FEM Analysis of a Robotic System Used in Concrete Spray Procedures

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Abstract. This research addresses a conceptual design of a flexible robotic system used in the civil engineering domain, respectively in concrete spray procedures. The robotic system has on its structure a 3DOF robotic arm and at the end, it will be mounted a flexible unit that can be bent in four directions under pneumatic pressure. The research core was focused on a finite element analysis of the proposed flexible segment. The obtained results, represented by stress, strain, and displacement will assure a feasibility study for developing a prototype.

Keywords: Finite Element Method · Civil Engineering · Concrete Spray · Robotic System · Flexible Unit

1 Introduction

Over time Civil Engineering domain had major evolutions due to the involvement of rapid prototyping, robotic and mechatronic systems. These instruments were used in several procedures, specific to this domain. One of them, which is also the main key of this research, is represented by the concrete spray procedures, especially applied in road or railroad tunnels as can be seen in Fig. 1. The sprayed concrete or "shotcrete" technology consists of applying concrete under a pneumatical pressure through a tube line to a nozzle onto a wall and compressed by the impact energy. This process is often found out to "Torkretieren". This process has its origins in Germany, namely the engineer Carl Weber who patents this process [1].

But over time this process evolve a lot and also include the use of robotic arms for moving the spray nozzle over walls, especially in the case of tunnels, as can be remarked in [2, 3].

The weak point of the robotic arms use is the DOF limitations. In addition, it is well known that these are used in rough conditions, and the quality during exploitation is affected. Always the robotic arm is near the nozzle and a part of sprayed concrete quantity will go onto its structure and will affect its functionality of this.

Also during the time, the DOF got enlarged from 3DOF to 5DOF, to cover with concrete in tight areas where classic machines can not perform this type of work.

By having insight into several robotic systems specially developed for concrete spray procedure, reported in [4, 5] it can be remarked that their motions can be improved.

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Thus the proposed research objective is to enlarge the concrete spray robotic systems motions by adding a flexible unit that can perform complex motions for concrete spray in tight areas.

After completing a state of the art by analyzing several robotic systems which can be found in [1, 6, 7], this research will be focused on flexible unit design and analysis with the finite element method. The second part of this research will be presented the proposed robotic arm which will be attached at the end effector the designed flexible unit. In the third part will be performed a finite element analysis of the designed flexible unit. Results and discussions are presented in the last part of the proposed research.

2 Robotic System Concept

In this section, it will be presented the robotic system and the designed flexible unit. Thus the robotic system is characterized by 3DOF, namely one rotation and two linear motions of the robotic arm. The 3D model is shown in Fig. 2.

The entire concept was designed with the aid of SolidWorks program. The rotational motion will be assured by an actuated worm gear situated on its base, as it can be remarked in Fig. 2. The other two linear motions will be assured through two pneumatic cylinders, and at the end of the robotic arm will be mounted the flexible unit as it can be seen in Fig. 2.

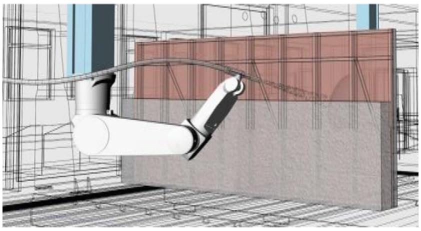


Fig. 1. Spraying concrete with a robotic system [1]

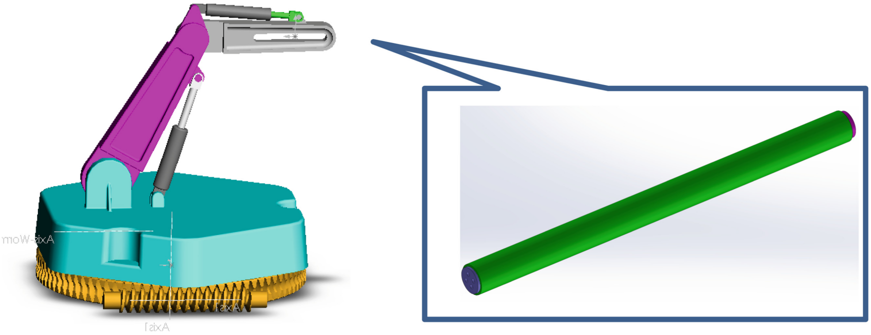


Fig. 2. Robotic system concept

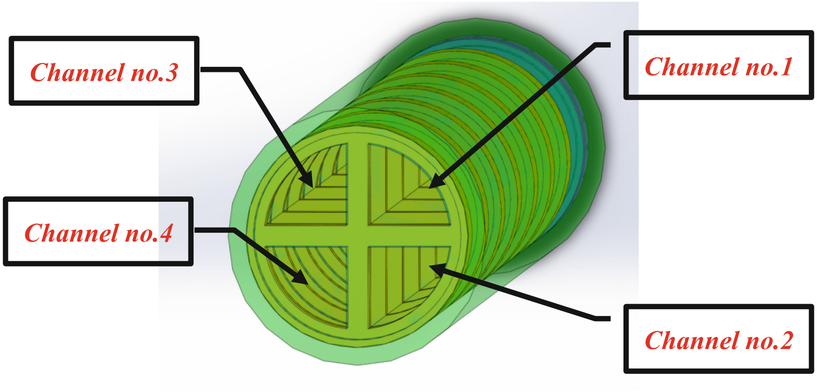


Fig. 3. Flexible unit architecture

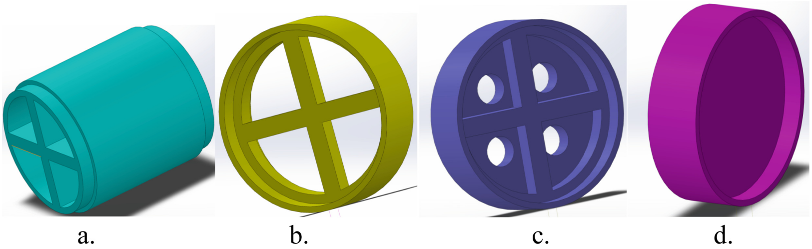


Fig. 4. Flexible unit components (a – rigid element; b – flexible connecting body; c – input part; d – end seal part)

The flexible unit can bend in four directions due to its specific architecture. This architecture is represented by four pneumatic channels which will cross the flexible unit longitudinal axis as it can be observed in Fig. 3.

The designed unit structure was made from 13 rigid elements made from specific rubber connected through 12 flexible connecting bodies. At the end was placed an end seal element to close all pneumatic channels. At the begin, it was placed an input element which separates the pneumatic channels and is characterized by four holes, as it can be remarked in Fig. 4.

The entire flexible unit will be cover with a rubber tube as in the 3D model case presented in Fig. 2. Thus the rigid elements, the end seal element and the input one will be made from steel, and the other components will be made from a special rubber. The designed flexible unit was developed in a parametrized form, in order to be imported into ANSYS software for finite element analysis. This it has a length of 500 mm and a diameter of 36 mm. The entire structure and components identification can be found in Fig. 5

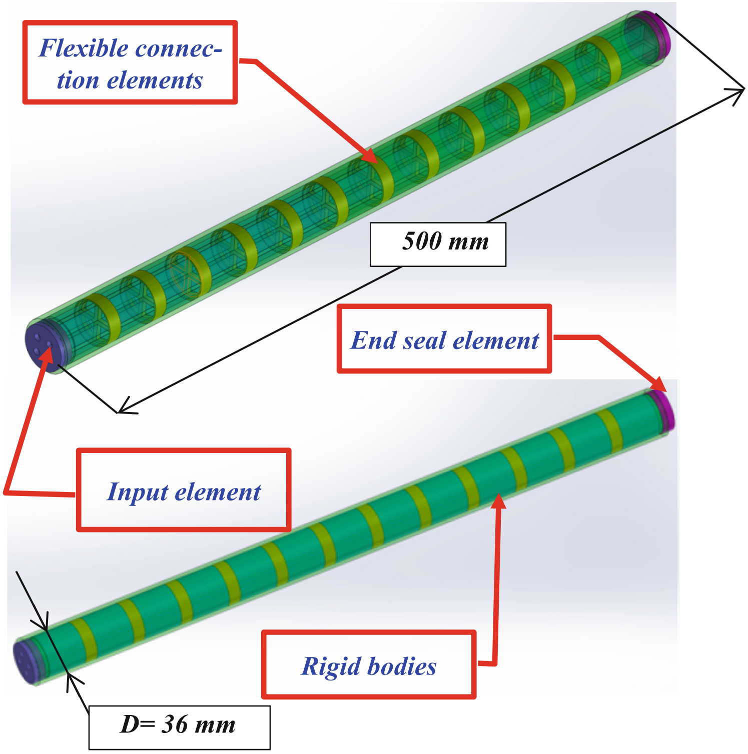


Fig. 5. Flexible unit structure

3 FEM of Flexible Unit

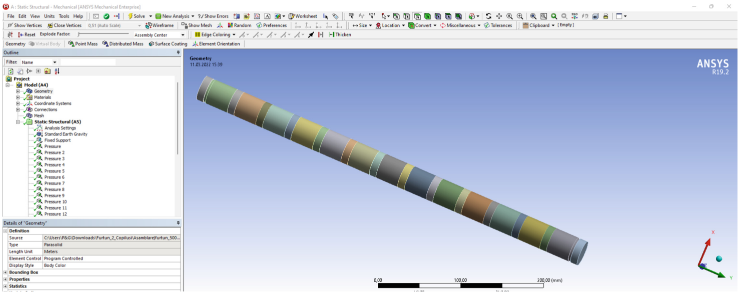
The designed flexible unit was imported in ANSYS software in order to analyze this with finite element method aid according with [8, 9]. Thus, it was created a special interface for transferring the developed 3D model as it can be seen in Fig. 6. For this, there were identified and defined the proper materials for each component. Another argument is the contact definition for the entire analyzed structure, and this was a bounded type as it is shown in Fig. 7.

The entire structure was meshed with finite elements, namely with hexahedral type, and it was obtained a number of 88996 nodes and 33047 finite elements.

Regarding the load application and contour definition step, it was applied only on a single channel a total pressure of 7 bar and the input element was considered fixed in space. Also it was taken into account the standard earth gravity, and all loads and contour definition for a static structural analysis is shown in Fig. 8.

The desired results were represented through stress, displacements and strain. After solving the parameterized model it was obtained the behavior of the analyzed flexible unit. Some snapshots during virtual simulations are shown in Fig. 10 (Fig. 9).

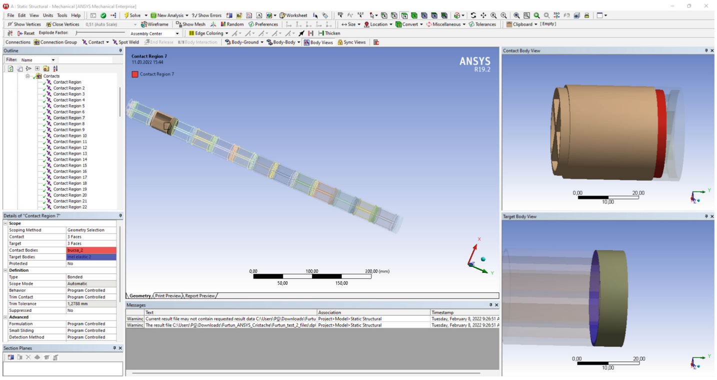
Thus in Fig. 11, Fig. 12 and Fig. 13 are reported as main results von Misses stress, unidirectional displacements and total mechanical strain.



Details of "Geometry"

Definition	
Source	C:\Users\P&G\Downloads\Furtun_2_Copilusi\Asamblare\furtun_500...
Type	Parasolid
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Properties	
Statistics	

Fig. 6. The imported flexible unit in ANSYS



Details of "Contact Region 7"

Scope	
Scoping Method	Geometry Selection
Contact	3 Faces
Target	3 Faces
Contact Bodies	bucsa_2
Target Bodies	inel elastic 2
Protected	No
Definition	
Type	Bonded
Scope Mode	Automatic
Behavior	Program Controlled
Trim Contact	Program Controlled
Trim Tolerance	1,2788 mm
Suppressed	No
Advanced	
Formulation	Program Controlled
Small Sliding	Program Controlled
Detection Method	Program Controlled

Messages

	Text	Association	Timestamp
Warninc	Current result file may not contain requested result data C:\Users\PG\Downloads\Furtu	Project>Model>Static Structural	Tuesday, February 8, 2022 9:26:51 A
Warninc	The result file C:\Users\PG\Downloads\Furtun_ANSYS_Cristache\Furtun_test_2_files\dpl	Project>Model>Static Structural	Tuesday, February 8, 2022 9:26:51 A

Fig. 7. Contact definition between flexible unit components

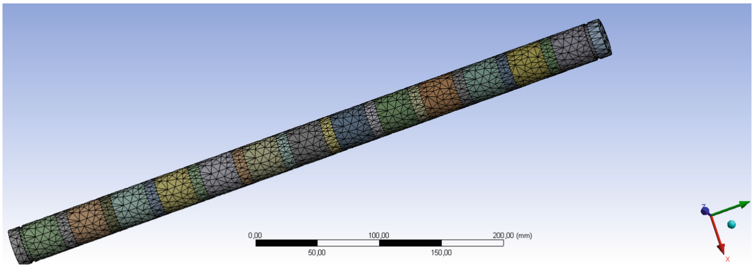


Fig. 8. Meshing the analyzed flexible unit

The obtained results are shown in Table 1. Thus, it can be remarked a maximum value of 19.415MPa and this was situated on the input element surface, which this was considered as fixed one. There were recorded high values of 63.99 mm and this represents an acceptable value of the flexible unit bending process. Also there were obtained unidirectional displacements on x, y, z axis as the one reported in Fig. 12, where it was obtained a value of 1,63 mm. It can be remarked an equivalent strain equal with 4% from flexible unit initial phase. This analysis allows to obtain other results such

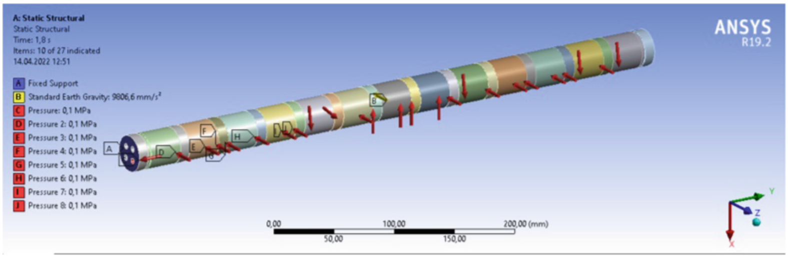


Fig. 9. Flexible unit initial conditions and load application

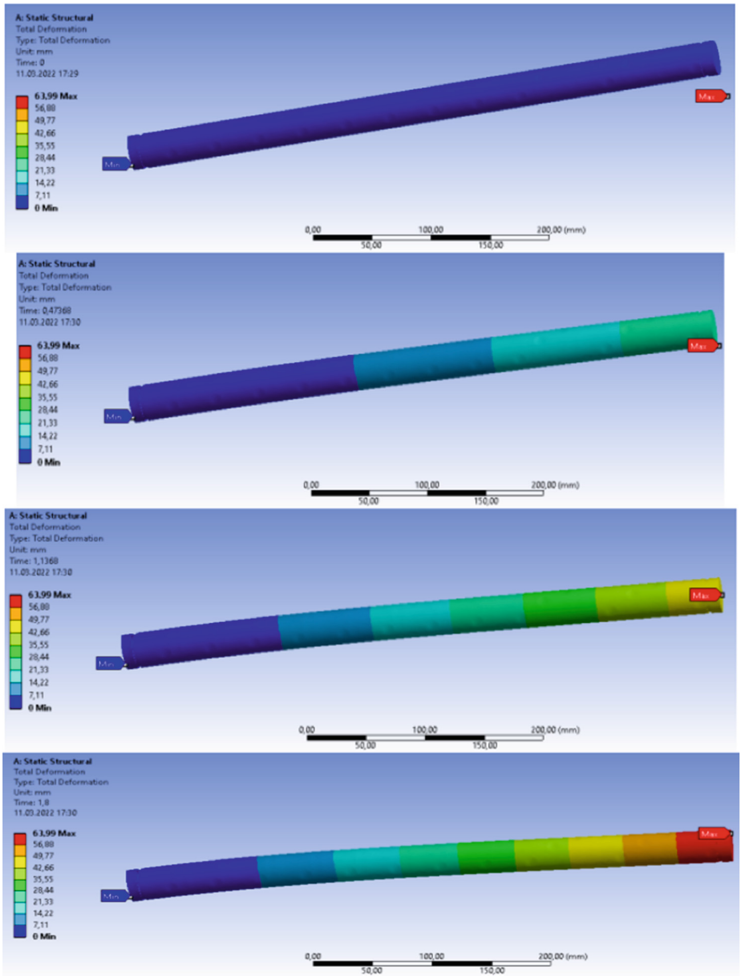


Fig. 10. Snapshots during simulations of the analyzed flexible unit

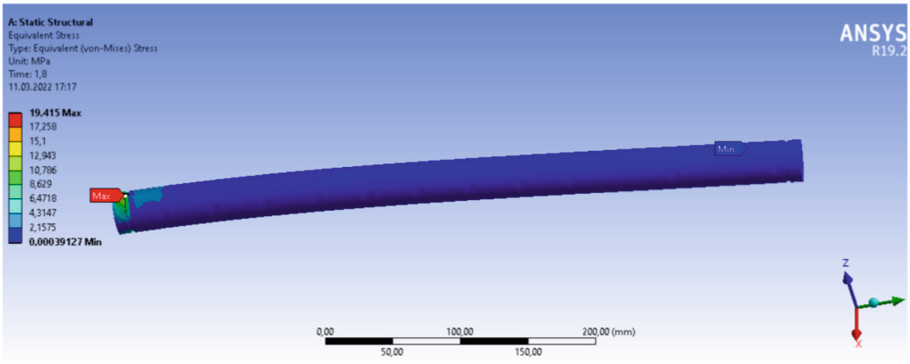


Fig. 11. Von Misses stress distribution [MPa] of the analyzed flexible unit

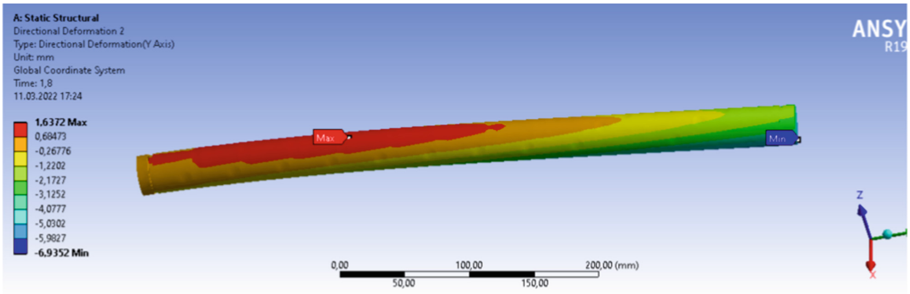


Fig. 12. Displacement on y-axis distribution [mm] of the analyzed flexible unit

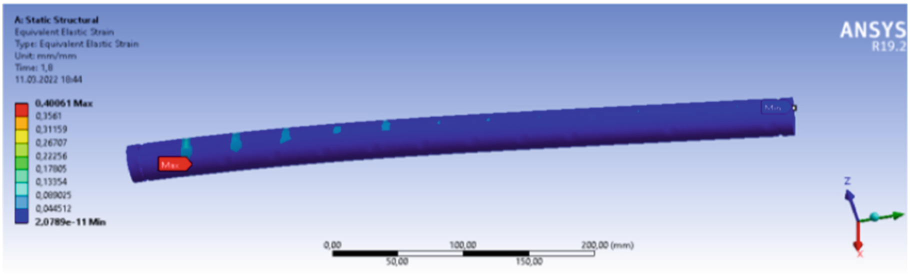


Fig. 13. Von Misses equivalent elastic strain [%] of the analyzed flexible unit

Table 1. FEM of flexible unit results.

Parameter	Maximum Value [Unit]
Von Misses stress	*19.415 [MPa]*
Total displacements	*63.99 [millimeters]*
Equivalent strain	*0.4 [%]*
Contact pressure	*2.41 [MPa]*
Specific sliding	*0.074 [millimeters]*

as contact pressure, specific sliding or penetrating depth, which can be used in future analyses.

4 Conclusions

Through this research it was validated a concept of a robotic system that can be used in concrete spray procedures. The research core was focused on developing a finite element analysis of a pressure hose with a specific structure.

Finite element analysis was carried out under a static structural mode and the desired results validate the conceptual solution.

It can be remarked a conceptual design of a parameterized flexible unit similar to a hose which can bend under a pneumatic pressure on four directions. This can be attached to a classical robotic system in order to increase his capacity to spray concrete in narrow spaces.

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