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LIGHTWEIGHT MATERIAL MODEL LIMITS WITH APPLIED PRE-STRESS

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Summary: *In this article is designed concept of the new lightweight material based on the pre-stressed membrane structure filled with the circular particles. The stability is discussed and model parameters outgoing from the comparison with the bending of cantilever beam are presented.*

1. INTRODUCTION

Current industrial robots and manipulators are designed with relatively stiff and heavy arms especially for the structures of the open kinematic chain type. During the motion of these structures high loading forces act that negatively influence the duration of the production cycle due to the large masses resulting into high inertia forces or low ration stiffnessmass resulting into low eigenfrequencies and limited feedback gains. The concept of lightweight material is one of the possible ways how to remove this disadvantage.

The idea using pressurized membrane together with a beam to prevent its bending is presented in [1, 2]. The pressure doesn't significantly influence eigenfrequencies of such structure and it needs more space than using just a respective beam. This paper deals with the design and investigation of properties of a concept of the new lightweight material based on the pre-stressed membrane structure either deflated (with vacuum) filled with the circular particles or inflated. In analogy with tensegrity [3] and tensairity [2] this can be called tensvacrity (tension-vacuum-integrity).

Using this concept a robotic arm as a beam is designed and investigated. Several different design concepts were proposed and a promising one was selected [4]. It consists of pre-stressed deflated membrane filled with balls closed in outer inflated membrane. This enables that the balls with good buckling properties are kept together by pressure of required value. The balls are hollowed from different materials. This structure is investigated for the ratio stiffness-mass and for the stability corresponding to the strength of such material.

2. STRUCTURE PREVIEW

The structure of new material consists of the hollow balls enveloped by the deflated membrane, see Figure 1 left. The simplified membrane model is developed for the plane [4] and it results, that membrane pre-stress and pressure difference ensures the ball topological position in the structure and that the interaction forces between the membrane and balls are coming through the balls center of mass.

2.1 Model

The balls in model are simplified as a mass points and interaction between the balls is represented by the spring, see Figure 1 right. The spring zero length equals the sum of balls radii which are in contact. The underpressure and membrane interaction with balls is represented by the external mass point forces. All balls has the same radius, thickness and material parameters, membrane is homogenous, flexible and frictionless material.

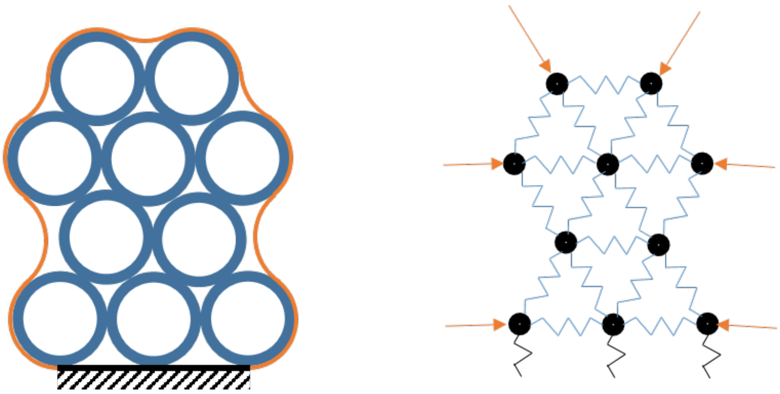

Figure 1. Membrane with balls model (left) and its simplification (right).

2.2 Stability

The tensvacrity structure, modeled in the section 2.1is stable if there is no contact loss. For the simplified spring-mass model (Figure 1 right) the stability means that springs are only under the compression.

If there is no external load except the membrane and underpressure forces, the structure is stable. The failure strength of tensvacrity structure is reached, when the structure is on the edge of stability due to the external load. Under external load the underpressure influences only the failure strength until it becomes unstable.

3. MATERIAL LIMITS

The tensvacrity structure is loaded and stiffness-mass ratio is evaluated. It is compared with the cantilever beam having corresponding dimesions. The simulation experiments are static and are performed for the plane structure and for the structure fully in 3D. Material parameters are the same for balls and the cantilever beam, the values are in the Table 1.

ball radius	0.01 m
ball thickness	0.001m
ball and cantilever material	steel
ball contact stiffness	8.04e7 $\frac{N}{m}$

Table 1. Tensvacrity structure parameters.

3.1 Plane structure

The structure contains one layer of elements, the first (lower) row is hooked to the base frame. The situation is shown on the Figure 2. There is applied horizontal force acting on the upper border element, see Figure 2. The force brings bending to the structure.

For the comparison is used the cantilever beam with the same length and thickness, the horizontal cantilever dimesion w_c is calculated to ensure the same stiffness as tensvacrity structure has, see resulting Figure 3.

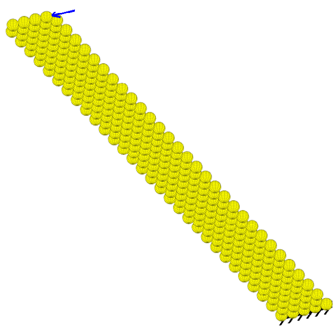

Figure 2. Plane tensvacrity model structure, loaded and hooked.

The static bending evaluation of the tensvacrity beam was performed in FE solver ANSYS, Figure 4. The stiffness-mass ratio for tensvacrity structure and for cantilever beam is in the Table 2. The tensvacrity beam has 1.43 times higher stiffness-mass ratio and it is lighter than full beam, even if the horizontal dimension of tensvacrity model w_t is much higher than horizontal dimension of cantilever w_t from the Figure 3.

plane tensvacrity	4045 $\frac{N}{m \cdot kg}$
cantilever beam	2832 $\frac{N}{m \cdot kg}$

Table 2. Stiffness/mass ratio.

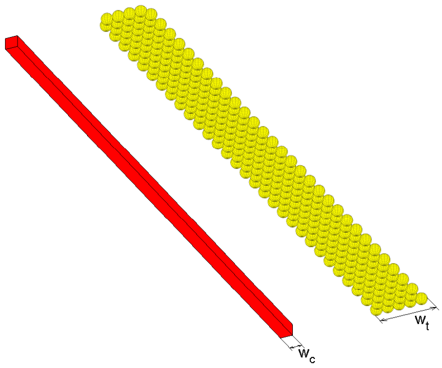

Figure 3. Plane tensvacrity model (right) with corresponding cantilever (left).

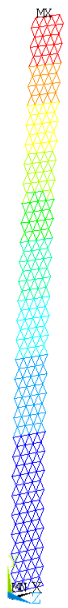

Figure 4. Plane tensvacrity bending evaluation.

3.2 Fully 3D structure

The tensvacrity structure has more layers within the third dimension. The lower plane elements are fixed and there are horizontal forces acting on the elements on top, see Figure 5. The comparison between the cantilever beam and tensvacrity structure is on the Figure 6, evaluation procedure is the same as in the plane case with cantilever horizontal dimension w_c and tensvacrity horizontal dimension w_t, see Figure 6.

3D tensvacrity	3989 $\frac{N}{m \cdot kg}$
cantilever beam	3084 $\frac{N}{m \cdot kg}$

Table 3. Stiffness/mass ratio for 3D case.

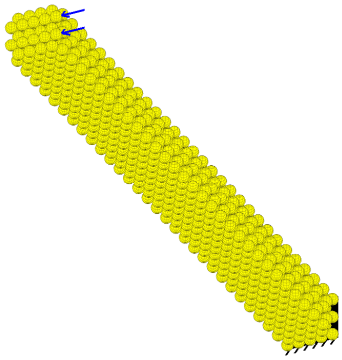

Figure 5. Fully 3D tensvacrity model structure, loaded and hooked.

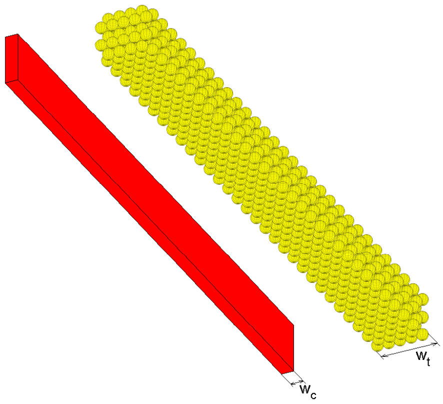

Figure 6. Fully 3D tensvacrity model (right) with corresponding cantilever (left).

The calculation of bending is done in ANSYS, and on the Figure 7 is visualized. In the Table 3 are the stiffness/mass ratios and the tensvacrity beam has the ratio 1.3 times higher.

4. CONCLUSIONS

The simple model of new lightweit material is developed. The idea is to replace beams and rods in the construction by the hybrid structure consisting of the elastic membrane and hollow balls. The membrane envelopes the balls in such structure to replace the beam and keeping its main properties by keeping underpressure in the structure. The stability of the structure is defined. Using the simplified spring-mass model there are performed loading tests. The comparison is evaluated with corresponding cantilever beam.

The properties of new proposed structure are promising and together with other preliminary results leads to new lightweight structure which can be used in robotics. The more complex structures like complete robots can be assembled. The robot can consist of separate links designed from this new lightweight material interconnected by traditional joints (revolute, prismatic) or the robot can consist of one complete arm that is split into particular links by contracted necks which create the flexible joints. Such robotic structures can be then driven by

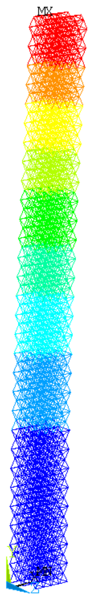

Figure 7. Fully 3D tensvacrity bending evaluation.

cables.

The main advantages are lighter construction and some parameterization for the stiffness value of the new structure. Possible disadvantages authors see in the membrane durability, discrepancies in the ball radius and underpressure level uncertainity. The further properties of the new material are studied.

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