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THE STUDY OF MECHANICS OF DEFORMATION BEHAVIOUR OF SERVICE ROBOTS GRIPPING SYSTEMS

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Abstract: *This paper presents an analysis of the gripping system and contact links with a vertical plane of contact. It focuses on comparing the classic gripping elements and elements which combined methods of gripping force deducing with the using of different physical principles (vacuum, friction and adhesion). The first part of the paper describes the behavior of suction cups used as standard during radial loading using a computer simulation depending on rigidity of an elastomer sealing rim of the suction cup. The second part illustrates structural modifications of the suction cup by means of a bearing supporting plate having a material with an adhesion layer on the contact boundary and allowing the down-pressure to be regulated depending on mechanical properties of the object kept.*

Keywords: ***Gripping element, suction cup, vacuum, adhesion, contact.***

1. Introduction

In most cases it concerns applications combining the latest smart vacuum technology with high-tech systems of multi-angle industrial robots having six degrees of freedom that replace standard single-purpose manipulators step by step. When handling of jumbo formats of sheets having boundary dimensions ca. 3 x 6 m, nowadays a cooperation of two robots placed on a common travelling device is used. It is obvious that a handling task like this makes high demands for providing the parallel motion of both robots. Possible inaccuracies in positioning (Horák, 2005) find distinct expression in an undesirable loading of the sheet gripped, excessive loading of the robot wrist and vacuum gripping elements.

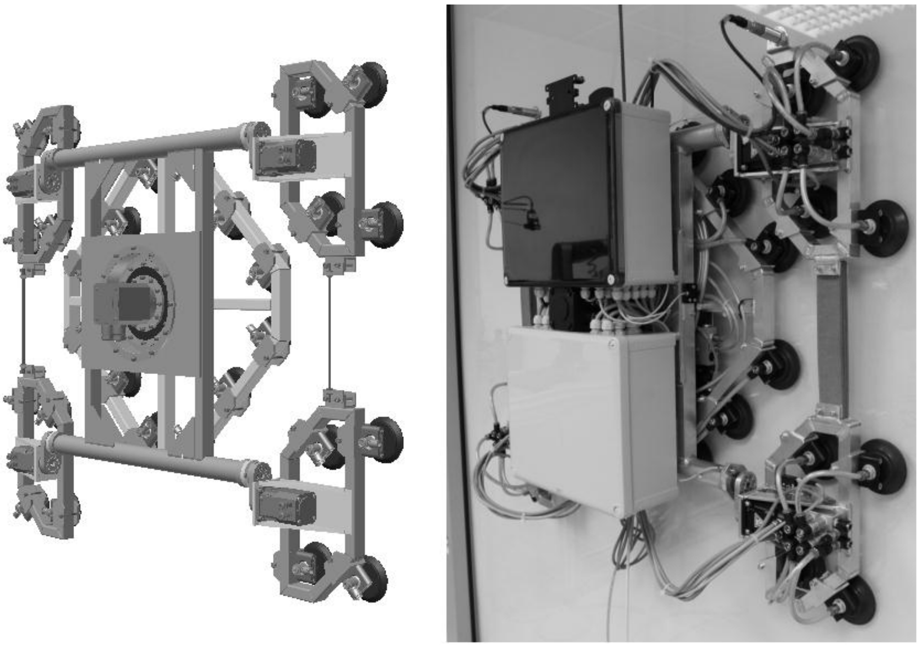

Fig. 1: Developed service robot platform for a motion on the vertically oriented glass walls

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The use of suction cups in the field of holding-down systems, such as locomotion devices (chassis) of service robots allowing the autonomous motion on vertically oriented walls, is a reciprocal task (Fig. 1). As for the systems based on the stepping principle of the robot motion (Novotný & Horák & Plavec, 2011), changes in the center of gravity distance occur, which has a negative impact on the loading pattern of particular suction cups subjected to radial and axial forces as well as to tilting moments depending on the geometry of the chassis kinematics (climbing robot).

It is necessary to specify such safety level so that the gripping or holding-down system satisfied the requirements for the stable keeping in the all regimes of loading. Thus, authors put the accent on an analysis of deformation behavior of suction cups with a rigid body and flexible sealing rim. The basic aim is focused to modify the contact areas of the suction cup in order to increase their load capacity in radial direction when a preservation of the vacuum level, because during the robot motion on the vertical walls the suction cups are overtaxed in the radial direction.

2. Deformation analysis of standard suction cup – computer model

The contact of the suction cup and sheet in accordance with the classic power conception has been already analyzed in (Novotný & Horák, 2008), where it was found that a resultant value of the safety coefficient is in the region of 14 to 20 respecting changes in the friction character in any position of the gripping plane. To have the full picture, the classic power analysis was supplied experimentally verified results of the computer simulation using the finite-element method, when an adequate numerical model of the standard suction cup was created (Fig. 2) respecting material properties of TPU (Horák, 2008) for the description of which the Mooney-Rivlin rheological model was used, when it is valid that

$$\frac{F}{2A_0\left(\lambda_1-\frac{1}{\lambda_1^2}\right)}=c_{10}+\frac{c_{01}}{\lambda_1}, \tag{1}$$

where F = force, λ_1 = deformation, c_{10} and c_{01} is Mooney-Rivlin material constant and A_0 is the cross section initial area during uniaxial tension test (1). When the test results are known, it's possible to determine the material constants from main stress in dependency on the actual deformation λ_1. In the other cases it can be used the relations (2) and (3) for the determination of material constants depending on the modulus of elasticity E.

$$c_{01}\cong\frac{1}{4}c_{10}, \tag{2}$$

$$6\cdot(c_{10}+c_{01})\cong E\,. \tag{3}$$

Boundary conditions describing the character of frictional conditions were set on the basis of the laboratory test results. It was demonstrated that the friction coefficient values have been dependent substantially on a state of the contact material surface (glass), which is resumed clearly in the diagram in Fig. 3.

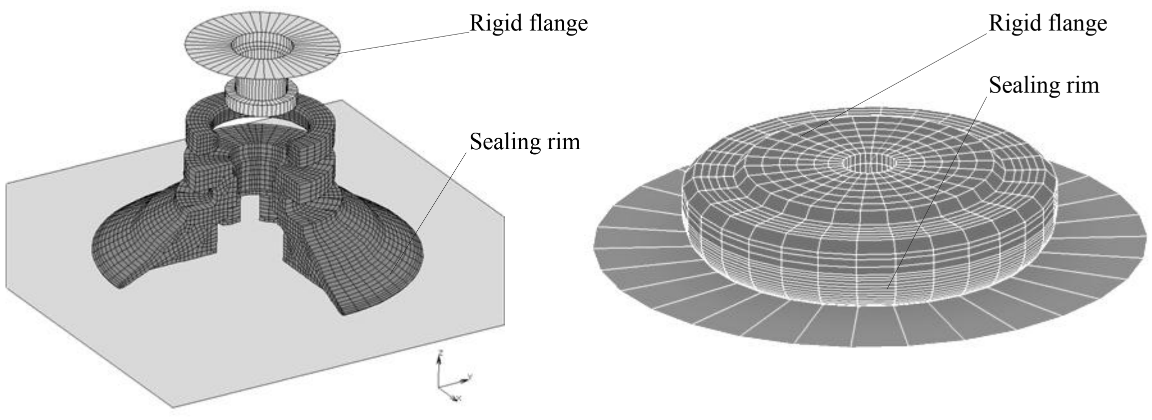


Fig. 2: Computer models for two basic types of standard suction cups

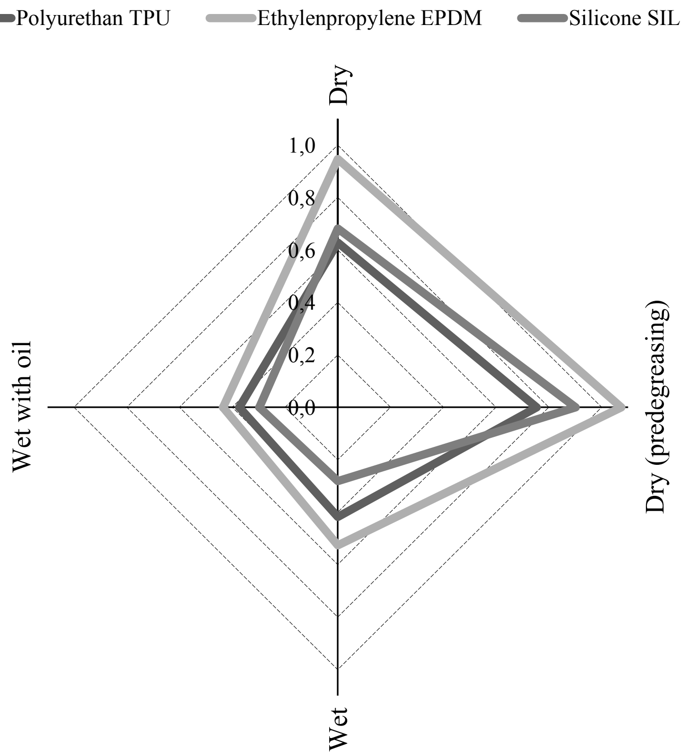
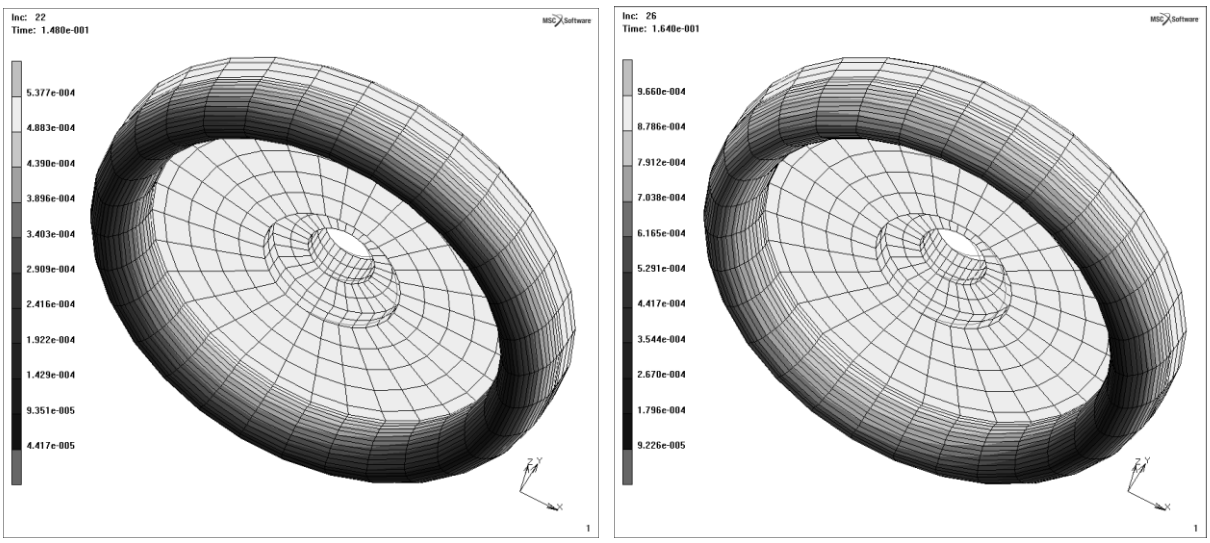


Fig. 3: Friction coefficient

The computer model was also optimized from standpoint of a variable active surface of the suction cup depending on the loading profile; this surface is defined by the suction cup effective diameter (important for the suction cup without a rigid body). The actual contact area corresponding to the loading level was detected in view of the state of contacting bodies (the contact quality) during each step of the calculation. This effect contributed greatly to obtaining of the representative computer model of the suction cup behavior during external loading.

3. Computer simulation results

During the computer simulation of the suction cup (with the rigid body - rigid bearing plate) deformation behavior (the geometrical diameter of 60 mm), the series of calculations was carried out. Subsequently the model created (Fig. 4) allows an influence of the sealing rim rigidity on a course of the contact profile shift to be evaluated depending on the radial loading force F_{RAD} value.



F_{RAD} = 120 N *F_{RAD} = 160 N*

Fig. 4: Deformation of the suction cup's sealing edge in axis x (vacuum level -60 kPa)

Being based on a series results, the course of the contact profile shift in the plane perpendicular to the suction cup axis was analyzed in detail at pre-selected points owing to the action of the external radial force. The course characters depending on the elastic modulus in the range 2-30 MPa and the friction coefficient 0.8 are shown in diagrams in Figures 5 and 6. The real behaviour of the sealing rim is replaced by the Mooney-Rivlin material model (MSC.Marc, 2004, MSC.Marc, 2005).

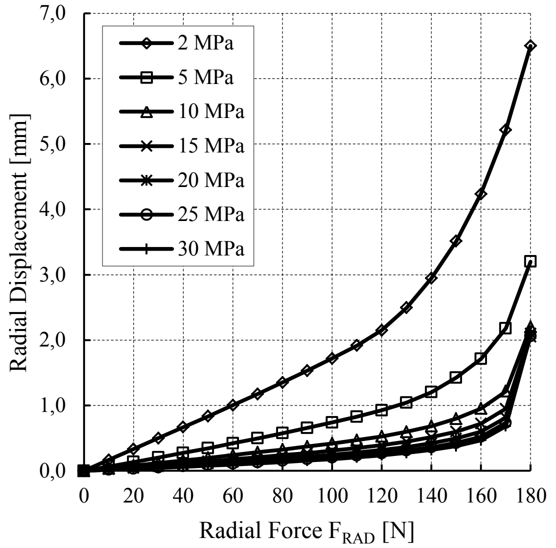


Fig. 5: Distance of the suction cup center

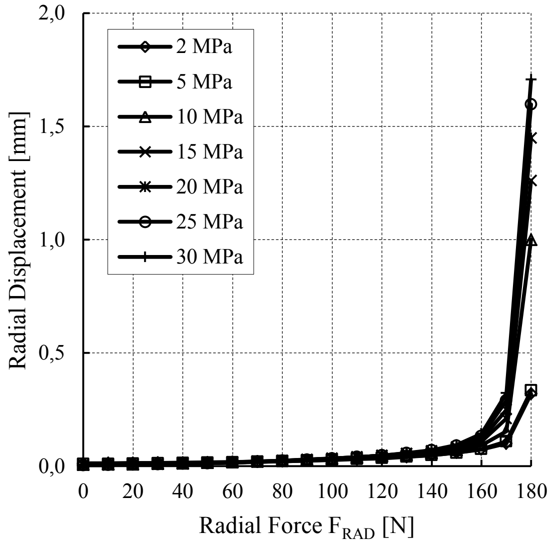


Fig. 6: Distance of profile edge

From the standpoint of the contact stability, the given results show that primary shifts of the contact profile of the suction cup occur already in the radial loading range from 60 to 120 N. The range from 120 to 140 N is to be found on the contact stability limit. Any next increase of the loading results in a collapse and subsequently it leads to the suction cup shifting in the plane of loading (Novotný & Horák, 2009, Novotný & Horák, 2010).

4. Combined vacuum adhesive gripping element

The proposed design solution combining the vacuum gripping element (GE) with a rigid flange, a flexible sealing rim, and a withdrawable positionable plate treated by an adhesive layer is a one possibility to increase the radial load capacity (Horák & Novotný, 2011).

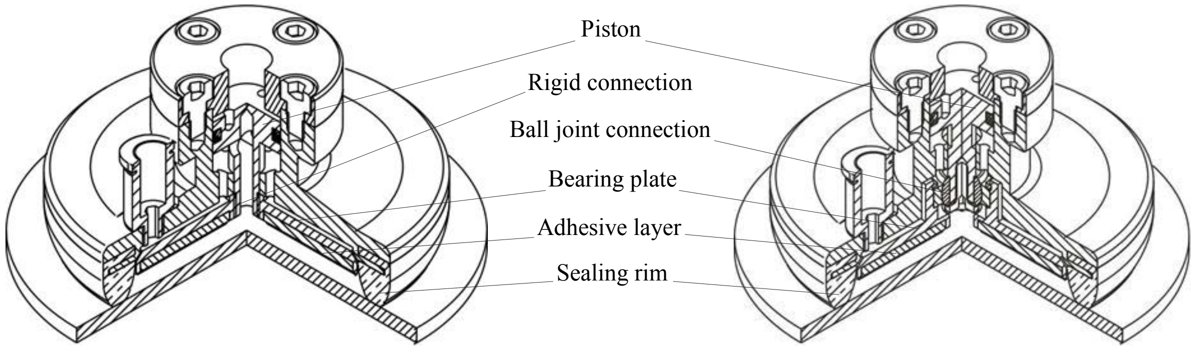


Fig. 7: GE without flatness compensation

Fig. 8: GE with flatness compensation

The technical solution concept is illustrated in Fig. 7 which comprises a detailed section of the gripping element configuration with a rigid threaded connection of the bearing plate and the piston. Fig. 8 shows the solution enabling to adjust automatically the adhesive layer or the bearing plate orientation depending on an orientation of the object contact surface (the plate and the piston are connected through a ball joint) in position when the adhesive insert is out of the contact with the object handled.

4.1. Results of laboratory tests

The aim of tests was to verify a utility of the solution in terms of an increase in the element load capacity particularly in the radial (tangential) direction as well as to analyze the gripping system behavior at various vacuum levels, and in different degree of the bearing plate putting out or putting in owing to the handled object, and also to define its optimal position. Results of primary tests are shown in diagrams in Figures 9 and 10.

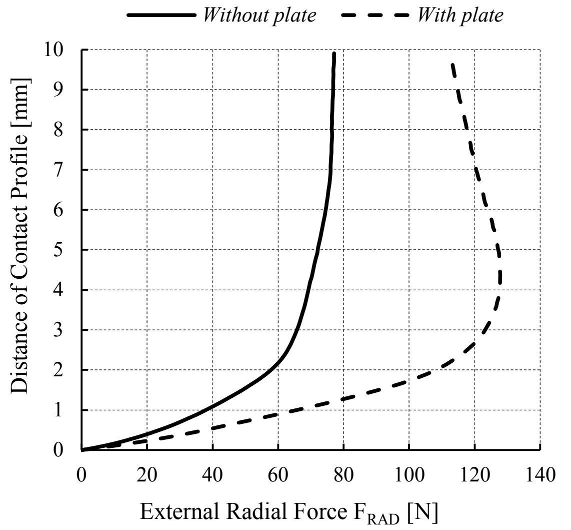


Fig. 9: Rad. distance of profile (vacuum -40 kPa)

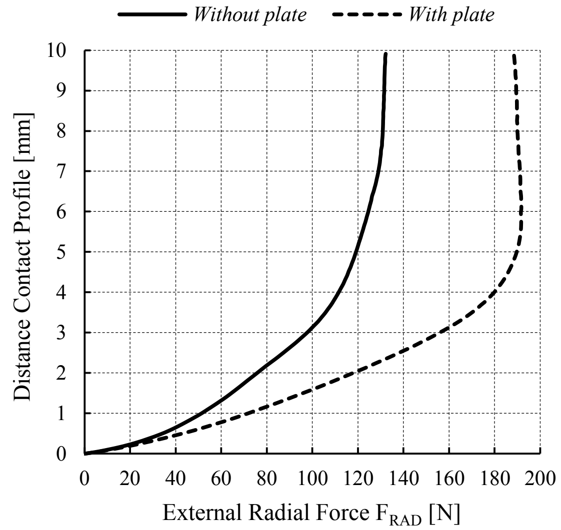
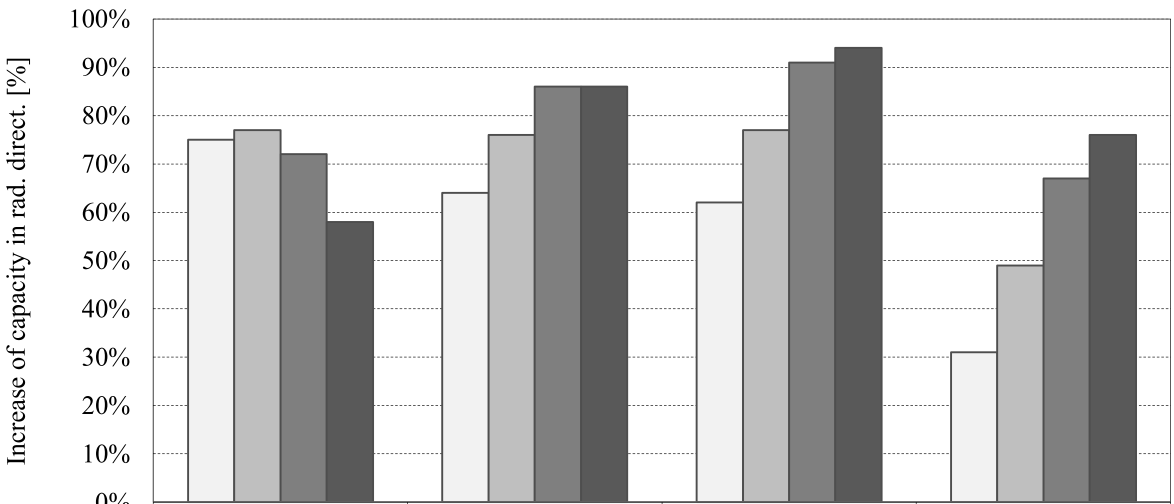


Fig. 10: Rad. distance of profile (vacuum -80 kPa)

4.2. Tests evaluation

From the diagrams given it results that the adhesive layer together with the bearing plate affects evidently the gripping (contact) stability and finds expression in a marked increase of the load capacity (Fig. 11) which is dependent on the observed level of the contact profile shift and vacuum, and ranges from 31% to 94%. As for a pure stabile character of the contact defined by the determined maximum shift 0.5mm, the load capacity increase as high as **60 %** at average.



Displacement / Vacuum	- 20 kPa	- 40 kPa	- 60 kPa	- 80 kPa
0,5 mm	75%	64%	62%	31%
1,0 mm	77%	76%	77%	49%
1,5 mm	72%	86%	91%	67%
2,0 mm	58%	86%	94%	76%

Fig. 11: The increase in load capacity of gripping element in the radial direction

5. Conclusions

The paper submitted describes possibilities of an industrial utilization of adhesive layers for designing gripping elements. The computer model of the vacuum gripping element used as standard was prepared, and the effect of the sealing rim rigidity on the contact stability was analyzed during external loading in the contact plane.

The main part was focused on problems related to increasing the load capacity of elements in radial direction by reason of unprecedented demands on vacuum gripping heads in connection with the new production technologies and methods. A vacuum-adhesive gripping element was designed and tested in laboratory. Provided clean operation, it was shown during tests that the use of adhesive layers leads to increasing of the radial load capacity at tens of per cents in comparison with standard solutions whereas the vacuum level is kept.

Acknowledgement

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References

Horák, M. (2005) Dynamická manipulace s tenkými deskami skla. *Disertační práce*, Liberec: Technická univerzita v Liberci, 2005. 133 s.

Novotný, F. & Horák, M. & Plavec, M. (2011) Mobilní plošina pro pohyb po vertikální stěně. *Utility model No. 22900*, http://spisy.upv.cz/UtilityModels/FullDocuments/FDUM0022/uv022900.pdf

Novotný, F. & Horák, M. (2008) Robot Handling in Automatic Flat Glass Production. *Acta Mechanica Slovaca*, 12 [2008], č. 2-A, s. 419-430. ISSN 1335-2393.

Horák, M. (2008). Dynamická manipulace s plochým sklem. Liberec: TU v Liberci. 2008. 165 s., ISBN 978-80-7372-425-2.

MSC.Marc® (2004) Nonlinear Finite Element Analysis of Elastomers. *Technical paper*, p. 66.

MSC.Marc® (2008) Manual Volume A - Theory and User Information. p. 793.

Novotný, F. & Horák, M. (2009) Computer Modelling of Suction Cups used for Window Cleaning Robot and Automatic Handling of Glass Sheets. *MM Průmyslové spektrum - MM Science Journal*, č. 2, MKČR E 7645. p. 113-116. ISSN 1803-1269. www.mmscience.eu/20090304.

Novotný, F. & Horák, M. (2010) Problems of Loading Capacity of Suction Cups in the Radial Direction. In: *Proceedings of the Fifth International Conference on Optimisation of the Robots and Manipulators*, Calimanesti, Romania, p. 70-74, ISBN 978-981-08-5840-7, doi: 10.3850/978-981-08-5840-7_S2-4.

Horák, M. & Novotný, F. (2011) Podtlakový úchopný prvek. *Utility model No. 22075*, *Patent No. 302959*, http://spisy.upv.cz/UtilityModels/FullDocuments/FDUM0022/uv022075.pdf, http://spisy.upv.cz/Patents/FullDocuments/302/302959.pdf

Horák, M. & Novotný, F. (2011) Increases in the Radial Capacity of Vacuum Gripping Elements. *MM Science Journal, October 2011*, Special Edition - 20th International Workshop on Robotics in Alpe-Adria-Danube Region (RAAD), October 5-7 2011, MKČR E 7645, www.mmscience.eu, p. 122-127. ISSN 1803-1269 (Print), ISSN 1805-0476 (On-line)