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SUMAR

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INFLUENCE OF CLOSED CELL ELASTOMER SCALE FACTOR ON THE PASSING POWER FLOW TRANSFORMATION

BY

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Abstract.

The object of study is an elastomer in a closed cell, through which power flows. FEM approach has been applied to solve the problem. An axisymmetrical FEM model has been developed in which the model of elastomer material employs the Arruda-Boyce model. It is based on the specific potential strain energy which is the energy accumulated per unit of volume. For a selected optimized cell geometry the emphasis is laid on the influence of the scale factor, respectively, the elastormer volume impact upon the transformation of the power flow. The obtained results are visualized by graphics and relevant conclusions have been made.

Key words: scale factor optimization, closed cell, hyperelastic material, finite element simulations

1. Introduction

The hyperelastic materials belong to the polymer materials group. Depending on the nature of the matter which builds these materials, they can be hydroplastic, rubber like, foam like and other polymers. In the machinery construction the components made of hyperelastic materials are known as elastomers. As a part of machine-building products, the elastomers perform various functions: vibro-insulation, as congestion elements, as components in tightening mechanisms, for compensating the deflection of the mutual position of connected shafts. Analyzing the elastomer applications in the tightening mechanisms, a practical and scientific interest is the case when a force flow passes through the elastomer, i.e. when the elastomers perform basic role in the tightening process. Simultaneously, elastomer applications in tightening mechanisms where the transformation of the force flows to be at hand are not known.

The present investigation basis is the idea for an optimization of the application of elastomers made of rubber mixes as a medium for transferring of a pressure in the tightening mechanisms in a such manner that the force flow to be increased to direction of the workpiece to be fixed. For that purpose the elastomer is fit in a closed cell having the form of a truncated cone and two short cylindrical sections [1].

The main objective of this work is to obtain quantitative estimation of the influence of the scale factor, respectively the elastomer volume on the force flow transformation. The problem has been solved by means of finite element (FE) approach.

2. Nature of the technical solution

The principle scheme of the technical solution is presented in Fig. 1. To reach an intensification of the force flow from piston 1 to piston 2 it is necessary elastomer Poisson ratio to be $\approx 0,5$, i.e. the elastomer to be almost incompressible. For that purpose, on the basis of experimental studies it is chosen a rubber-like material with Shore hardness of 55 [2]. In order to receive a quantitative assessment of the passing force flow transformation, the coefficient of the force intensification k is introduced as [1]:

$$k = F_2 / F_1 \tag{1}$$

where F_1 and F_2 are respectively the input and the output forces, relative to the top of the elastomer's contact surfaces.

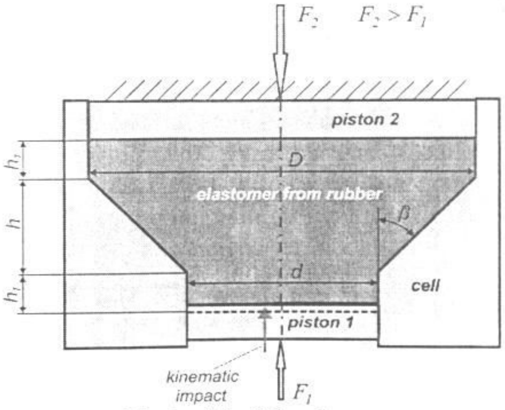


Fig. 1 - Principle scheme.

3. Organization of the study

In order to make an optimization of the elastomer geometry, a multi-objective optimization is carried out by means of numerical simulations. In the condition of a constant volume and when $d = const$ and $h_1 = const$ (Fig. 1), all the rest parameters depend on only angle β. It is established that when $\beta = 70^0$ the coefficient k is the biggest and the losses are the smallest. The objects of this study are the elastomers having optimal geometry but having different scale factors. The variation of its geometrical parameters depending on the scale factor, respectively depending on the elastomers volume, is shown in table 1.

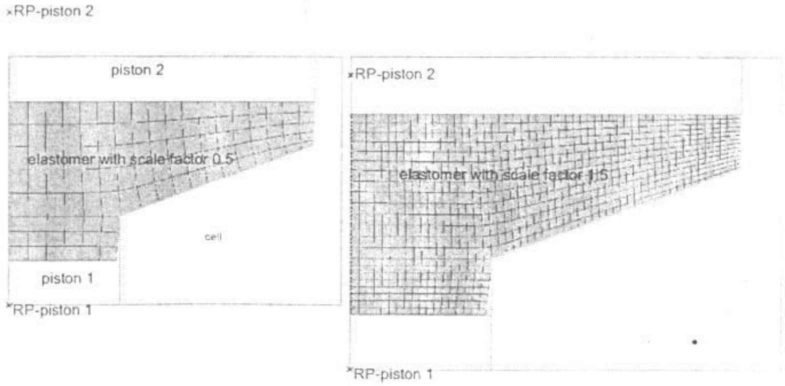
Table 1. Geometrical parameters of elastomers

Scale factor	d, mm	D, mm	h, mm	h_1, mm	V, mm^3
0.5	12.5	34.426	3.99	2.5	4484.644
0.75	18.75	51.639	5.985	3.75	15135.677
1	25	68.852	7.98	5	35877.16
1.25	31.25	86.065	9.975	6.25	70072.578
1.5	103.278	103.278	11.97	7.5	121085.412

4. Finite element model

4.1. General characteristic

In view of the nature of the problem to be studied, an axisymmetrical FE model has been developed (fig. 2 a, b). The pistons 1 and 2, and the cell are modeled as analytical rigid and the elastomer is modeled as deformable body.



a) b)

Fig. 2 - Axisymmetrical finite element model, a) scale factor 0.5; b) scale factor 1.5.

According to the construction of the closed cell, FE model consist of three parts –piston-1, piston-2 which simulate respectively small piston and big piston and cell. Tangential and normal contact between the elastomer and components of the cell allowing a separation are defined as the technique "master" and "slave" surfaces is applied [3]. According to experimental results obtained [4], for the rubber to be studied the friction coefficient 0.8 is assigned.

The kinematic impact applied on the piston 1 is assigned by means of a rectilinear translation with an amplitude defined by means of a tabulation. The input and the output forces, relative to the piston-1 and piston-2 are obtained by reactions in Reference point (RP) of their models (fig. 2 a, b).

The elastomer FE model is built from quadratic quadrilateral FE, type CAX8R. In order to obtain correct FE results the geometric similar elastomers are built with equal average size of the FEs - $1\ mm$ (fig. 2a, b).

4.2. Constitutive model of the elastomer

On the basis of a comparison between experimental and FE results, it is proved that the Arruda-Boyce constitutive model is the most appropriate for describing the behavior of the investigated rubber mix [3-UNITECH'2008]:

$$(2)\quad \Omega = G[\frac{1}{2}(\bar{I}_1 - 3) + \frac{1}{20\lambda_m^2}(\bar{I}_1^2 - 9) + \frac{11}{1050\lambda_m^4}(\bar{I}_1^3 - 27) + \frac{19}{7000\lambda_m^6}(I_1^3 - 81) +$$

$$+ \frac{519}{673750\lambda_m^8}(\bar{I}_1^5 - 243)] + \frac{1}{D}(\frac{J_{el}^2 - 1}{2} - \ln J_{el})$$ the first deviatoric strain invariant

where G, λ_m and D are temperature dependent material parameters; $\bar{I}_1$ is the first deviatory strain invariant defined as:

$$(3)\qquad \bar{I}_1 = \bar{\lambda}_1^2 + \bar{\lambda}_2^2 + \bar{\lambda}_3^2$$

$\bar{\lambda}_i$ are the deviatory stretches: $\bar{\lambda}_i = J^{-\frac{1}{3}} . \lambda_i$; J is the total volume ratio (ratio of current volume to initial); J_{el} is the elastic volume ratio; λ_i are the principal stretches ($\lambda_i = 1 + \varepsilon_i$; ε_i are the principal linear strains).

The initial shear modulus G_0 is related to G with the expression:

$$G_0 = G\left(1+\frac{3}{5\lambda_m^2}+\frac{99}{175\lambda_m^4}+\frac{513}{875\lambda_m^6}+\frac{42039}{67375\lambda_m^8}\right). \tag{4}$$

A typical value of λ_m is 7, from where $G_0 = 1{,}0125G$. The initial bulk modulus K_0 is related to D with the expression: $K_0 = 2/D$.

The following material constants are obtained: $G = 1{,}8516824$; $G_0 = 1{,}87480038$; $\lambda_m = 7{,}00020847$; $D = 0{,}0432$.

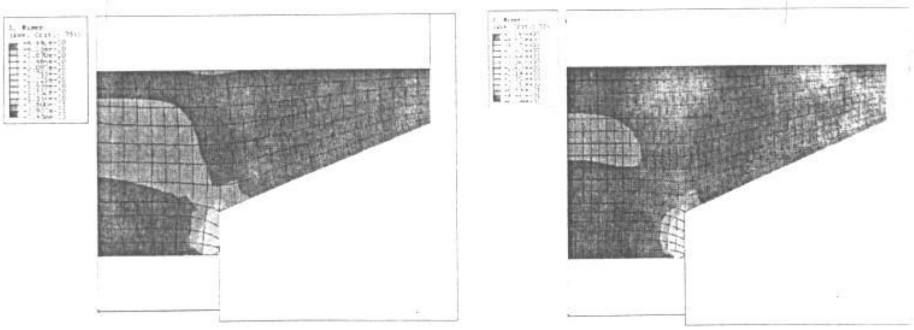
5. Finite element results and discussions

The equivalent von Misses stress distribution for elastomers having scale factors respectively 0.75 and 1.25 and corresponding to the maximum displacement of the small piston are shown in Fig. 3. For each studied case the maximum displacement is conformable to the condition the maximum equivalent stress to be less than $\approx 5\ MPa$. In the field surrounding small piston the deforming process is the most intensive because of that the stresses are maximum in this zone.

The generalized results obtained from the numerical simulations for different scale factors are shown in Fig. 4-8. For the elastomers from Table 1, the output force F_2, N and the coefficient of the force intensification depending on the small piston displacement, are graphically visualized.

On the basis of the graphical dependences obtained, the following comments can be made:

- With increasing of the output force F_2, the coefficient of the force intensification k decreases because of the bigger friction forces between the elastomer and the cell;



a) b)

Fig. 3 - Equivalent stress distribution; a) scale factor 0.75; b) scale factor 1.25.

- The dependence between the applied kinematics influence (the small piston axial displacement) and the output force F_2 has almost linear character. This gives a possibility comparatively easily to control the force applied to workpiece to be fixed by means of a control on the small piston displacement;

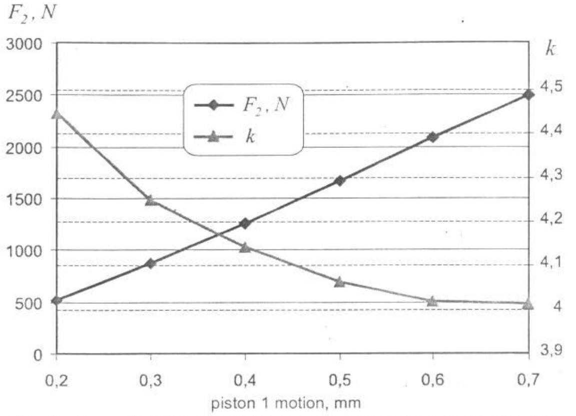


Fig. 4 - Power flow transformation in elastomer with scale factor 0.5.

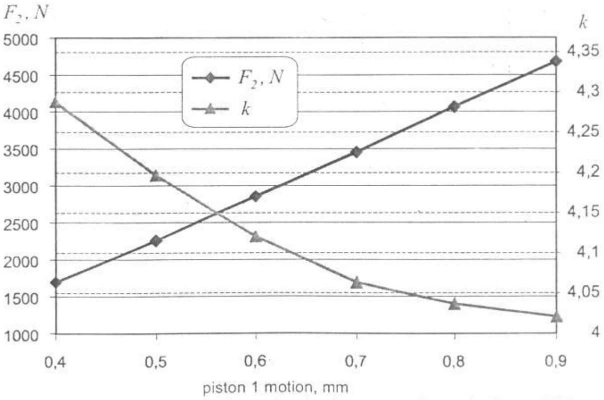


Fig. 5 - Power flow transformation in elastomer with scale factor 0.75.

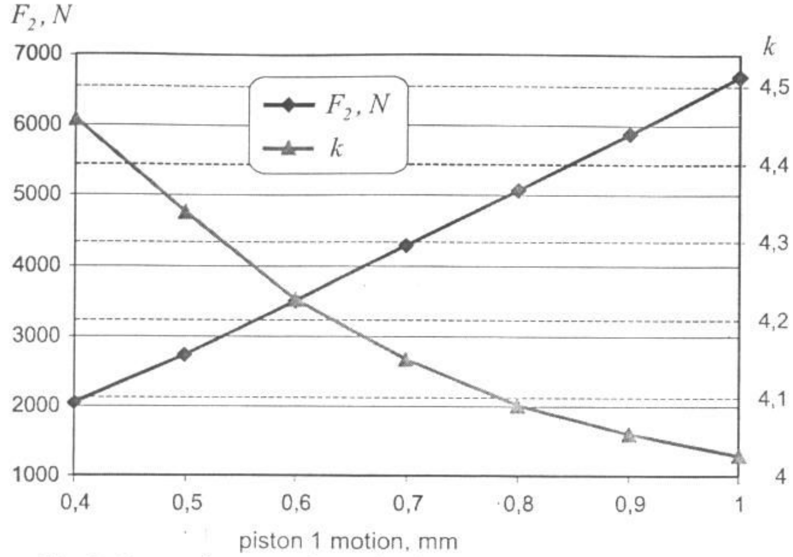


Fig. 6 - Power flow transformation in elastomer with scale factor 1.

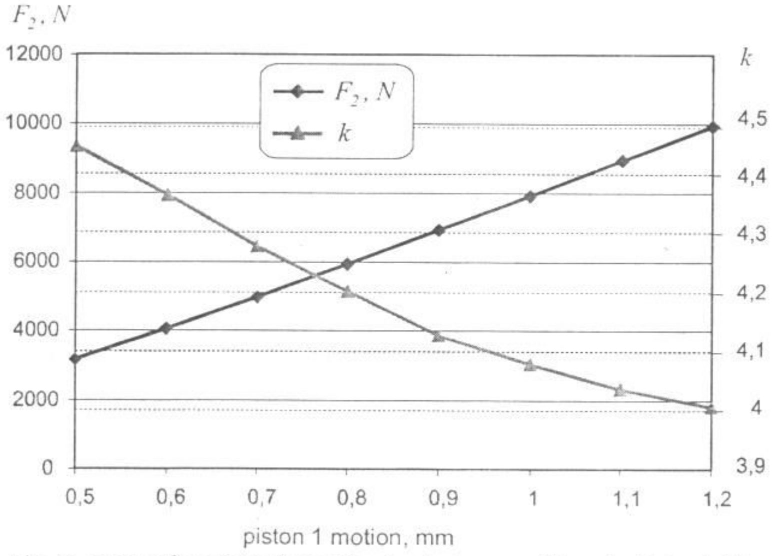


Fig. 7 - Power flow transformation in elastomer with scale factor 1.25.

- With increasing the small piston displacement, the coefficient of the force intensification decreases with changeable rate. It is observed that the scale factor leads to relatively little dispersing of k in the conditions of the maximum displacement for a given elastomer.

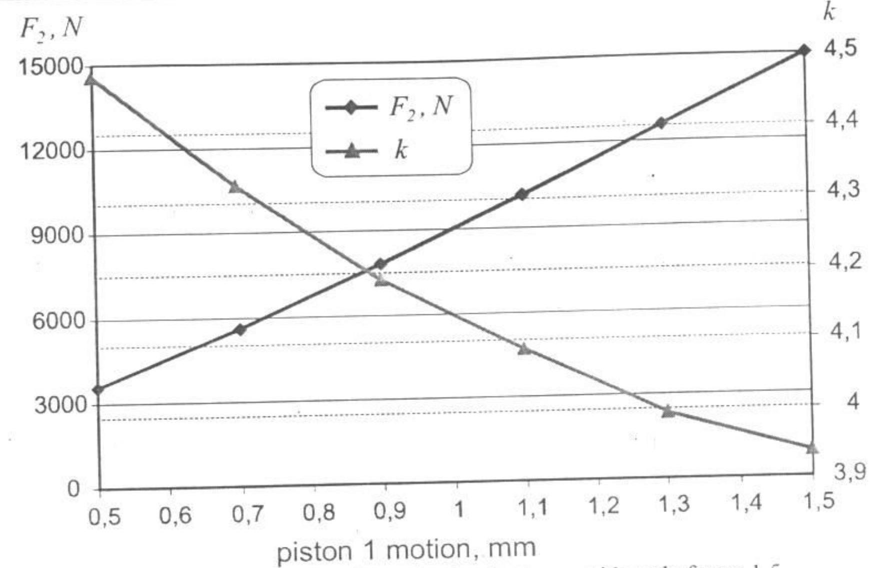


Fig. 8 - Power flow transformation in elastomer with scale factor 1.5.

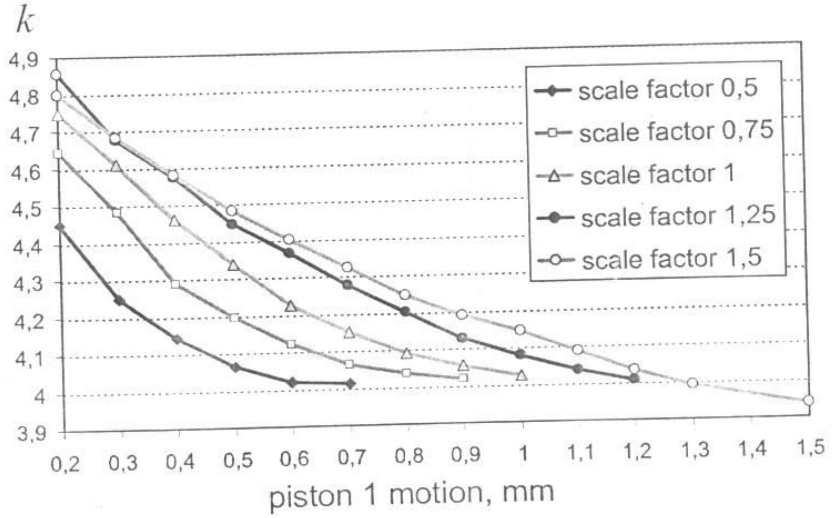


Fig. 9 - Variation of k from scale factor and kinematic impact.

Fig. 9 shows the variation of the coefficient of the force intensificatio of elastomers having different scale factors depending on the small pisto displacement. Obviously, for one of the same kinematic impact the coefficien of the force intensification increases with increasing the scale factor. This can be explained by relatively smaller losses causal by external friction for elastomers having larger volume.

6. Conclusion

A generalized FE model of the elastomer in a closed cell has been developed, trough which force flow passes so that it is intensificated.

The influence of the scale factor on the flow force transformation has been studied by means of numerical simulations of the geometric similar elastomers.

The quantitative dependences between elastomers power characteristic and admissible values of the applied upon them kinematic impacts are obtained.

The results obtained can be used for design of tightening mechanisms based on the studied technical solution.

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