3. Elasticity of rubber

Crystalline substances and metals are deformed practically immediately in case of influence of external forces and between the force and deformation is a direct proportion. Such deformation behaviour is defined as ideal and the dependence between force and deformation is described by Hooke´s law. Ideal elastic deformation behaviour is characterized by reversible, time independent small deformations, validity of Hooke´s law, high value of modulus of elasticity and low thermal dependence.
Elasticity of rubber differs from ideal elasticity of metals and crystalline substances. The reachable deformations of rubber are big, many times bigger than with ideal elastic substances [3]. The dependence of stress and deformation of rubber is linear only in area of small deformations. The shape of stress dependence on deformation has regularly a characteristic sigmoid course. The rubber is deformed already in case of influence of small forces. The ratio of stress and deformation is about ten thousand times smaller than with ideally elastic substances. The deformation of rubber is time dependent. The elastic deformation changes have a certain delay because they are

retarded by internal viscous resistances inside the rubber mass. The deformation behavior of the rubber has in general simultaneously elastic and viscous signs. Such behaviour is defined as viscoelastic. The main consequences of viscoelastic character of rubber deformation are relaxation of stress at constant deformation, growth of deformation with time at constant stress and phase shift of deformation after the stress at cyclic stresses.

4. Defining of material properties for flexible element

With regard to elasticity of rubber it is necessary for solution of tasks of deformation and stress analysis by help of pneumatic-flexible element to consider in the program the non-linearity of material and solve the non-linear task by means of FEM. Non-linear tasks are usually dependent on the history of loading, i.e. on the way in which the individual external forces and prescribed non-zero shifts gradually gained their final size. Time curves are used for description of history of loading in the FEM program. [4]. Also for description of material properties of rubber-cord bellows is used a curve, i.e. the experimentally determined curve of Mooney-Rivlin material. Mooney-Rivlin equation for calculation of material properties is given by formula (1).

$$F/A_0 = 2 \cdot C_1 \cdot (\alpha - \alpha^{-2}) + 2 \cdot C_2 \cdot (1 - \alpha^{-3}) \qquad (1)$$

where F – loading force,
A_0 – initial section of sample,
F/A_0 – tensile stress for initial section,
α – deformation ratio,
$\alpha = l/l_0$ i.e. ratio l – of lengthened and l_0 – non-lengthened sample,
C_1, C_2 – constants dependent on material and technology of production [5].

Constants C_1 and C_2 are determined by means of course of dependence of stress on relative deformation for the given flexible material [6].
It is then possible to express the Young's modulus of elasticity by means of these constants by the following relationship:

$$E = 6 \cdot C_1 + 6 \cdot C_2 \qquad (2)$$

One of the advantages of use of this material model described by Mooney-Rivlin curve is that the relevant constants can be relatively simply determined on the basis of tensile test of rubber-cord bellows. Dependence of deformation (lengthening) on loading force determined by means of tensile test of the investigated pneumatic-flexible element is shown in Figure 1.

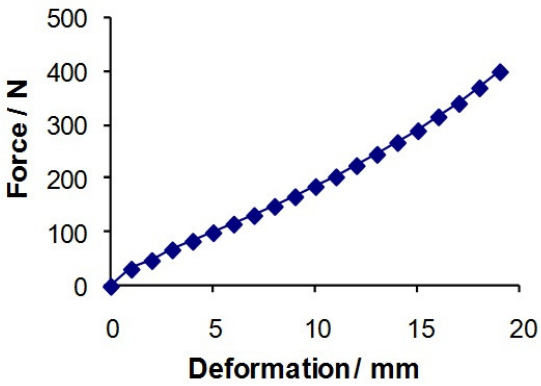

Figure 1. Stress-strain diagram of pneumatic-flexible element

In Figure 2 is the flexible element with preparation which was used for tensile test.

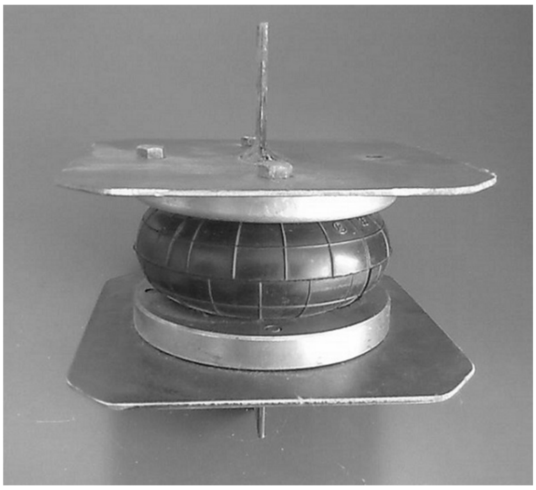

Figure 2. Pneumatic-flexible element with preparation

The used program COSMOS/M moreover allows direct calculation of material constants from results of several tensile tests (Table 1).

Table 1. Mooney-Rivlin Constants

Approximation	Mooney-Rivlin constants
1	0,703461 E-01
2	-0,479715 E-01
3	-0,120271 E-01
4	0,300176 E-01
5	-0,189043 E-08
6	0,300686 E-02

It is important to mention that such formulation of material properties is valid only for single axis stress and at calculation by means of finite element method it is necessary to use total Lagrange formulation i.e. to consider not only the material but also the geometric non-linearity.
The pneumatic-flexible elements are weak elements in pneumatic flexible couplings. Therefore, it is useful to know the distribution of stresses in the pneumatic-flexible element. For this purpose was used the Finite Element Method (FEM) and program Cosmos/M. To determine the computer model is necessary to define the type of finite element and specify boundary conditions. From the library of finite elements was used element type SHELL3T. It is a symmetric problem, therefore, for solution by FEM is sufficient to create a partial - half model. The form of the load is changing the pressure. Deformation was determined at various pressure (from 100 kPa to 1 400 kPa). At these pressures also is examined the stress of pneumatic-flexible element.
The manufacturer prescribes a maximum load worthy of 800 kPa. Failure of the resilient member in solving the task FEM was under load pressure 1 400 kPa.
For the material of the pneumatic-flexible element has been in the program COSMOS / M defined: modulus of elasticity E = 1.381 MPa and modulus of rigidity G = 0.452 MPa.

5. Conclusion

The development of an accurate material model for cord/rubber composites is a necessary requirement for the application of these powerful finite element programs to practical problems but involves numerous complexities. The deformation of rubber is time-dependent. Deformation behaviour of rubber has generally elastic and viscous characteristics simultaneously.
A viscoelastic constitutive model of rubber-cord composite is established by introduction of strain energy density function. For description of material properties of rubber-cord element is used a curve, i.e. the experimentally determined curve of Mooney-Rivlin material. The relevant constants were determined on the basis of tensile test of rubber-cord element. Results are presented for a material of pneumatic-flexible element of differential pneumatic flexible coupling with autoregulation.

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