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# DESIGN OF A FLEXIBLE TUBE ROBOT

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**Abstract**. *The aim of our research activity is to analyse and develop several new types of compliant structures such as new types of flexible actuators and grippers made of silicone rubbers. Nowadays these materials offer a new perspective for the construction because of their special mechanical, electrical, optical and chemical properties.*

**Key Words**: *Silicone Rubber, Flexible Actuator, Inchworm-like Robot*

## 1. INTRODUCTION

We have shown in our publications [1], [2] that the material and dynamic behavior of silicone rubbers allows for the layout of special high elastic constructions in the precision engineering and medicine. Further, we have also shown that special dotted silicone rubber elastomeres can be used as sensor and actuator materials because of their electric and magnetic properties. A recent paper summarizes the results of the newest investigations and gives some ideas for the application of this material in special high elastic hydraulically controlled actuators.

We also show the special instability problems of the constructions since these devices are controlled by the inner pressure. The numerical modeling of the dynamic behavior and the optimization are important since the manufacturing costs of precision tools are rather high.

## 2. SILICONE RUBBER ACTUATORS

The high elasticity of silicone rubber materials does not allow their direct application as fixing or gripper elements. Our investigations in the field of self-moving endoscopes [3] has shown, however, that bellow-like elastic pipes filled with liquid ensure the necessary stiffness for the construction; moreover, they can produce the desired translating movement and the surface of this actuator allows soft contact.

We present in this paper the modeling and optimization of a hydraulically controlled bellow-like actuator for worm-like locomotion.

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## 3. DESIGN OF SPECIAL ACTUATOR FOR FLEXIBLE ROBOT

There are some fields in engineering systems and in medicine where conventional locomotion forms such as by-wheels can not be invented. This type of self locomotion represents the instruments in small tubes or the actuating with endoscopes inside the human body. The conventional intestinal flexible endoscopes in the medicine are led by force from outside into the body. The aim of the investigations is to create an instrument with self-locomotion to avoid the damages occurred by the external forces. We have built and presented at the 47th IWK a biologically inspired three-chamber instrument with hydraulic drive [6].

The chambers are fiber reinforced and can change their dimensions in different ways. The chambers on the both ends have embedded fibers along the axis and the wall of the middle part is strengthened with cylindrical fibers. Each of the chambers can be controlled separately so the device moves in a tube like the worm (see Fig. 1).

To increase the velocity and to avoid the closing of the cross section of the tube a more complicated device is constructed. The direction dependence of strain can be realized by material or structural inhomogenity. In this case we have achieved the different abilities for strain with structural inhomogenity especially with bellow-shaped hydraulic actuators. Fig. 2 shows the ANSYS simulation of the bellow-pipe actuator.

The device shown in the Fig. 1 right is able to move also in curves since the longitudinal actuators can be controlled separately.

Fig. 1. Phases of locomotion of inchworm, a fiber reinforced 3-chamber hydraulic device with inchworm-like locomotion form

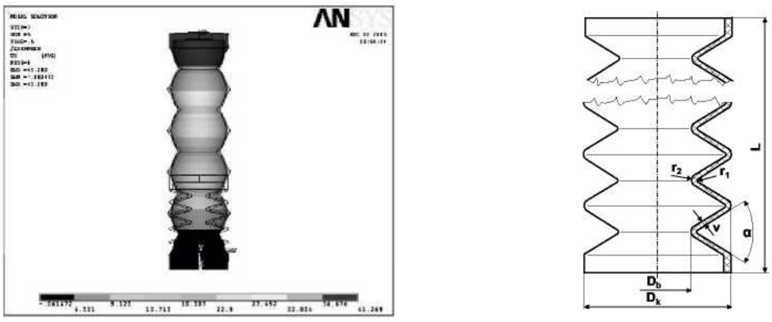



Fig. 2. Simulation of the actuator working and geometric parameters of the bellow shape actuator

The test object of the apparatus is built and tested (see later). The next goal is to decrease the dimensions without decreasing the mechanical stability.

In addition to stability in the whole working range, another interesting problem is to optimize the bellow angles, the wall thickness and the relation between the outer and inner diameters to achieve maximal elongation.

The elongation can increase if the static length of the actuator represents the manufactured length. So, we can decrease the static length with vacuum and increase it by pressure but the stiffness no longer remains constant; rather, it depends on the pressure. This simple solution, however, demands stability calculations with FEM modeling. Unsuitable angle and wall thickness lead to instability and the bellow collapses instead of shortening like our simulation results show.

## 4. FEM MODELLING OF THE BELLOW ACTUATOR

We have used the ANSYS program for the FEM simulations which allows the calculations also with high elastic material parameters. The model is built up with hyper elastic elements.

The nodes along the lower edge of the model are fixed in both directions. The inner side of the bellow is loaded in 1 s by linear increased pressure up to 0.75 bar. The material of the actuator is silicone rubber with the hardness Sh 40. The nonlinear behavior of the material is described by the five parameter Mooney-Rivlin model. According to our former calculations, the elongation of the bellow shaped actuator depends on the proportion between profile depth and wall thickness. Varying the geometric parameters we obtain that if the wall thickness (v) is significantly smaller than the profile depth (Rk-Rb) the actuator produces the best elongation results. In the case if the wall thickness is equal to the profile depth the actuator will not be able to work regularly. The cross section will increase instead of producing elongation since the energy is not sufficient to fold the bellow elements. One of the simulations is shown in the Fig. 2. The shape of the start position of the bellow is marked by thin lines. In the case of optimized geometric parameters the elongation is suitable and the change of the cross section is negligible.

The Fig. 3 shows the realized result of the optimization process. On the basis of the simulations a test tool is manufactured of steel. In the figure one actuator can be seen in use by pressure (a) and vacuum (b).

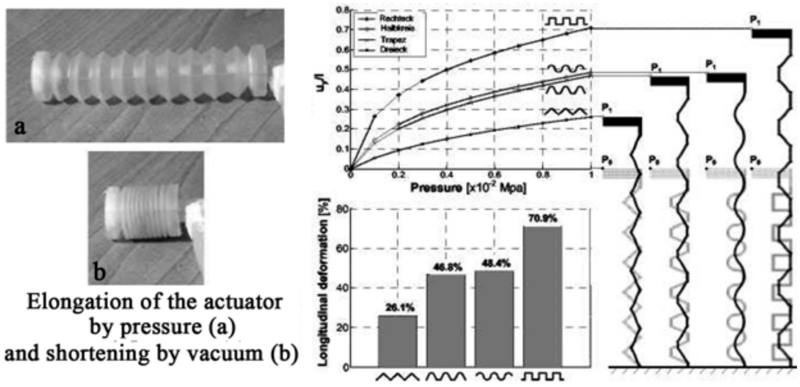



Fig. 3. Examination of different profiles in the case of equal length of differently shaped actuators

## 5. Simulation and control measure of stability

We have decided to control the simulation results by manufacturing a special tool to produce a bellow actuator with calculated instability.

The proportion between profile depth and wall thickness is optimized for maximal elongation but we have chosen an angle exactly near to the stability limit. The test object works for pressure well but one can observe in the Fig. 4 that the bellow collapses in the case of vacuum and the simulation result using the same geometrical parameters confirms this. The investigation shows that such coincidence between simulation and practice can only exist if the material parameters used in the computer simulations are exact. The optimization process was extended to the analysis of the influence of the shape of the bellow. Fig. 3 shows the result of the simulations.

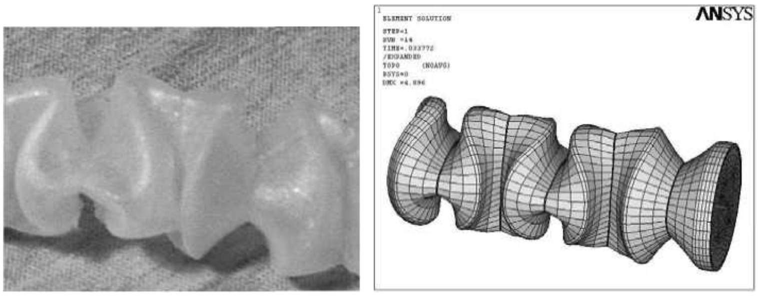



Fig. 4. Structural instability of test object for vacuum and the result of control simulation of instability

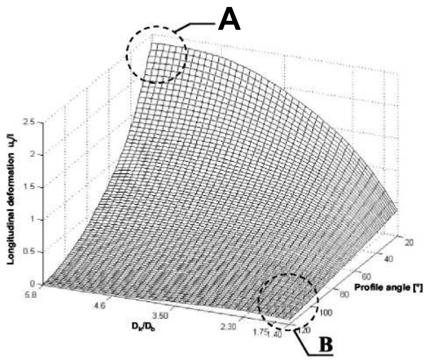


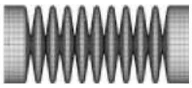

Fig. 5. Optimization of the geometry for longitudinal deformation structural instability of test object for vacuum and the result of control simulation of instability

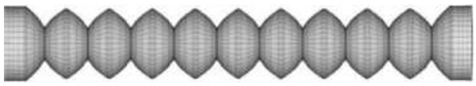
Let see the elongations of the actuators in Figs. 6 and 7 with two radically different groups of parameters. It is clear that the case ",B" is not suitable as actuator since the elongation is practically zero.

We have measured the change of length depending on the inner pressure on the test actuators (see Figs. 6 and 7).

**The case „A" see Figs. 5 and 6**

Parameters:
Proportion (see Fig. 2): Dk/Db=5.8, Angle: a=20°
Basic length without inner pressure Deformed state with inner pressure see above





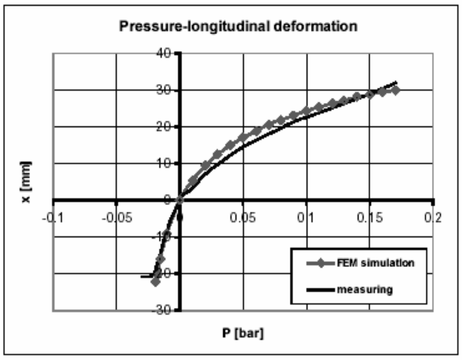
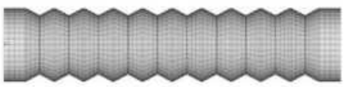
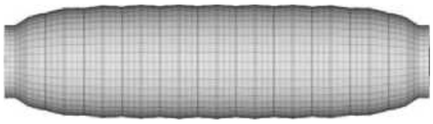



Fig. 6. FEM and measured results of the test actuator with 45° profile angle

**The case „B" see Figs. 5 and 7**

Parameters:
Proportion (see Fig. 6): Dk/Db=1.4, Angle: a=120°
Basic length without inner pressure Deformed state with inner pressure see above





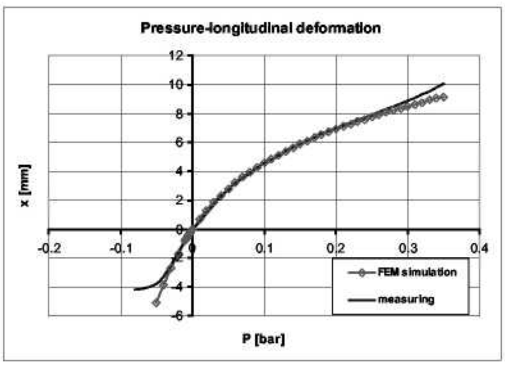



Fig. 7. FEM simulation and measured results of the test actuator with 30° profile angle

We show in Fig 8. bellow-shaped hydraulic actuators in different sizes and with different profile angles and the tools for manufacturing. The tools are complicated and expensive. The shape is always a compromise between the desired shape and the technology since the ready bellow has to be able to remove from the tool after vulcanization. This problem appears mainly by the miniaturized versions. Profile and angle mainly influence the acting length of the bellow actuator.

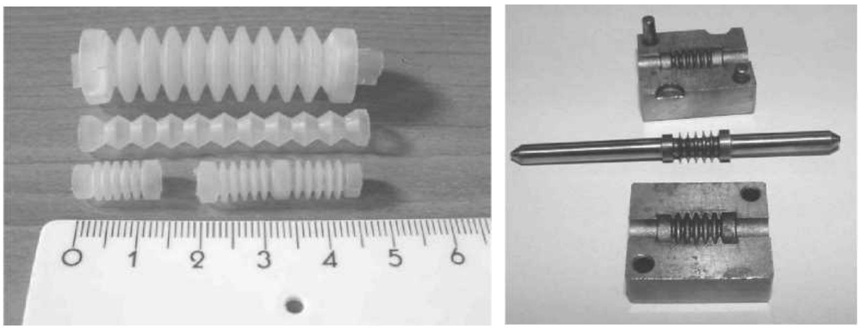
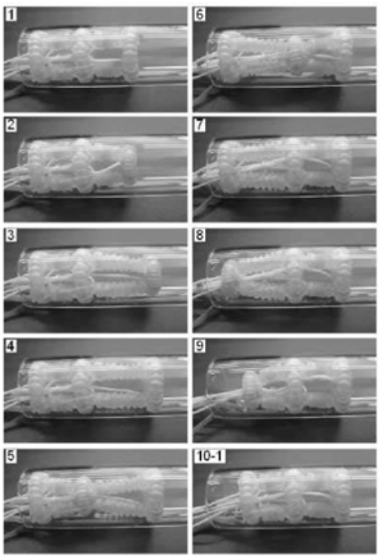
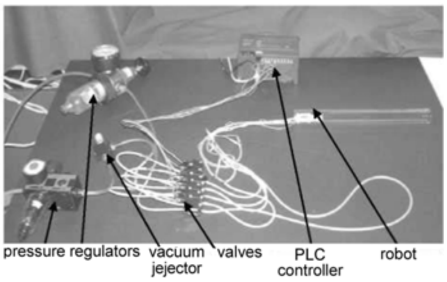



Fig. 8. Bellow-shaped actuators in different sizes and the tool set of miniature actuator

The patented endoscope [5] of Fig. 1 based on the worm locomotion is built and tested. The control of the separated actuators is realized by pneumatic elements and by PLC. The results are positive. We show the phases of the movement of test endoscope below. The investigations are continued by replacing the rigid wall of the test tube by high elastic structures to simulate the intestinal living organs. Further on, the friction coefficient between the tube wall and device will be changed.

The next pictures in the Fig. 9 show the worm like "robot" in different phases of movement.




PCL control of the robot

Fig. 9. Moving Phases of High Elasticity Patented Pneumatic [5] Tube "Robot"

The separated control of segments allows also the controlled bending of the device. The same figure shows the test arrangement of the PLC controlled pneumatic endoscope moving in a glass tube.

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# PROJEKTOVANJE FLEKSIBILNOG ROBOTA U OBLIKU CEVI

**Antal Huba, Jozsef Keskeny**

*Cilj našeg istraživanja je analiza i razvoj nekoliko novih vrsta gipkih struktura kao što su nove vrste fleksibilnih aktuatora i hvatača napravljenih od silikonske gume. U današnje vreme ovi materijali nude novu perspektivu u procesu konstruisanja zbog svojih posebnih mehaničkih, električnih, optičkih i hemijskih osobina.*

Ključne reči: *silikonska guma, fleksibilni aktuator, robot u obliku pokretnog crva.*