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ROBOTICAL HANDLING OF POLYURETHANE FOAMS WITH NEEDLE GRIPPERS

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Abstract

The handling of non-rigid materials implicates different problems than handling usual rigid parts. The soft polyurethane foam is widely used in the production of car seats. Automating the handling of these materials requires special gripping methods. In this paper we focus on the needle gripping method. This method is based on a set of needles penetrating into the foam and lifting the foam by using the frictional force between the needles and the foam. A mechanical model is proposed for the calculation of the force needed to pull out a needle from a foam part. The theory is based on continuum mechanics and fractal geometry. The theory is then compared with the test values and measured results. A method for the principle of designing a needle gripper is also presented and explained on a newly developed gripper.

Keywords: handling, polyurethane, needle gripper, fractal geometry.

Introduction

When handling NRMs (non-rigid material) the problem occurs that such objects change their geometry under the influence of force. This non-rigidity makes automatic handling of these materials very difficult. Conventional robot grippers (like two-jaw grippers used for handling rigid materials) cannot be used because these methods can result in insufficient grasping. For NRMs different grasping methods have to be implied.

In this paper we deal with the designing steps of a gripper for handling soft polyurethane foam parts.

1. Problems when Handling Polyurethane Parts

When handling polyurethane parts such as seat foams, furniture parts, etc. the problem of deforming under gripping force occurs. Most of the time only one side of the part is accessible for grasping (this case happens when the foam is still in the mould, or the parts are stacked against each other), so a gripper is needed that grips only this (free) side of the part.

When designing the handling of polyurethane seat parts a careful analysis has to be made to map all the inserts that are polymerised into the foam. These inserts give comfort and safety for the seat but when a needle intersects an insert it breaks instantly. When designing the needle pad (see in chapter 3.3) these areas of the foam should be left free of needles. These areas reduce the space that can be implied for grasping, therefore reduces the number of needles to be used. This results in the reduction of implemented force.

2. Grippers for NRMs

Robot gripping methods may be loosely split into four basic types [1]: impactive, ingressive, astrictive and contigutive. The result effects of these gripping methods on any surface they are used with may be permeating or non-permeating. *Table 1* shows description of examples of grippers given for any particular method and effect.

Table 1. Description of gripping types and effects [1]

Gripping method	Gripping effect on material
Impactive	Jaws: clamps, chucks, e.t.c.
	Pinch: Clue-Picker, barbed blades
Ingressive	Brush: wire, velcro
	Needle: picklift, polytex, hackles
Astrictive	Magnetic, electroadhesive, vacuum, suction
Contigutive	Chemical adhesion, thermal adhesion

From the list the Ingressive type of gripper (Needle) was investigated.

Using vacuum for grasping can also be considered as a solution. However, because the foam is a porous material the air is sucked through the part and the vacuum is easily lost. In order to maintain the vacuum a powerful vacuum generator is needed, which is very expensive [8]. We focus on the needle gripper for a much cheaper solution.

3. Steps of Gripper Design

To start with the gripper design, the force that one needle can implement is discussed. When this knowledge is obtained the number of needles needed for the grasping and handling of the part can be calculated.

3.1. Needle Foam Interaction

In this section, a theory is introduced to calculate the pull out force of one needle. We assume that the distance between the needles is large enough that the deformations and stresses around a single needle are not influenced by the neighbouring needles.

Many experiments were performed with needles of various length (l) and diameter (d) to determine the pull out force. The measurement data are given in *Table 2*. Previously calculations [9] showed that the pressure (p) between the needle and foam does not depend on the diameter of the needle and can be assumed as a material parameter of the foam. We remark that the pressure (p) can be connected with the tearing strength of the foam.

Our first idea was to calculate the pull out force as $F = p\mu A$, where $A = dl\pi$ denotes the area of the surface of the needle and μ is the Coulomb type friction coefficient. The results of these equations for the needle force can be represented in the form

$$F = cdl, \tag{1}$$

where the material parameter $c = p\mu\pi$ can be determined from measurements. The other parameters p and μ are not needed in the calculations. The method results very low agreement with the experiments, therefore some modifications are needed.

Motivated from the *Fig. 1* we assume that the interface between the foam and the needle is a fractal [2,7].

This assumption results in another measure of the interface between the needle and the foam. This measure is assumed to be proportional to the diameter and the length of the needle as

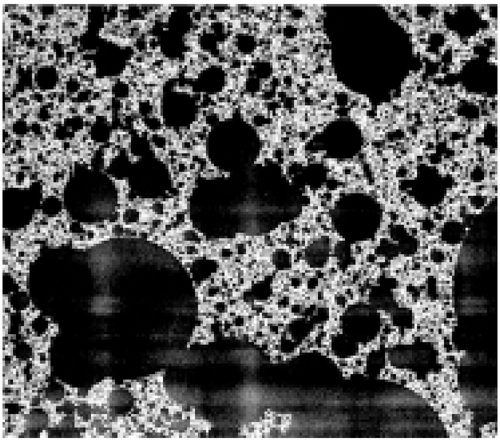
$$\overline{A} \sim d^{\alpha} l^{\beta}, \tag{2}$$

where $D = \alpha + \beta$ means the fractal dimension of the interface. For $\alpha = \beta = 1$, the above equation turns back to the area of the interface between needle and foam.

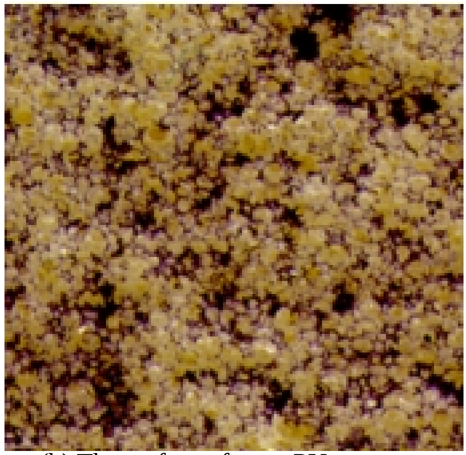
Based on the fractal measure of the interface, we generalise the *Eq.* (1) and propose to calculate the pull out force $\overline{F}_N$ as

$$\boxed{\overline{F}_N = \overline{c} d^{\alpha} l^{\beta}} \tag{3}$$

The constants $\overline{c}$, α and β are material parameters, which depend on the mechanical properties of the foam and on the quality of the surface of the needle. Here



(a) Computer generated fractal



(b) The surface of a cut PU part

Fig. 1. The similarity between the fractal and the PU foam

the parameter $\overline{c}$ contains also a friction like and a pressure like component. The parameter $\overline{c}$ has the dimension of $\frac{N}{\mathrm{mm}^D}$ and α, β are dimensionless.

Using the measurement data, we determined the model parameters with the program system Mathematica® [3] using the non-linear function fitting procedure 'NonlinearFit'. The values we obtained for the material parameters are:

$$\alpha = 0.040, \quad \beta = 0.819, \quad \overline{c} = 0.0343\frac{N}{\mathrm{mm}^{0.589}}. \tag{4}$$

The value of α is almost zero that is why the influence of the diameter (d) in the value of the force (F_N) is small. β is ≈ 1 so the value of the force (F_N) changes linearly with the needle length (l).

The numerical results for the pull out force $\overline{F}_N$ calculated with the *Eq.* (3) and the relative error E_{rel} to the measured force

$$E_{\mathrm{rel}} = \frac{|F_n - \overline{F}_N|}{F_n} 100[\%] \tag{5}$$

are summarised in the *Table 2*. The results show the agreement with the measurement data and the reliability of the proposed model is proved.

The 20% error is acceptable because the deviation of the foam materials can be even greater.

Table 2. Pull out forces from measurement and calculation

Diameter [mm]	Length [mm]	Measured force F_n [N]	Calculated force F_N [N]	Error E_{rel} [%]
0.6	60	0.88	0.96	9.13
0.6	60	0.8	0.96	20.05
0.7	50	0.88	0.83	5.42
0.7	50	0.84	0.83	0.92
0.9	50	0.84	0.84	0.09
0.9	50	0.8	0.84	5.09
0.9	70	1.12	1.11	1.11
0.9	70	1.08	1.11	2.55
1.1	50	0.88	0.85	3.69
1.1	50	0.92	0.85	7.87
1.2	50	0.96	0.85	11.40
1.2	50	0.96	0.85	11.40
1.5	50	0.92	0.86	6.72
1.5	50	0.92	0.86	6.72
1.8	40	0.64	0.72	12.52
1.8	40	0.6	0.72	20.02

3.2. The Needed Force

Usually when handling foam parts the needed force is gained by the weight of the part:

$$F = F_{tr} + F_{dem}, \tag{6}$$
$$F_{tr} = M(g + a), \tag{7}$$

where:
- F is the overall force of handling,
- F_{tr} transferring force,
- F_{dem} is other forces e.g. force from the demoulding [6],
- M is the mass of the part in kg-s,
- a is the maximum acceleration component of the robot arm that acts parallel with g,
- g is the gravitational constant [m/s^2].

From the transferring force the number of needles can be calculated by the next formula:

$$N = \frac{F}{F_N}\frac{1}{n}, \tag{8}$$

where: N is the number of needles needed for the transferring,
F is the overall force of handling,
F_N is the force that can be implemented by one needle,
n is a coefficient (between 0.75..0.85 according our tests) which emphasises that due to the deformation of the foam the whole length of the needles does not penetrate into the foam

3.3. Needle Pad Design

From the number of needles the size of the needle pad, on which the needles will be fixed, can be calculated. The spacing between the needles is 20 mms. Closer spacing would make the press in force (this is the force which is needed to press in the whole needle pad into the foam) is very high, because the needles effect each other where the spacing is too close. This effect does not occur when the needles are further away from each other ten times than their diameter. Looser spacing would make the needle pad very large. This value of spacing was experimented out empirically, and was derived from many tests.

The shape of the pad has to follow the graspable surface of the foam. In our case the best shape is a rectangle. With these values we can construct the pad. A design of the pad in Pro/E® can be seen in *Fig. 2*. This is the moving part of the gripper.

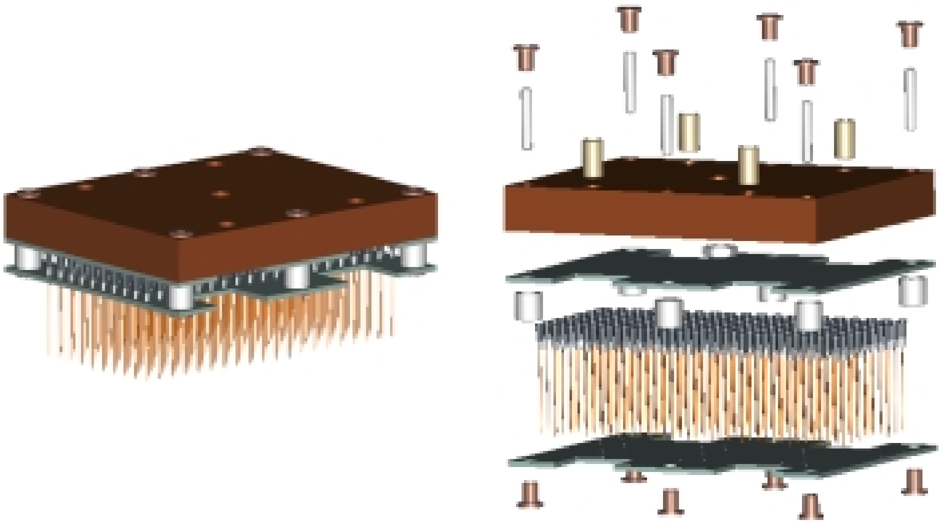
A disassembled model is shown in *Fig. 2* for better understanding.

3.4. The Gripper Base and the Cylinder Design

To move the plate we have chosen a pneumatically operated actuator. The pneumatic cylinder is the cheapest solution and is best suited for the task. Only two positions have to be set. The one when the needles are pulled back, this is the case when the gripper releases the foam. The other is when all the needles are fully extended. This is the case when the gripper grasps the foam and the largest force is implemented. Other positions are not acceptable because in those cases not enough force is implemented, or if the needles are not in the foam they can be dangerous to the environment and break easily.

The needles are guided by the guiding plate and the cylinder. Every needle has a guiding hole in the plate. The needles can only be implemented by forces that are parallel to their axis, otherwise the needles break. That is why it is very important for the gripper to have a proper guidance. Care should be taken not to move the gripper sideways inside the foam to prevent needle breakage.

To select an appropriate cylinder for the gripper the following method is advised.



(a) The assembled view of the part (b) Exploded view of the moving part

Fig. 2. The design of the moving part

We use the gross push in force for this calculation. This is the force when the safety coefficient (n) is 1. So this force is N times of the force implemented by one needle. $F_{\text{push}} = F_N N$.

This large force is used to be on the safe side of the values in case inhomogeneities occur in the friction in the foam, so a large force is needed to push the needles in.

When this value is obtained the next larger valued cylinder has to be selected from the catalogue. The fixing of the cylinder on the gripper is seen in *Fig. 3*. The assembled gripper is shown in *Fig. 4*.

The assembly structure of the gripper is shown in *Fig. 5*.

The test gripper that was manufactured at our department can be seen in *Fig. 6*.

4. Evaluating the Prototype Gripper

The tests showed that the guidance of the needles is suitable, because none of the needles was broken or damaged.

Once the needles penetrated into the foam the previously calculated force was implemented and the foam was firmly held with the gripper during the whole handling phase.

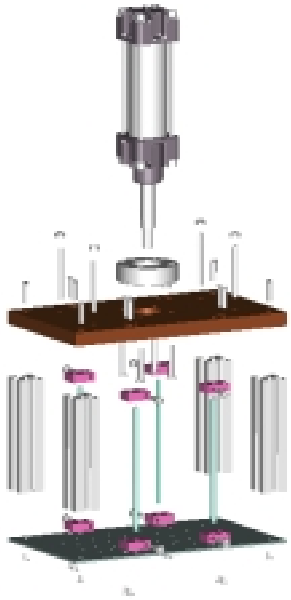


Fig. 3. Exploded view of the base part

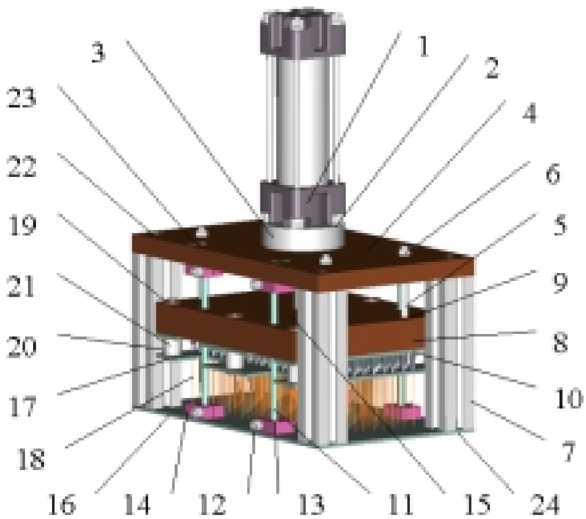


Fig. 4. The Pro/E model of the needle gripper

Table 3. The part list of the gripper

No.	Description	Pieces	No.	Description	Pieces
1.	Pneumatic cylinder	1	13.	Screw 3	8
2.	Screw 1	4	14.	Bracket	8
3.	Distance ring	1	15.	Nut 2	1
4.	Base plate	1	16.	Plate 2	1
5.	Adjustable bumper	4	17.	Plate 3	1
6.	Nut 1	8	18.	Needle	200
7.	Strut profiles	4	19.	Nut 3	6
8.	Moving plate	1	20.	Spacer	6
9.	Bearing	4	21.	Screw 4	6
10.	Plate 1	1	22.	Screw 5	4
11.	Shaft	4	23.	Screw 6	8
12.	Screw 2	8	24.	Screw 7	4

The gripper was suitable for placing, transferring and releasing the foam but not for demoulding parts with undercuts. Only those foams may be demoulded with the gripper that have vertical or outward sloping sides [4].

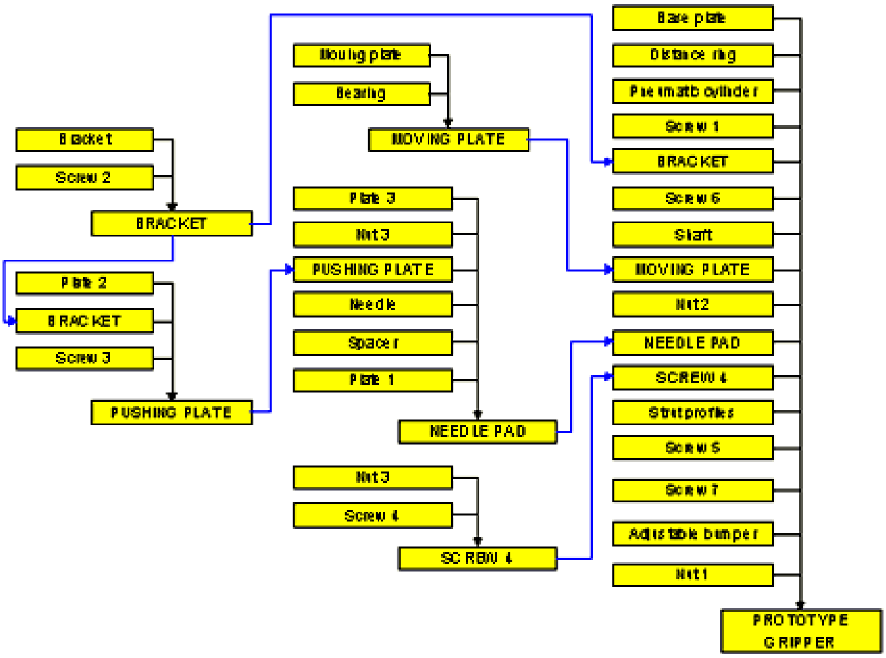


Fig. 5. The assembly structure of the gripper

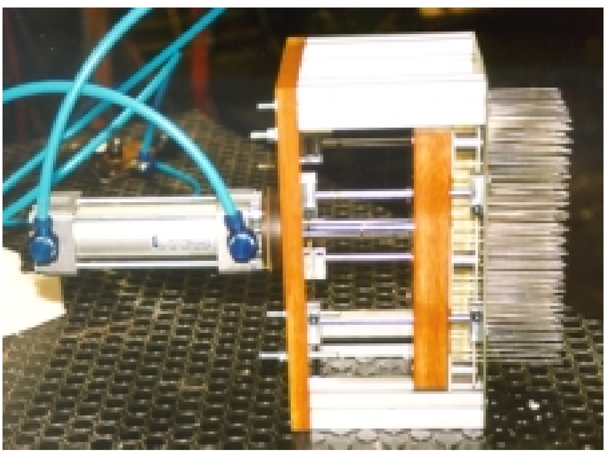


Fig. 6. Manufactured prototype gripper

The gripper's operational time is very good, it has fast grasping and fast releasing time. The gripping and the releasing is very reliable, the gripper can perform these tasks faultlessly.

The mass of the gripper may be reduced with further improvement in the design and using better and lighter materials.

5. Summary

The needle gripper proved to be a reliable, simple, cheap and fast gripper for handling foams that have enough free space to be gripped. A fractal geometry based method is proposed to calculate the pull out force of the needle.

The disadvantage is that the needles cannot implement large forces and the number of needles cannot be freely increased. For transferring heavy foams, and demoulding foam with undercuts cannot be accomplished with this gripper.

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