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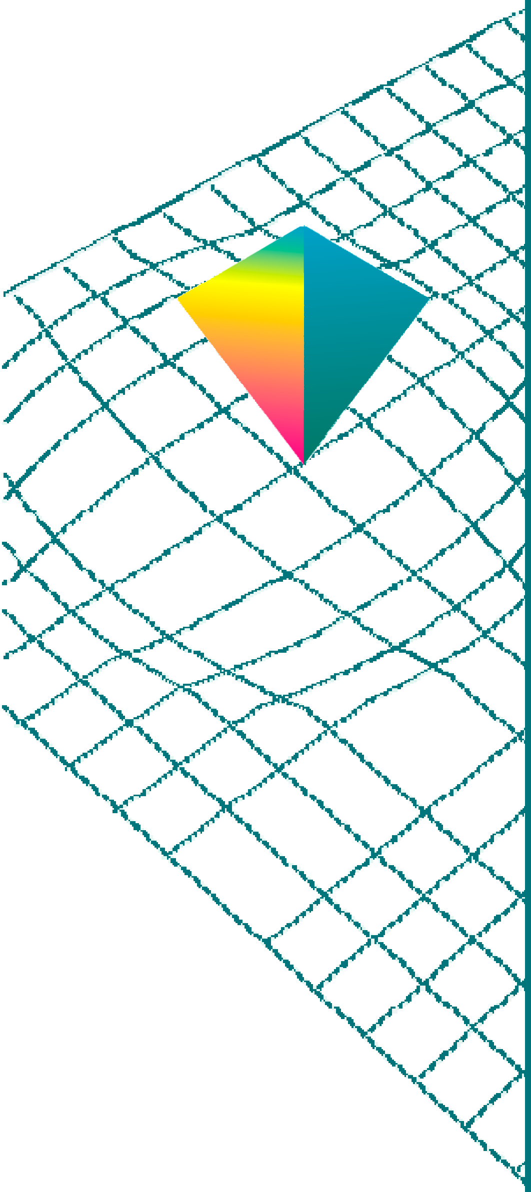
September, 19-23, 2005



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Mechanical Engineering from Macro to Nano

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50. Internationales Wissenschaftliches Kolloquium
Techniche Universität Ilmenau
19.-23. September 2005

Dr. A. Huba - J. Keskeny – B. Egri

Bionic Based Actuator and Gripper

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 from silicone elastomeres. Nowadays these materials offer new perspective for the construction because of their special mechanical, electrical, optical and chemical properties.

INTRODUCTION

We showed in our publications **[1], [2]** that the material and dynamic behaviour of silicone rubbers allows the layout of special high elasticity constructions in the precision engineering and in the medicine. Further we also showed that special dotted silicone rubber elastomeres can be used as sensor and actuator materials because of their electric and magnetic properties. Recent paper summarise the results of the newest investigations and gives some ideas for the application of this material in special high elasticity hydraulic controlled actuators.

We also show the special instability problems of the constructions since this devices are controlled by the inner pressure. The numerical modelling of the dynamic behaviour and the optimisation is important since the manufacturing costs of precision tools are rather high.

SILICONE RUBBER ACTUATORS

The high elasticity of silicone rubber materials does not allow the direct application as fixing or gripper element. Our investigations on the field of self moving endoscopes **[3]** showed however that bellow-like elastic pipe filled with liquid ensure the necessary stiffness for the construction and can produce the desired translating movement and the surface of this actuator allows soft contact.

We present in this paper two examples of hydraulic controlled actuators. First we show the modelling and optimisation of actuators for worm-like locomotion and the second example is the soft gripper for robotics.

ACTUATOR FOR SELF LOCOMOTION

There are some fields in the in technical systems and also in the medicine where conventional locomotion forms such as by wheels can not be invented. This type the self movements represent the instruments in small tubes or the actuating with endoscopes inside of the human body. The conventional intestinal flexible endoscopes in the medicine are lead *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 built and presented at the 47th IWK a biological inspired three-chamber instrument with hydraulic drive **[7]**.

The chambers are fibre reinforced and can change their dimensions on different ways. The chambers on the both ends have embedded fibres along the axis and the wall of the middle part is strengthened with cylindrical fibres. Each of the chambers can be controlled separately so the device moves in a tube like the worm see Fig. 1 and 2.

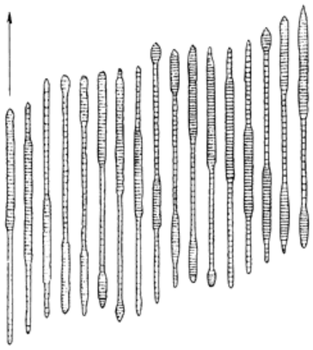


Fig. 1 Phases of locomotion of inchworm

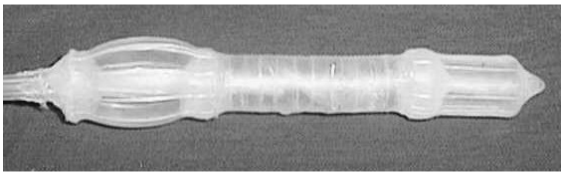


Fig. 2 Fibre reinforced 3-chamber hydraulic device with worm-like locomotion form

To increase the velocity and to avoid the closing of the cross section of the tube a more complicated device was constructed. The direction dependence of strain can realised by material or structural inhomogenity. In this case we achieved the different abilities for strain with structural inhomogenity especially with *bellow-shaped hydraulic* actuators**.** Fig. 3 shows the ANSYS simulation of the bellow-pipe actuators.

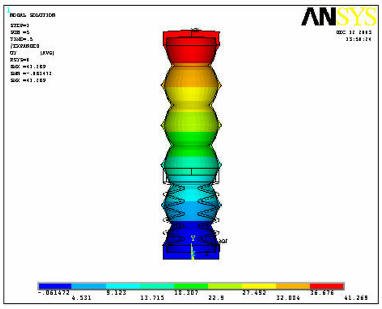


Fig. 3. Simulation of the actuator working area

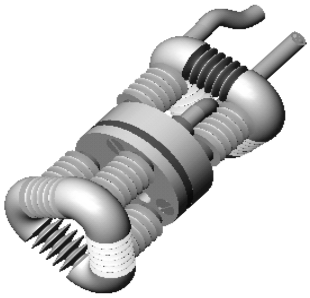


Fig. 4. Patented **[6]** controlled endoscope with bellow actuators

The device shown in the Fig. 4 is able to move also in curves since the longitudinal actuators can be controlled separately. The test object of the apparatus was built and tested see later. The next goal is to decrease the dimensions without decreasing the mechanical stability.

Beside of the stability in the whole working range one of the interesting problems is to optimise the bellow angles, the wall thickness and the relation between the outer and inner diameter 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 stays no more constant, it depends on the pressure. This simple solution however demands stability calculations with FEM modelling. Unsuitable angle and wall thickness lead to instability and the bellow collapses instead of shortening like our simulation results show.

FEM MODELLING OF THE BELLOW ACTUATOR

To decrease the calculation time we used two dimensional model since the object is cylindrical symmetric along the axis see Fig. 5. We used the ANSYS program for the simulations which allows the calculations also with high elasticity material parameters. The model was built up with two dimensional hyper elastic elements.

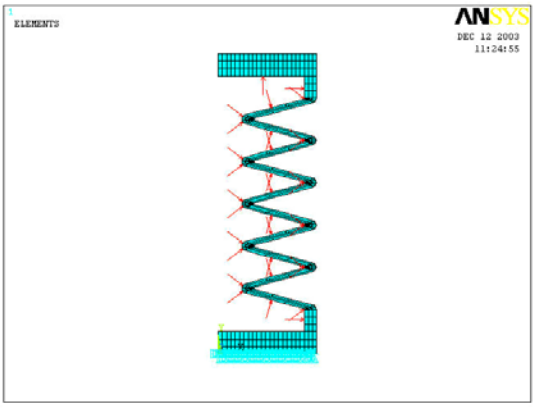


Fig. 5. FEM model with boundary conditions

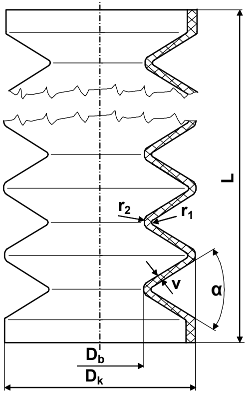


Fig. 6 Geometric parameters of the bellow shape actuator

The nodes along the lower edge of the model are fixed in both directions. The inner side of the bellow was 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 behaviour of the material was described by the five parameter Mooney-Rivlin model.

The elastic potential is described by:

$$W = \sum_{k+l=1}^{N} C_{kl}(I_1 - 3)^k (I_2 - 3)^l + \frac{1}{2}\kappa(I_3 - 1)^2$$

The five parameter Mooney-Rivlin potential:

$$W = C_{10}(I_1 - 3) + C_{01}(I_2 - 3) + C_{11}(I_1 - 3)(I_2 - 3) +$$
$$+ C_{20}(I_1 - 3)^2 + C_{02}(I_1 - 3)^2 + \frac{1}{2}\kappa(I_3 - 1)^2$$

with the invariants I_1, I_2, I_3

$$I_1 = \lambda_1^2 + \lambda_2^2 + \lambda_3^2 \; I_2 = \lambda_1^2 \cdot \lambda_2^2 + \lambda_2^2 \cdot \lambda_3^2 + \lambda_3^2 \cdot \lambda_1^2$$

The third invariant is known because of the constancy of volume:

$$I_3 = \lambda_1^2 \cdot \lambda_2^2 \cdot \lambda_3^2 = 1$$

where $\lambda_{1,}\, \lambda_{2,}\, \lambda_3$ are the specific strains along the main axes.

The parameters of the Mooney-Rivlin elastic potential in case of 40 Sh silicone rubber based on our measuring:

$$C_{10} = 0.36\ [MPa],\ \ C_{01} = 0,\ \ C_{11} = 0,$$
$$C_{20} = 0.0045\ [MPa],\ \ C_{02} = 0.002\ [MPa]$$

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 (e) is significant smaller than the profile depth (R_k-R_b) the actuator produces the best elongation results. In case if the wall thickness is equal to the profile depth the actuator will be not 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. 3. The shape of the start position of the bellow is marked by thin lines. In case of optimised geometric parameters the elongation is suitable and the change of the cross section is negligible.

The Fig. 7 shows the realised result of the optimisation process. On the basis of the simulations a test tool was manufactured from steel. In the pictures one can see the actuator in use both for vacuum (b) and for pressure (a).

a., b.,

Fig. 7. Elongation of the actuator
by pressure (a)
and shortening by vacuum (b)

SIMULATION AND CONTROL MEASURE OF STABILITY

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

Fig.8. Structural instability of test object for vacuum

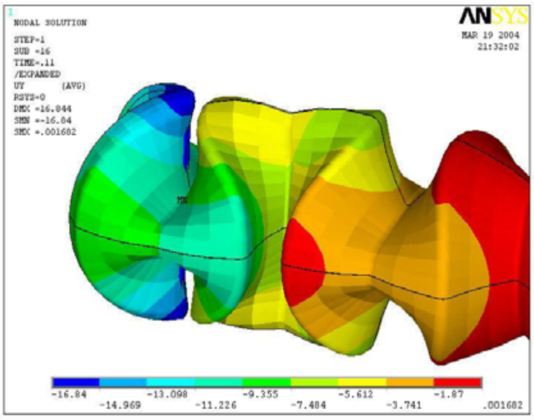


Fig. 9. Simulation of instability

The proportion between profile depth and wall thickness was optimised for maximal elongation but we have choose an angle exactly near to the stability limit. The test object works for pressure well but one can observe in the Fig. 8 that the bellow collapses in case of vacuum. The Fig. 9 shows the simulation result using the same geometrical parameters. 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 optimisation process was extended to the analysis of the influence of the shape of the bellow. The next figure shows the result of the simulations.

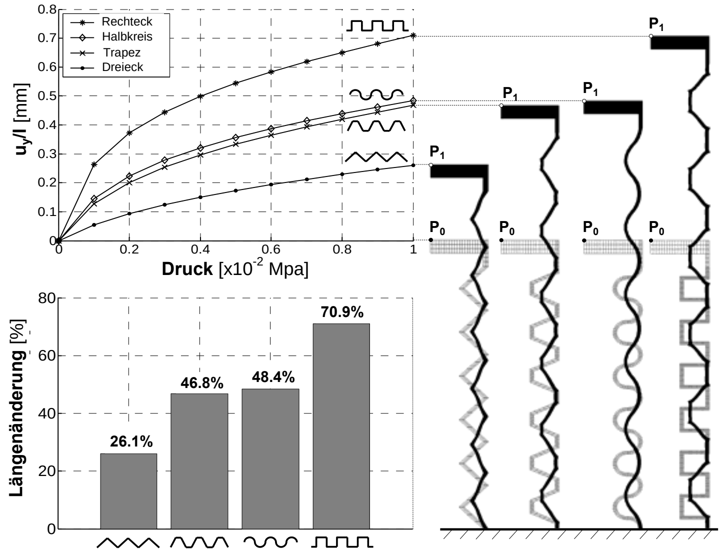


Fig. 10 Examination of different profiles in case of equal length of different shaped actuators

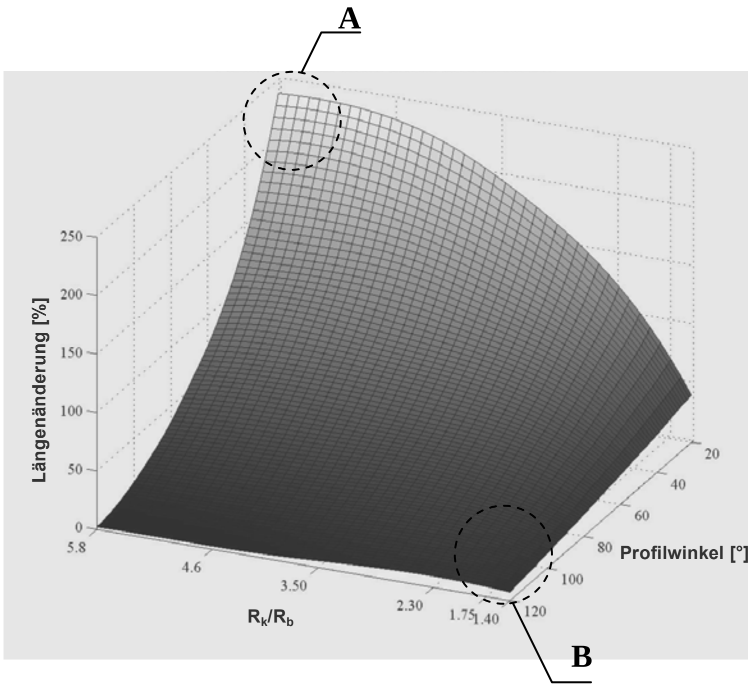


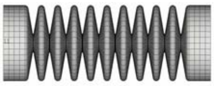
Fig. 11 Optimisation of the geometry for longitudinal deformation

See below the elongations of the actuators 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.

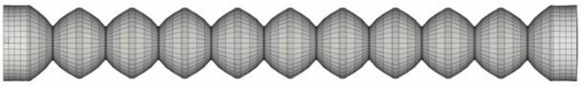
The case „A” see Fig. 11

Parameters:
Proportion (see Fig. 6): $R_k/R_b=5.8$, Angle: $\alpha=20°$, Pressure: $p=0.025$ Mpa

Basic length without inner pressure



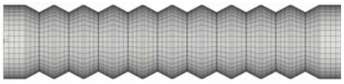
Deformed state with inner pressure see above



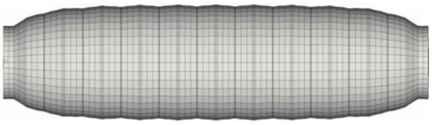
The case „B” see Fig 11

Parameters:
Proportion (see Fig. 6): $R_k/R_b=1.4$, Angle: $\alpha=120°$, Pressure: $p=0.025$ Mpa

Basic length without inner pressure



Deformed state with inner pressure see above



We show in the next figures bellow shaped hydraulic actuators in different sizes and with different profile angles see Fig 12/a and b. The tools for manufacturing 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 vulcanisation. This problem appears mainly by the miniaturised versions.

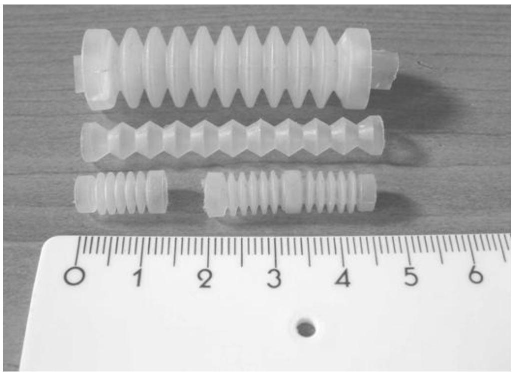


Fig.12/a Bellow shaped actuators

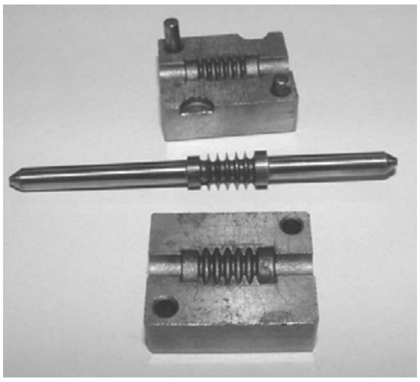


Fig.12/b Tool set of miniature actuator

Profile and angle influences mainly the acting length of the bellow actuator. We measured the change of length depending on the inner pressure on the test actuators see Fig. 13 and 14.

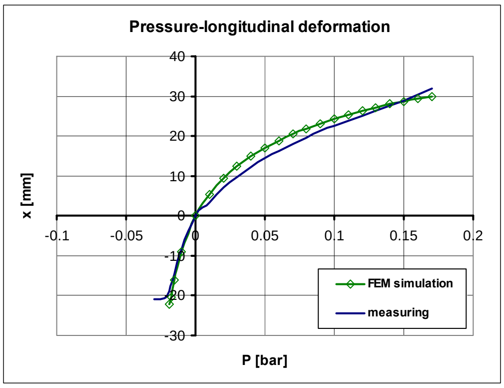


Fig. 13 The FEM and measured results of the test actuator with 45° profile

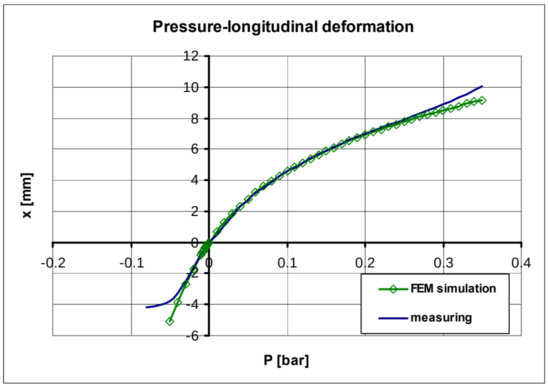


Fig. 14 The FEM and measured results of the miniaturized test actuator with 30° profile angle

The patented endoscope **[6]** of Fig. 4 based on the worm locomotion was built and tested. The control of the separated actuators is realised by pneumatic elements and by PLC. The results are positive we show the phases of the movement of test endoscope in the Fig. 16. The investigations are going on and we replaced the rigid wall of the test tube by high elasticity structures to simulate the intestinal living organs. In the next also the friction coefficient between the tube wall and device will be changed. Fig. 15 shows the test arrangement for the pneumatic controlled endoscope moving in glass tube.

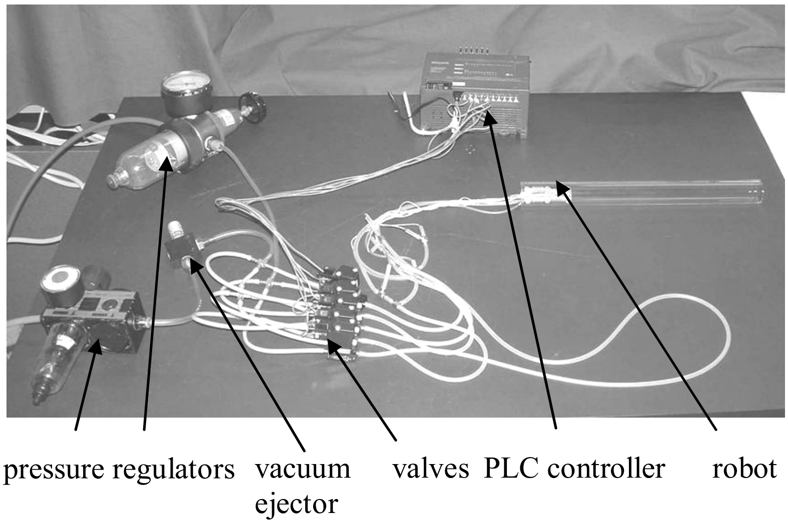


Fig 15. The pneumatic controlled test object moving in glass tube

The next pictures in the Fig. 16 show the worm like “robot” in different phases of movement. The special separated control of segments allows also the controlled bending of the device.

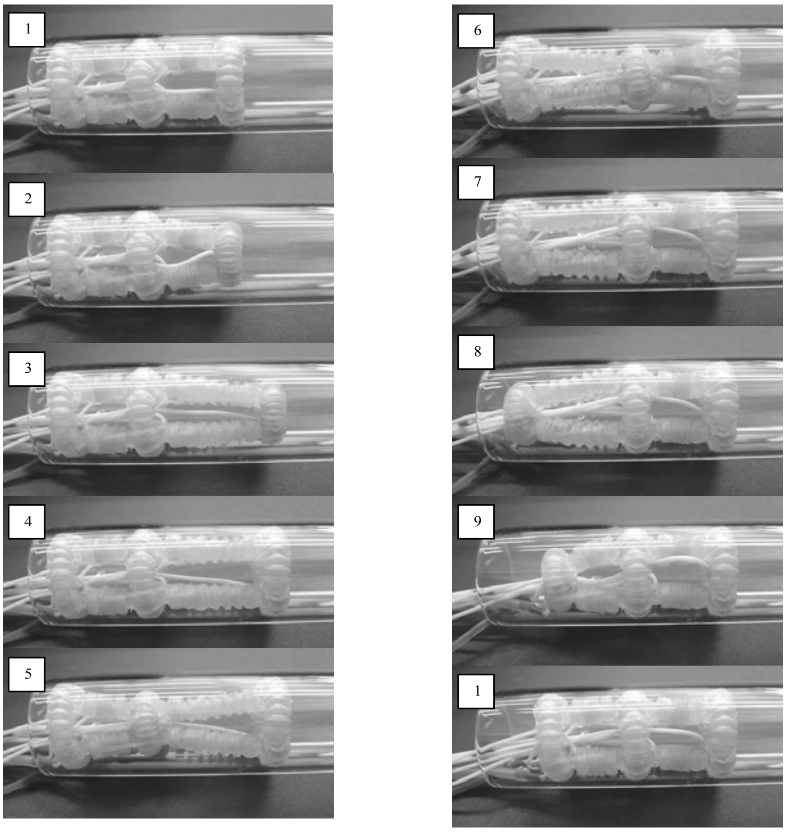


Fig. 16 Moving phases of high elasticity patented **[6]** tube „robot”

HIGH ELASTICITY GRIPPER

Böhm describes in his dissertation **[4]** special shaped soft grippers. His investigation in this field was the continuation of research work at the Dept. of Microsystemtechnics, Mechatronics and Mechanics of the TU Ilmenau. The “Silicone Rubber Research Group” of the TU Budapest work very close with the Group of Mechanics of the TU Ilmenau not only in manufacturing of test objects but also in the optimisation by FEM modelling. We present in this paper a soft gripper construction for robot handling based on the former investigations of Zentner **[5]**. The shape optimisation and the investigations about the placing of fibres in the structure is closed now we are going to manufacture the test objects with the metallic tool.

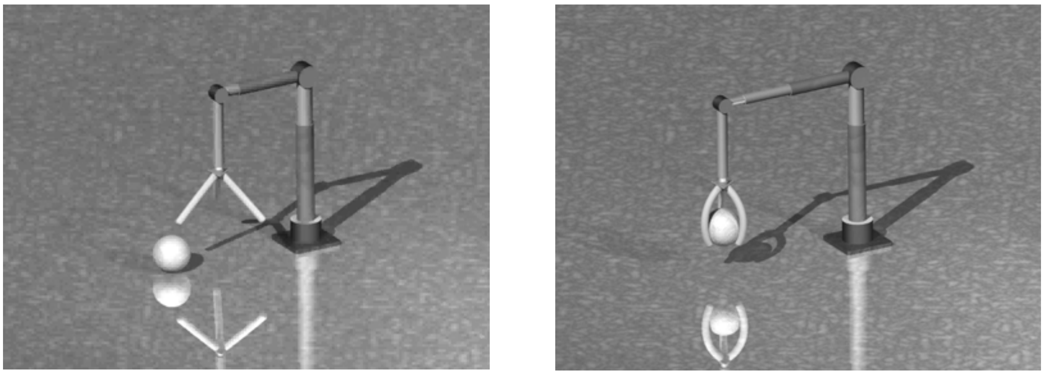


Fig. 17 Simulation of handling with the pneumatic controlled and fibre reinforced elastic gripper

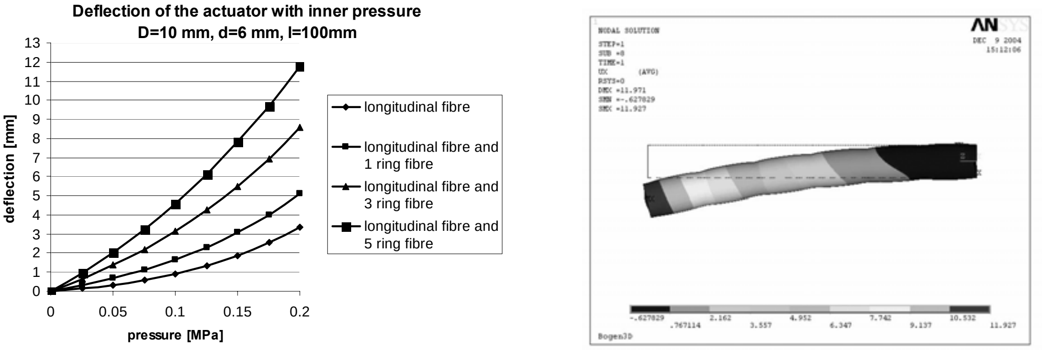


Fig. 18 The influence of the fibre reinforcing on the shape changing by inner pressure

The bionic approach combined with an excellent and durable material like silicone rubber allows realising compliant structures for special applications not only in the mechanical engineering but also in the medicine.

CONCLUSION

Silicone rubbers like other polymers have non-linear material behaviour. One has to calculate during the dynamic loading with relaxation and creep. In case of simulations with the program ANSYS we always used material characteristics obtained by own investigations on the field of material testing since the essential parameters only partial were given. We show in the paper ANSYS-supported shape optimisation of dynamic structures like hydraulic activated intestinal endoscopes and elements of soft grippers for handling.

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