GRANT journal
ISSN 1805-062X, 1805-0638 (online), ETTN 072-11-00002-09-4
ročník 7, č. 2
EUROPEAN GRANT PROJECTS | RESULTS | RESEARCH & DEVELOPMENT | SCIENCE

Stress Analysis of Pneumatic-Flexible Element

Silvia Medvecká-Beňová[1]
Peter Kaššay[2]

[1] University of Košice, Faculty of Mechanical Engineering, Letná 9, 042 00 Košice; Slovensko, email: silvia.medvecka@tuke.sk
[2] University of Košice, Faculty of Mechanical Engineering, Letná 9, 042 00 Košice; Slovensko, email: peter.kaššay@tuke.sk

Grant: 1. Project was created with support from the PhD students and young researchers project entitled. 2. APVV-16-0259.
Name of the Grant: 1. Solution of a control system element for mechanical systems' continuous tuning. 2. Research and development of combustion technology based on controlled homogenous charge compression ignition in order to reduce nitrogen oxide emissions of motor vehicles.
Subject: JR Other machinery industry

Abstract High elasticity and ability to withstand without damage relatively large repetitive deformations are technical properties of rubber. These properties of rubber are used in pneumatic flexible couplings. For solution of problem of deformation and stress analysis of pneumatic-flexible element by means of the finite element method it is important to define precisely the material properties of these pneumatic-flexible elements. The paper deals with creation of computational model of a pneumatic-flexible element of a pneumatic flexible coupling. This model is used for solution of deformation and stress problems by finite element method.

Keywords pneumatic-flexible element, material properties, finite element method, stress, deformation.

1. INTRODUCTION

Torsion vibration that occurs in mechanical systems can not in many cases be accurately eliminated. Its adverse effects can be reduced by appropriate tuning of the mechanical system. In the field of minimizing dangerous torsional oscillation and thus ensuring proper tuning of the torsionally oscillating mechanical system, at present the authors' attention focuses primarily on the development and application of pneumatic flexible couplings, i.e., pneumatic tuning of torsional oscillations. The weak elements in pneumatic flexible couplings are stretched pneumatic-flexible elements (rubber-cord bellows).

The aim of the article is to describe the material properties of rubber-cord elastic element necessary for assessment of pneumatic resilient element by means of FEM and this paper deals with stress of rubber – cord flexible element of pneumatic flexible coupling. This stress is investigation to determine identification the maximum stress. The stress of flexible element is solution by finite element method in program Cosmos/M.

2. DEFINE OF PNEUMATIC FLEXIBLE COUPLING

The pneumatic flexible coupling is use for minimization of torsional vibration, by which is assured the appropriate tuning of torsional vibrations of mechanical system [1-3].

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. [4, 5].

The problem is solved for pneumatic-flexible element of differential pneumatic flexible coupling with autoregulation. In figure 1 is shown the differential pneumatic flexible coupling with autoregulation which consists of the driving part (1) and the driven part (2), between which is situated a compression chamber filled with gas medium. The compression chamber is composed of three differential elements distributed on the circuit and mutually connected. Each differential element consists of the compressed and the driven (3, 4) pneumatic-flexible element. By means of regulator (6) and connecting tube (5) is realised the filling of the coupling. The basic principle of activity is protected by patent [6].

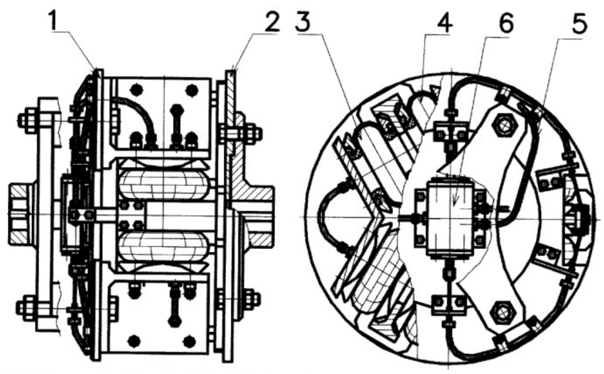


Fig. 1 Differential pneumatic flexible coupling with autoregulation

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).

3. USE OF FEM IN THE STRESS ANALYSIS OF PNEUMATIC-FLEXIBLE ELEMENT

The finite element method is one of the most widespread numerical methods. It is used to solve the problems of elasticity and strength,

GRANT journal
ISSN 1805-062X, 1805-0638 (online), ETTN 072-11-00002-09-4

the dynamics of pliable bodies, heat transfer and many other engineering problems [7-9]. There are several program products for problem solving using MKP, including the complete modular program system Cosmos / M, in which the problem of deformation of the rubber – cord flexible element will be solved. Program Cosmos/M allows you to solve both planar and spatial tasks. Due to the method of loading of the rubber – cord flexible element, its deformation analysis can be solved by means of a plane (2D) task by finite element method.

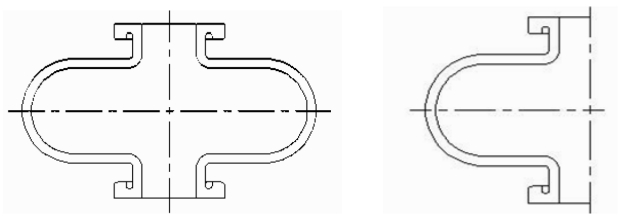
When calculating using FEM, we generally do in stages, namely:

1. Creating a computer model of an object under investigation, in our case a pneumatic-flexible elements.
2. Analysis - own calculation.
3. Processing of calculation results.

Creation of a computer model consists of creating a geometric model of the object under study, entering material properties, defining the type of finite elements and defining boundary conditions.

3.1 Geometric model of pneumatic-flexible elements

The program Cosmos/M allows direct geometry creation using drawing commands. This procedure is many times tedious and complex. A very efficient procedure can be to transfer geometry from a CAD system. In Figure 2-a) is a geometric model of the entire pneumatic-flexible element is constructed using the AutoCAD and its drawing commands. Because this is a symmetric task, create a partial - half model (Figure 2 - b) is sufficient to solve the problems by of finite element method. This geometric model is exported to Cosmos/M as a DXF file.



a) b)

Fig. 2 2D geometric model of a pneumatic-flexible element

Another possible way is to build a geometric model using a Pro/Engineer system that provides a volume modeling approach. Using such a system assumes the idea of being a perfect drawing tool. The geometric models thus created exist as complete spatial bodies and enable the creation of realistic geometry with precise calculations. In Figure 3 is a 3D geometric model of a part of the examined pneumatic-flexible element.

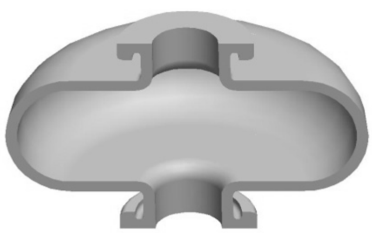


Fig. 3 3D geometric model of a pneumatic-flexible element

There is no universal guide to creating a geometric model. The decision on how the geometric model will be created is a matter of computing experience as well as access to the necessary computer software [10].

3.2 Defining of material properties for pneumatic-flexible element

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 [11]. 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.

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. [12]. 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).

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

where F – loading force,
A_0 – initial section of sample,
F/A_0 – tensile stress for initial section,
$$\alpha = \frac{l}{l_0}$$
α – deformation ratio, l – of lengthened and
l_0 – non-lengthened sample,
C_1, C_2 – constants dependent on material and technology of production [13].

Constants C_1 and C_2 are determined by means of course of dependence of stress on relative deformation for the given flexible material [14].

It is then possible to express the Young's modulus of elasticity by means of these constants by the following relationship:

$$E = 6 \cdot C_1 + 6 \cdot C_2 \tag{2}$$

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 4.

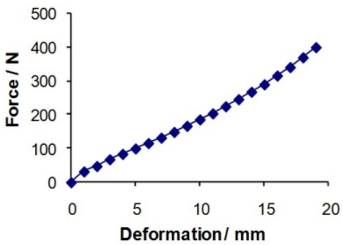


Fig. 4 Stress-strain diagram of pneumatic-flexible element

In Figure 5 is the flexible element with preparation which was used for tensile test.

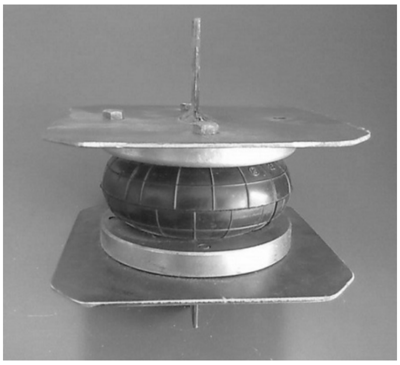


Fig. 5 Pneumatic-flexible element with preparation

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.

3.3 Maximum stress identification of pneumatic-flexible element solved using FEM

Figure 6 depicts the deformation of the pneumatic-elastic member PE130/1 at a pressure load of 800 kPa, i.e. the maximum pressure prescribed by the pneumatic-flexible element manufacturer.

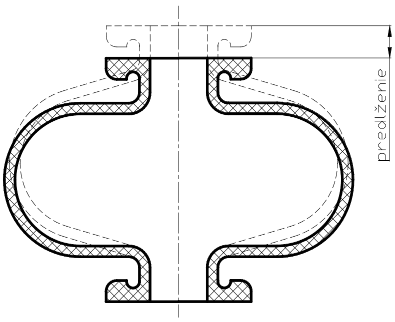


Fig.6 The maximum deformation of pneumatic-flexible element

At this maximum load, the stress distribution of the pneumatic-elastic member was investigated using the finite element method using the Cosmos/M program.

The maximum stress at the load being investigated here occurs in the area of the maximum diameter of the pneumatic-flexible element (Figure 7).

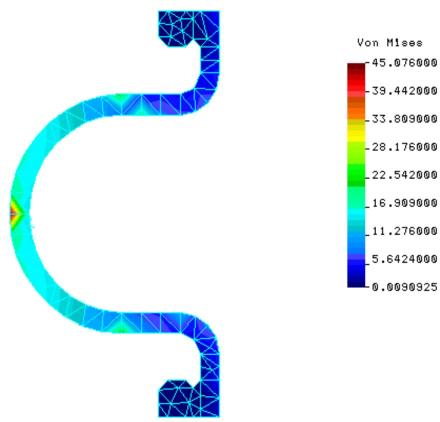


Fig. 7 Decomposition of stress in the maximum loading

The stress distribution in the investigated pneumatic-flexible elements influences the bellows temperature.

4. 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.

For solution of deformation and stress analysis of pneumatic-flexible member is necessary to create a computer model. Creation of a computer model consists of creating a geometric model of the object under study, entering material properties, defining the type of finite elements and defining boundary conditions. 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.

This article was created with support from the PhD students and young researchers project entitled, Solution of a Control System Element for Mechanical Systems' Continuous Tuning and project APVV-16-0259 - Research and Development of Combustion Technology Based on Controlled Homogenous Charge Compression Ignition in Order to Reduce Nitrogen Oxide Emissions of Motor Vehicles.

Reference

1. Han Y.H., Becker E. B., Fahrenthold E. P.: Fatigue Life Prediction for Cord-Rubber Composite Tires Using a Global-Local Finite Element Method. In. Tire Science and Technology. 32 (2004) 1, 23-40.
2. Czech P.: Vibroacoustic diagnostics of gasket under engine head damage with the use of probabilistic neutral networks. Transactions of the University of Košice. 3. 2012.ISSN 1335-2334.
3. Kaššay P., Homišin J., Urbanský M.: Formulation of Mathematical and Physical Model of Pneumatic Flexible Shaft Couplings. In:Scientific Journal of Silesian University of Technology-Series Transport. Vol. 76, no. 1864 (2012), p. 25-30.
4. Cembrola R.J., Dudek T.J.: Cord/Rubber Material Properties. In: Rubber Chemistry and Technology. 58 (1985), 830-856.
5. Ivančo V., Kubín K., Kostolný K.: Program COSMOS/M. Košice. (2000).
6. Homišin J.: Pneumatic flexible coupling, patent 278025/95.
7. Urbanský M.: Theoretic and Experimental Determination of the Flow Resistance Coefficient at Gaseous Medium Flow into and out of the Pneumatic Coupling, Scientific Journal of Silesian University of Technology. SeriesTransport. Volume 85, No. 1925, p.119-125, 2014.
8. Mácha A.: Výpočet deformačních síl pryžové valcové pružiny pomocí MKP. Konferencia katedier častí strojov a mechanizmov, Zvolen .(2002), 177-180.
9. Homišin J., Urbanský M.: Partial Results of Extremal Control of Mobile Mechanical Systém. In: Diagnostyka. Vol. 16, no. 1 (2015), p. 35-39.
10. Petríková I., Marvalová B., Prášil L.: Modelling of mechanical properties of cord-rubber composites. In. International Scientific Conference Experimental Stress Analysis, Olomouc, (2010), 325-332.
11. Urbanský M.: Comparison of piston and tangential pneumatic flexible shaft couplings in terms of high flexibility. In: Scientific Journal of Silesian University of Technology = Zeszyty Naukowe Politechniki Śląskiej : Series Transport : Seria Transport. - Katowice (Poľsko) : Faculty of Transport Silesian University of Technology č. 99 (2018), s. 193-203.
12. Fengfa Z., Zhihui F., Xingwen D.: Study on Viscoelastic Propertiesof Cord–Rubber Composite Subjected to Biaxial Loading. In. Journal of Elastomers and Plastics, 36 (2004) 4, 143-158.
13. Homišin J. et al.: Continuous tuning of ship propulsion system by means of pneumatic tuner of torsional oscillation. In: International Journal of Maritime Engineering: Transactions of The Royal Institution of Naval Architects. Vol. 158, no. Part A3 (2016), p. A231-A238.
14. Petríková, I., Marvalová B.: Determination of the Mechanical Properties of Naturally Aged Rubber. In. International Conference of Model for Rubber, Dresden, Germany, (2009), 143-147.
15. Satiepková A. a kol.: Utilizing of sensitivity analysis in preparation of optimizing procedure. Transport z.76, Gliwice, 2012. ISSN 0209-3324.
16. Urbanský, M.: Harmonic analysis of torsional vibration force excitation. In: Scientific Journal of Silesian University of Technology: Series Transport. Vol. 97 (2017), p. 181-187.