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Dominik Kwiatkowski (dkwiatkowski@pk.edu.pl)
Edward Lisowski
Dominik Kwiatkowski, Edward Lisowski, Institute of Applied Informatics, Faculty of Mechanical Engineering, Cracow University of Technology

Nonlinear static analysis of air cushion in SolidWorks Simulation 2016

Badania nieliniowe poduszki pneumatycznej w programie SolidWorks Simulation 2016

Abstract

The paper presents the results of research for load lifting process for a single pneumatic cushion. The load lifting process has been simulated in SolidWorks Simulation using the model of Mooney-Rivlin for hyper-elastic material. Research was conducted based on a simplified 3D model and drawn up a mathematical model of pneumatic cushions determining of non-linear static characteristics for the lifting height depending on the weight of the load and supply pressure. The results compare with the results of laboratory tests conducted for the platform equipped with four air cushions.

Keywords: CAD 3D, FEM, Mooney-Rivlin, air cushion

Streszczenie

W artykule przedstawiono wyniki badań dla procesu podnoszenia ładunku dla pojedynczej poduszki pneumatycznej. Proces podnoszenia ładunku zasymulowano w programie SolidWorks Simulation, wykorzystując model Mooney-Rivlin'a dla materiału hiper-sprężystego. Bazując na uproszczonym modelu 3D i opracowanym modelu matematycznym poduszki pneumatycznej, przeprowadzono badania statyczne nieliniowe, wyznaczając charakterystyki dla wysokości podnoszenia w zależności od masy ładunku i ciśnienia zasilającego. Otrzymane wyniki porównano z wynikami badań laboratoryjnych, przeprowadzonymi dla platformy wyposażonej w cztery poduszki pneumatyczne.

Słowa kluczowe: CAD 3D, MES, Mooney-Rivlin, poduszka pneumatyczna

1. Introduction

Transportation systems on air cushions designed to transport heavy load are used in industrial halls and production plants where the low value of system's displacement in the direction of the height of lifting (*Y*-axis) is the significant parameter.

In order to estimate such a value, it can be simulated as a simplified system reducing its to one air cushion. In this research software specialised in solving problems connected with nonlinear static analysis and possibility of defining hyper-elastic material was used. A program used in this purpose was SolidWorks Symulation 2016.

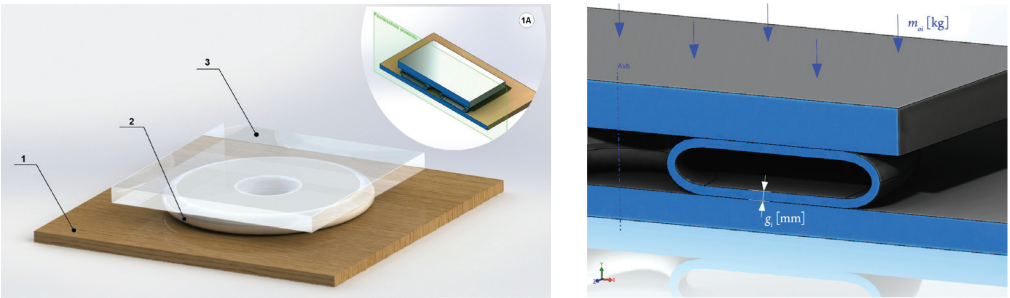


Fig. 1. Simplified geometrical model of air cushion, where: 1 – work surface; 2 – rubber toroid; 3 – rigid carrier plate; 1A – Cross-section view of air cushion; g_i – rubber toroid thickness, m_{oi} – load

A simplified geometric model is shown in the Fig. 1 where – for the needs of research – the parameter for thickness of a toroid made of a hyper-elastic material with value $g = 2$ [mm] and three configurations of load: $m_{o1} = 500$ [kg], $m_{o2} = 750$ [kg], $m_{o3} = 1000$ [kg] are introduced.

To calculate pressures which are present in- and under air cushion during system's work, mathematical model of air cushion and results of laboratory research for value of lifting basing on study [1] was used.

2. Hyper-elastic material model

To define the material of the toroid element, the Mooney-Rivlin hiper-elastic model [2] was used. This model describes material made from sythetic rubber from the group EPDM (ethylene propylene diene monome) [3].

The Mooney-Rivlin strain energy density function is expressed as [4]:

$$W_1 = A(\mathrm{I}-3) + B(\mathrm{II}-3) + X\left(\frac{1}{\mathrm{III}^2} - 1\right) - 1 + Y(\mathrm{III}-1)^2 \tag{1}$$

$$W_2 = C(\mathrm{I}-3)(\mathrm{II}-3) + D(\mathrm{I}-3)^2 + E(\mathrm{II}-3)^2 + F(\mathrm{I}-3)^3 \tag{2}$$

$$W = W_1 + W_2 \tag{3}$$

where:

A, B, C, D, E and F – are Mooney material constants,

I, II, III – invariants of the right Cauchy-Green deformation tensor,

and

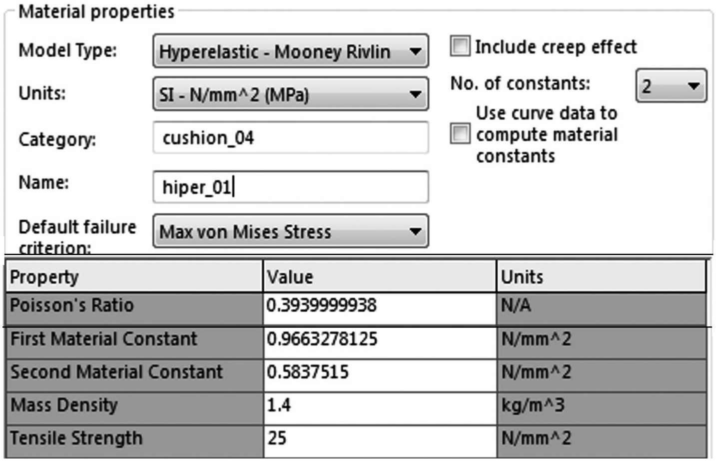
$$X = 0.5A + B \tag{4}$$

$$Y = \frac{\left[A(5\nu - 2) + B(11\nu - 5)\right]}{\left[2(1 - 2\nu)\right]} \tag{5}$$

where:

ν – Poisson's ratio.

To define the hyper-elastic material in SolidWorks, data shown in the Fig. 2 were used.



Property	Value	Units
Poisson's Ratio	0.3939999938	N/A
First Material Constant	0.9663278125	N/mm^2
Second Material Constant	0.5837515	N/mm^2
Mass Density	1.4	kg/m^3
Tensile Strength	25	N/mm^2

Fig. 2. The definition of properties for hyper-elastic material in SolidWorks

3. Definition of properties for FEM

In order to realize a simulation for air cushion with proper loading and supply pressure where height research was taken into consideration, contacts between elements, boundary conditions and type of the mesh and its density were defined.

The model used for strain and displacement calculations was reduced to cross-section, so it means to 2D model.

For this simplified model, a program generated 2D linear triangular elements which have got three degrees of freedom in every node: two transations and one rotation. Translation degrees of freedom are motions in global directions X, Y. Rotation degrees of freedom are rotation around global axis Z.

Parameters of the mesh was prepared according to thickness of toroid. For example, for $g_1 = 4$ [mm] (Fig. 3), max element size was equal 4 [mm]; min element size was equal 0.5 [mm]. In the areas where the biggest strains and deformations were forecasted, the mesh refined.

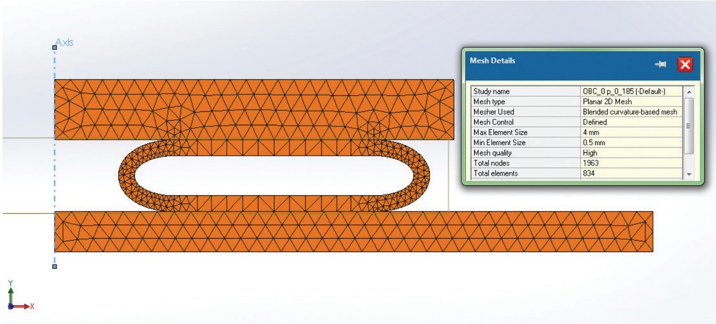


Fig. 3. The definition of properties for mesh where $g = 4$ [mm], the other variants depend on the thickness of rubber toroid

Then, a contact of elements occuring in the model was defined. A bonded contact for edges between rigid carrier plate and toroid was created (Fig. 4 – red color). The mesh must not have been compatible. If the is compatible, the program merges common nodes along cooperation sufrace. In other case, it applies constrain equations internally to symulate a link.

To make a link between work surface and toroid there was created constrain without penetration (Fig. 4 – blue color). This constrain does not allow to penetration of elements but it allows to creating gaps [5].

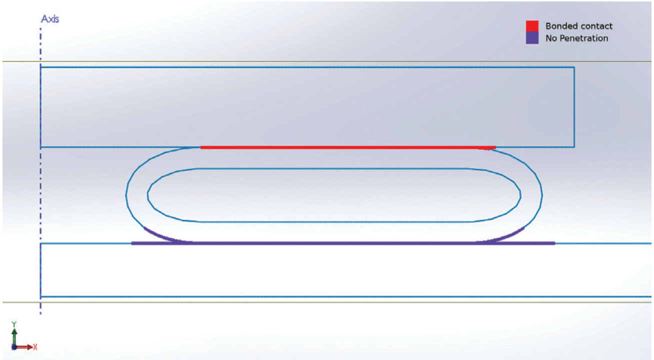


Fig. 4. The definition of component contact, where color red color – bonded contact, blue color – no penetration

In the next stage, restraints were defined. For work surface (Fig. 5), fixed possibility of motion in direction *Y*-axis and in direction *X*-axis. When defining strengthening for the rigid carrier plate (Fig. 5), it was decided to divest one degree of freedom for *X*-axis on side of the plate because of the possibility of decline state of balance with simulation calculations.

For bottom edges of toroid, a displacement on *Y*-axis which is variable in time was defined to simulate a moment of transition of air cushion from state of work to state of lifting with possibility of moving a load. The second state is connected with occuring an air film between work surface and working layer of toroid. A value R_y assessed from 0 to 1 [mm] in time of simulation 10 [s].

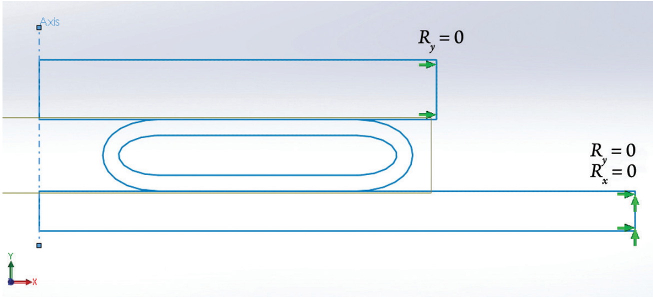


Fig. 5. The definition of restraints for work surface and rigit carrier plate

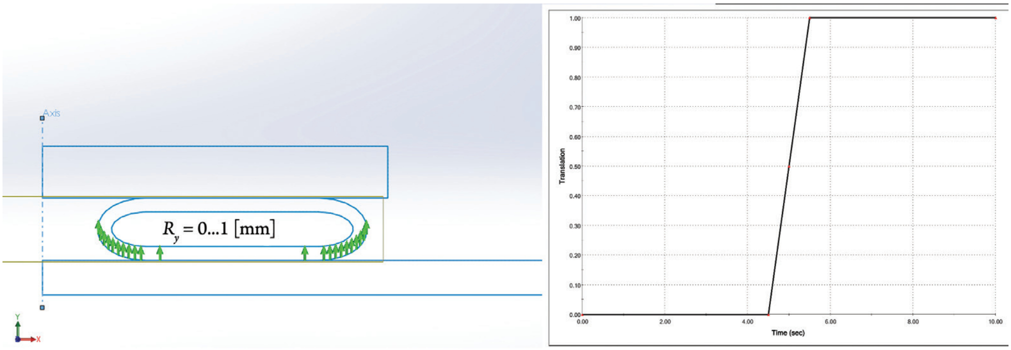


Fig. 6. The definition of restraints for rubber toroid in left and curve of Y translation in time ($R_Y[t]$) for rubber toroid in right

After defining restraints, defining of external loadings for the model has begun. Rigid carrier plate was loaded with a force equaling a mass of the loas in three variants (Fig. 7). The load was picked according to laboratory results for the system of four air cushions and respectively calibrate in proportion to simulation of single air cushion.

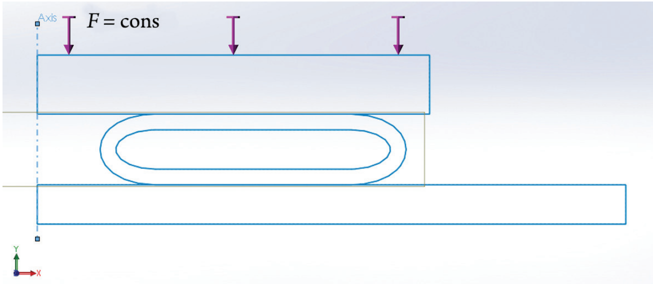


Fig. 7. The definition of external load for rigid carrier plate for the three variants: 1) $F = 1250$ [N]; 2) $F = 1875$ [N]; 3) $F = 2500$ [N]

Then, pressure variable in time $p_2(t)$ found in the toroid. A change of the value in time stems from increasing quantity of air during work inside the air cushion, so that inside the toroid. Both direction of pressure and characteristics are shown in the Fig. 8.

For the rigid carrier plate pressure variable in time $p_{31}(t)$ simulating pressere found in chamber under the air cushion which modifies slightly its value in the moment of occuring an air film was also defined (Fig. 8).

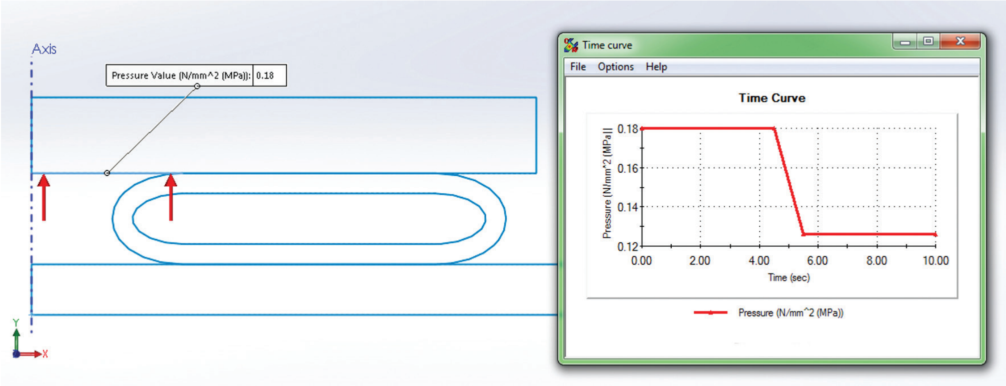


Fig. 8. Left image present the definition of pressure $p_2(t)$ inside of rubber toroid, one example. Right image present definition of pressure $p_{31}(t)$ for rigid carrier plate, one example

Additionally, two components pressure found in the chamber under air cushion was defined (Fig. 9). Second component, $p_{32}(t)$, occurs on external layer of the toroid inside the object. Its value decreses with moment of occuring an air film.

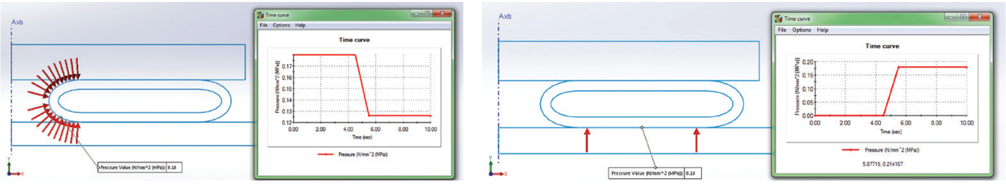


Fig. 9. Left image present the definition of pressure $p_{32}(t)$ for outside of rubber toroid, one example. Right image present the definition of pressure $p_{33}(t)$ for outside of rubber toroid, one example

Third component, $p_{33}(t)$, occurs under toroid and appears in the moment of appearing of an air film.

The model prepared this way was submitted for simulation for various values of supply pressure p_1.

4. Results of the simulation

As a result of the simulation for every configuration, a picture of a map of equivalent strains von Mises, maps of deformations and maps of displacements were obtained (Fig. 10). In that, there was a possibility of estimating height of air cushion lifting according to every case of value of supply pressure.

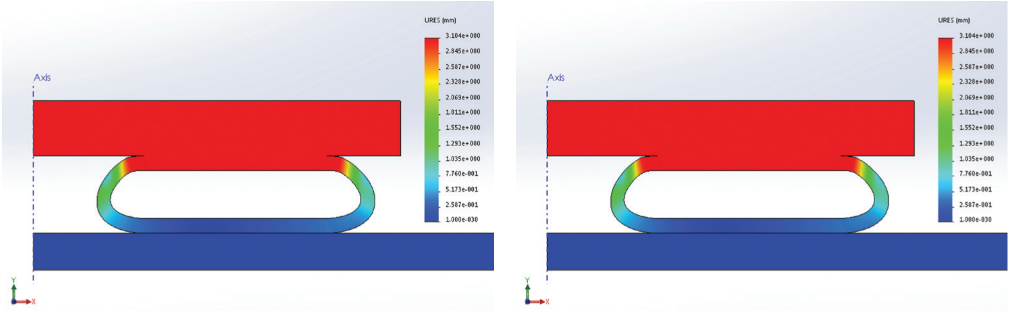


Fig. 10. Example of von Mises stress (left image) and *Y*-displacement (right image)

Gathered data let create characteristics (Fig. 11) for three cases of loading with possibility to compare them with results had done in laboratory (blue color).

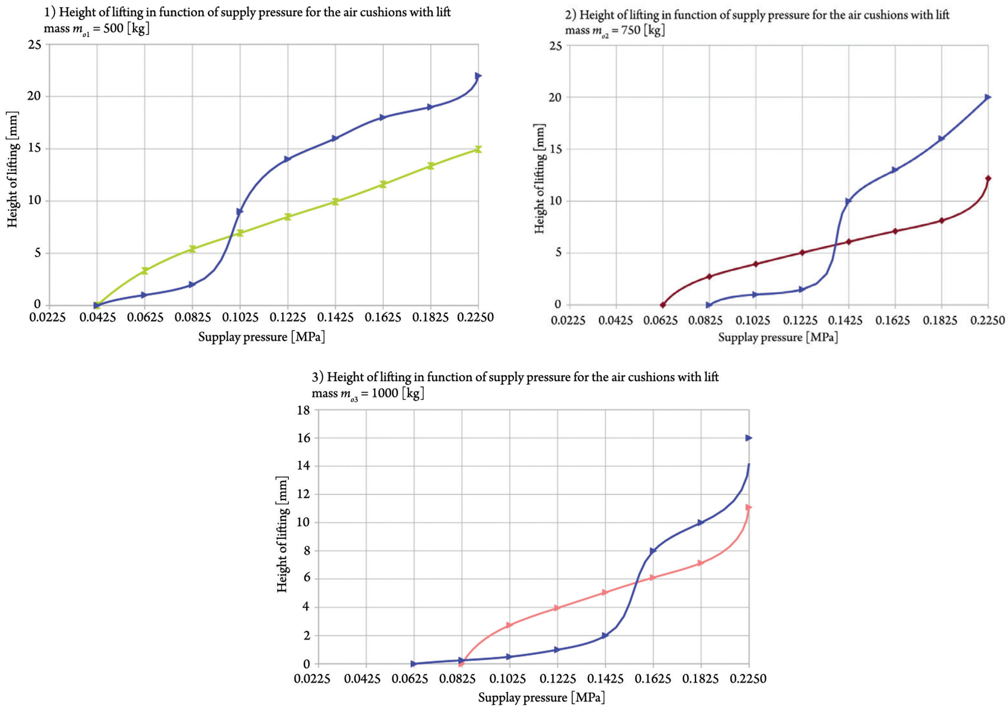


Fig. 11. Height of lifting in function of supply pressure for the air cushions with lift mass:
1) m_{o1} = 500 [kg] 2) m_{o2} = 750 [kg], 3) m_{o3} = 1000 [kg]

5. Summary

Too large difference in results for the geometry akin to a real object shows that picked model used in the symulation must be verified. With this end of view, further studies with consulting change of hyper-elastic material model, omitting simplifying model to flat model and symulation whole system on four air cushions as well as additional laboratory rasearch will be done.

References

[1] Lisowski E., Filo G., *Automated heavy load lifting and moving system using pneumatic cushions*, Automation in Construction, Vol. 50, 2015, 91–101.

[2] I-Shih L., *A note on the Mooney-Rivlin material model*, Continuum Mechanics and Thermodynamics, Vol. 24, 2012, 583–590.

[3] Jaszak P., *Modelowanie gumy za pomocą metody elementów skończonych*, Elastomery, Vol. 20, No. 3 , 2016, 31–39.

[4] http://help.solidworks.com, Mooney-Rivlin hiper-elastic model.

[5] http://help.solidworks.com, Contact between elements.