Design and Analysis of Multilayer Beams which are Used for Motion

Hasan LAFCI
PD Functional Quality
Ford Otosan
Istanbul, Turkey
hlafci@ford.com.tr

Cihan DEMİR
Mechanical Engineering Department
Yıldız Technical University
Istanbul, Turkey
cdemir@yildiz.edu.tr

Absract- Multilayer beams are widely used in robotic area due to some advantages. To create a special motion in fixed spaces , multilayers are essential for both designers and engineers.This motion can be used for moving a system or another purposes. Nowadays, the soft grip is a new term for robotic and mechanical engineering fields. It uses the same theory of multilayer beams to create a displacement. Unlike conventional multilayers beams, it uses soft material such as silicon, rubber or fabric because of some advantages. In this study , a pneumatic soft gripper have been designed and analysed with engineering softwares. Also a design of experiment (DOE) have been performed to see effect of each factor such as air pressure, material property, geometrical variables etc. Results and graphs of study have been shared at the final stage. According the results of DOE, designers can optimise their systems.

Keywords— Soft grip , Multilayer beam , DOE

I. INTRODUCTION

The development of new types of robots, and materials offers new opportunities for cross-functional researches. This paper focus on a new methodology based on multilayer beam theory. Due to some advantages of bending , science and engineering world have created a new definition , the soft robotic.

With the absence of wheels, electric motors and rigid skeletons, the motions of soft robots are usually inspired from the soft organisms [23]. For the easy fabrication, actuation and control of soft robots, only simple motions of natural species have been used in soft robots, such as caterpillar inspired locomotion [8,9], multi-gait quadruped [10,11], bristle-crawler [12], worm inspired locomotion [13–14], snake inspired locomotion [15], jellyfish inspired swimming [16], etc.

II. THEORY OF MULTILAYER MOTION

A. Relationship Between Multilayer Beams & Soft Robots

Soft robotics is a sub-field of robotics that deals with non rigid robots constructed with soft and deformable materials like silicone, plastic, fabric, rubber, or compliant mechanical parts like springs. Soft robots can actively interact with the environment and can undergo “large” deformations relying on inherent or structural compliance due to their softness and other morphological features.

The multilayer beam bending theory can be explained as follow.A simple cantilever beam can be bend by a concantraded nodal force, pressure or heat.The main question is that can we use this bending for different purposes.This question have been created the soft robotic area.

If we have a beam which has different layers and different stiffness sections , with internal forces like pressure it can be bended. So , this reaction gives a new name the beam. Shown as in figure 2.1 a multilayer beam can work as a robotic gripper to carry objects.

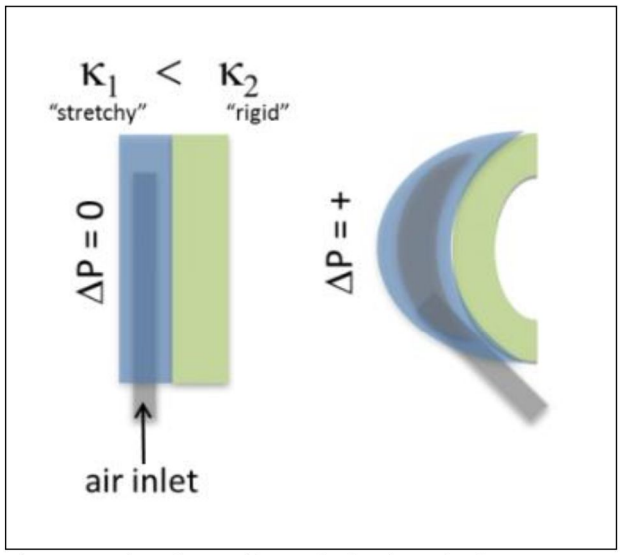


Fig. 2. 1 Two layer beam with one air chamber soft gripper [25]

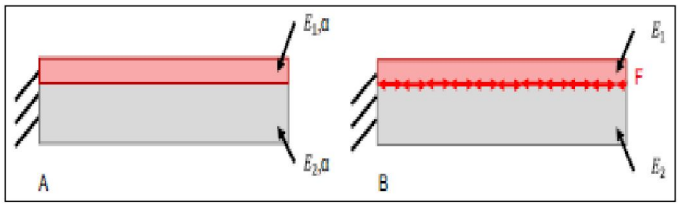


Fig2.2. Embedded electrical wire can create adequate heat to bend the beam because of thermal expansion [22].

As in practical applications the bending deformation of the beam may be actuated by other methods (e.g. shape memory polymers [4], electroactive polymers [5], dielectric elastomers [6] and pneumatic pressurization [7]),

Shown as in figure 2.3 a muscular thin films also shares the bending theory like multilayer beams. A phsical action will create a different reaction in layers not only because of their material properties but also their geometry. For example , if we heat up a multi-layer beam shown as figure 2.2 or like a MTF which is shown in figure 2.3 , different axial displacement going to be occured. Thus, the overall beam going to have a circular shape. Other sources can be used as action like air. In next sections, the effect of pressured air will be discussed widely.

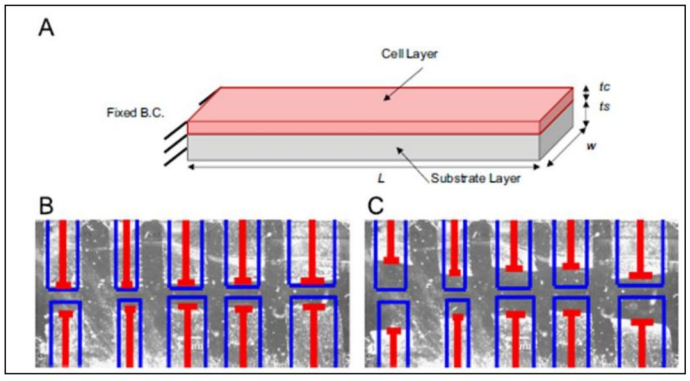


Fig. 2.3. (A) Schema of the MTF cantilevers. A biocompatible cantilever is supported by a fixed boundary condition(B.C.)and a thin cell layer is seeded on the surface. Contraction in the cell layer causes the substrate layer of the MTF to bend upwards. (B) Experimental image of 'Heart-on-a-chip' muscular thin films in their minimum contracted state(diastole). C:Experimental image of 'Heart-on-a-chip' muscular thin films in their maximum contracted state(systole).In Band C solid blue outlines indicate the original shape of the PDMS film while capped red bars indicate the projection of the thin film during contraction. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper[22].)

B. Pneumatic Pressurization

To bend the system for using bending theory of multilayer beam , pressured air is one of the best method. An inlet line which comes into between two layer is a force source. High pressure going to push walls from inside to outside to as a reaction. This creates the displacement. The example of pressured air effect can be seen in figure 2.1.

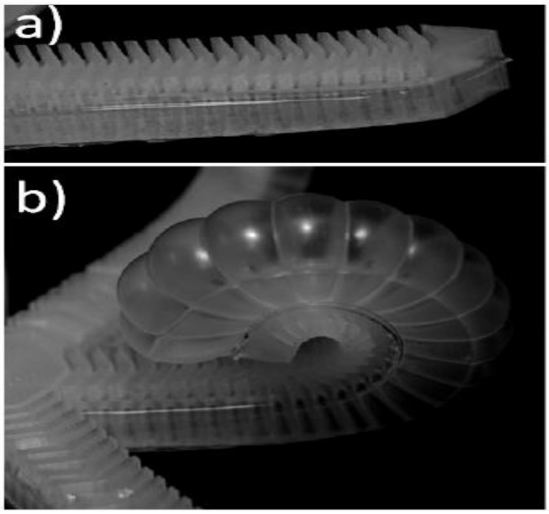


Fig. 2.4 a) A close-up photograph showing a textured surface which has been modified independently of the PneuNets. A set of ridges formed in Ecoflex provided better traction than a flat surface (this texture is more compliant than a solid surface because half of the volume has effectively been removed, and each ridge is pliable and deforms easily). b) A photograph demonstrating an actuated leg on the gripper; the individual chambers that make up the network are visible. The minimum radius of curvature achieved in this design is less *than 5 mm[24].*

According to design, soft parts can react the pressured air differently. In Figure 2.4 the design shows rotational reaction but there is also creative design which can extent axially. For example, Pneumatically-driven McKibben-type actuators are among the most highly developed soft actuators, and have existed for more than fifty years; they consist of a bladder covered in a shell of braided, strong, inextensible fibers[17].

Another design can provide a crawling motion to system. If the pressure of air changes alternately maximum to zero the beam can move like caterpillar shown as figure 2.5.

As you see, the

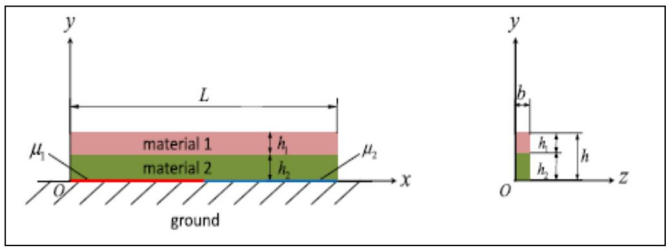


Fig. 2.5 Bilayer beam with different frictional coefficients at the two ends of the contact surface. The cross sections of each layer are rectangular with the same thickness and different heights of h1 and h2 [23].

III. Soft Gripper Design

In our modern industry , there are many different robotic parts or systems try to grip object without any damage but the hardness of surfaces of many system causes fundamental material problem. Convectional robotic systems use the rigid material to grip objects. This may create surface cracks or other type damages.

The use of compliant materials allows grippers to manipulate objects such as fruit[20] with varied geometry[21]. The egg example can be seen in figure 3.1. The gripper holds the it gently.

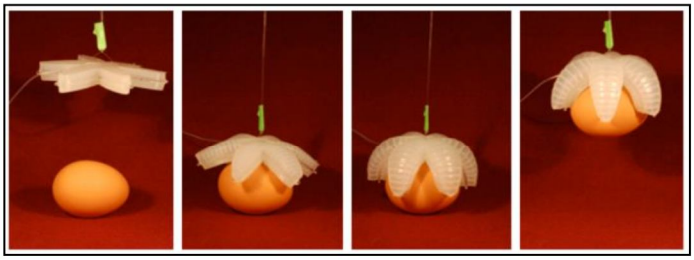


Fig. 3. 1 An egg translated by a soft gripper without any damage in four step.

Figure 3.2 illustrates the 3D model the soft gripper which analyzed in paper. In the egg example the soft gripper has 6 beam. It is clear to say that increasing of beam number going to decrease the contact stress which will be occurred between egg and soft material. In our study , there is only one beam has been designed and analyzed. The results can be optimize or assumed for multi-beam grippers.

CAD data of our soft gripper can be seen in figure 3.2 Cross section of solid model serves some technical trick. Every air chamber connect each other by small links. In next figure (fig. 3.3) these links are occurred.

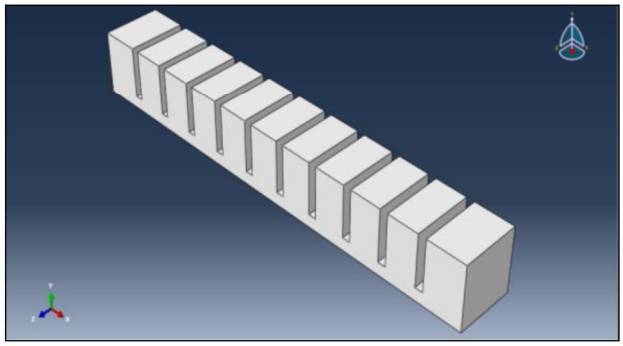


Fig. 3.2 Solid model of Gripper

There are many various factors which plays an important role on soft gripper design. In our study, we have focused on some variables like air pressure , material stiffness, geometrical variables.

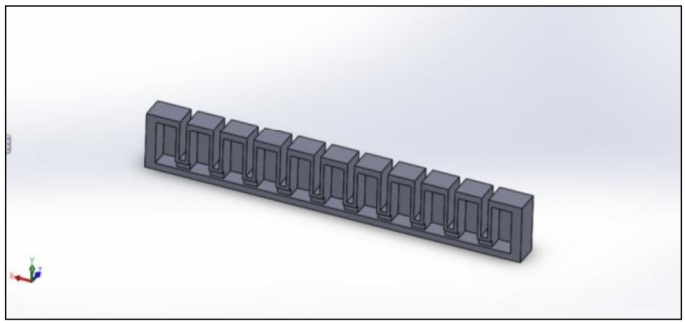


Fig 3. 3 Cross Section of Solid Model. Little tubes let air goes to another chamber. This causes the equal pressure distribution

A. Materials of Soft Robotic Parts

Soft robots are usually fabricated predominantly in elastomeric polymers without hard skeleton. Through appropriate design a simple elastomeric structure can provide a multifunction such as joint [1], bearing [2] and actuation[3], without the complexity of a multicomponent mechanical structure in hard machines.

Silicone rubber is an elastomer (rubber-like material) composed of silicone—itself a polymer—containing silicon together with carbon, hydrogen, and oxygen. Silicone rubbers are widely used in industry, and there are multiple formulations. Silicone rubbers are often one- or two-part polymers, and may contain fillers to improve properties or reduce cost. Silicone rubber is generally non-reactive, stable, and resistant to extreme environments and temperatures from -55 °C to +300 °C while still maintaining its useful properties.

B. Geometry Of Gripper

The shape of gripper must designates the purpose of system. There are many different systems in soft robotic area.

According to demands , a system can show a axial or rotational displacement. For example , if someone wants to simulate muscular behaviors, the axial extension type actuators should be used as mentioned previous sections.

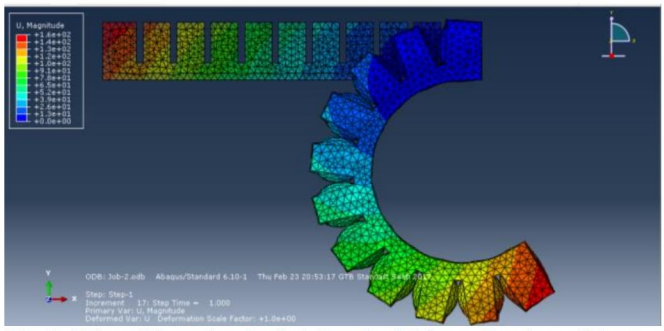


Fig. 3. 4 Three Dimension Analysis Result of Gripper. Touch condition areas can be seen clearly.

In our study , we try to reach and hold an object. Thus, the gripper must show axial and rotational movement at the same time. Thanks to its unique shape this aim can be achieved by our design.

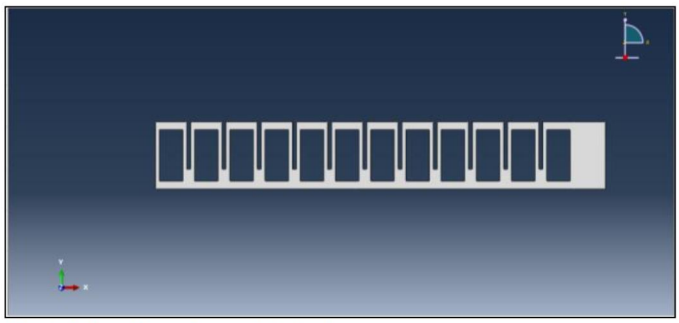


Fig. 3. 5 Two dimension model of gripper

The system work as follows, the air chambers, around top of layer , filled by a pressured air. This force initially extents the gripper axially and rotationally. But the majority of the first stage of movement is extending axially. In first stage, there is only minor rotational displacement . At the same time the walls of chambers close each other as extent from inside to outside due to the pressure. When a chamber wall touch to another, because of frictionless contacts walls slip on each other. This creates a huge rotational torque which can be used to wrap objects.

As you can see ,the design of gripper is the main factor of a gripping strategy which has an important role on behavior of system.

C. Geometry Of Target Object

The target object means that the object which is held by soft gripper in our study. Target objects may have various shapes such as cylindrical, cubic , prismatic etc. One of the advantages of the soft gripper is that they can handle very big range on shapes. Even a cactus can be held by well designed a soft gripper without any damage.

Our analysis have been performed to grip a cylindrical target object with different radius and different center of gravity centers.

IV. ABAQUS CAE

A. Stages of CAE Analysis

Like many other commercial computer added engineering soft wares, Abaqus also needs to be given some specific inputs from user to calculate the finite element method demands such as stress , displacements etc.

Before we start the calculation, we need to set up a few steps as follows.

1) Create or Import Parts : There is a embedded CAD module in Abaqus which can be used create 2D,3D or Wire elements. Or import menu can be used import a part which created by another CAD softwares.To decrease work load and use time efficiently, we use the simplified 2D part.

2) Define Materials : Two material properties have been created .One of these is hyperelastic material which makes up the gripper. The Neo Hookean method has been chosen for hyperelastic material.Another one is elastic material for target object.

3) Create Sections : Both gripper and object section have been created as solid homogenous.

4) Create Steps : General ,Static step has been created.

5) Create Assembly : Two parts have been imported and arranged in assembly space.

6) Define Intersections : There are two intersection in model. One is between gripper and object. Another one is self-intersection which is necessary to see touch condition of walls of air chambers.

7) Define Boundary Conditions : One side of gripper has been fixed. For this, encastre boundary condition has been applied.To simulate air the pressure has been applied inside of chamber walls.

8) Meshing Parts : To get maximum resolution minimum mesh size has been created

9) Create A Job : Jobs allow that a model can be used for different analysis such as static, thermal or explicit. Thus , in abaqus every model requires a job which will has the results according the analysis type

10) Results : After completed job running the program creates a output file which can be monitored in visualization menu.

V. Design Of Experiment Anaylsis

A. Definiton Of DOE

DOE (design of experiments) helps researchers to investigate the effects of input variables (factors) on an output variable (response) at the same time. These experiments consist of a series of runs, or tests, in which purposeful changes are made to the input variables. Data are collected at each run. You use DOE to identify the process conditions and product components that affect quality, and then determine
the factor settings that optimize results.

B. Create Factors

Reaction forces are one of responses of the system. To investigate which factors affect reaction forces, we should investigate main variables. According to a study content, number of factors can be changed. As factors increase, the total time and number of experiments going to rise.

In our study four different factors have been chosen. These are System Pressure (P) , Material Stiffness(K) , Radius of Target Object (R) and Position of Target Object (PTO).

Another criterion of doe method is factor level. It means that variance of factor internally. For example, if the pressure has two different options such as low or high, it means that this factor has two levels. Each factor of study has two levels.

For two levels factor , count of total experiments calculated shown as follows in equation 1. The n means number of factor and two indicates level of factors. In our study, there are four different factors. Thus, we have to run sixteen different cae analysis according to DOE method.

$$\text{Total Experiment Number} = 2^n \quad (1)$$

VI. Results

A. CAE Results

CAE analysis results are shown as below:

Different results have been displayed in various monitoring type . Next graphs going to mention some important output of the analysis and system.

Major output of the system is reaction forces which will be occurred between the target object and soft gripper.

The first image (Figure 6.1) shows the beginning of the analysis. As you can see , there is no any touch condition between the gripper and target object.

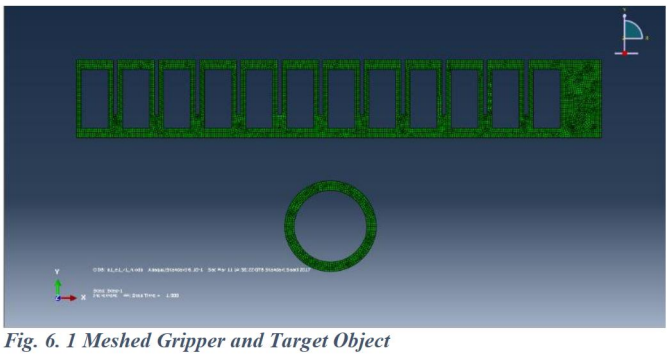


Fig. 6. 1 Meshed Gripper and Target Object

Second image (Figure 6.2) illustrades the strees level which occured at the end of holding proccess. High stress areas have occured mostly at chamber walls. Because of thickness this is not unexpected situation.

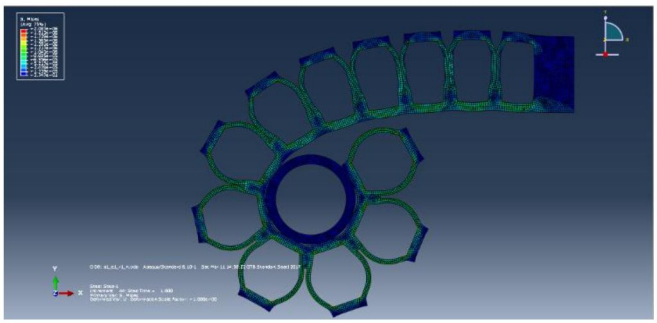


Fig. 6. 2 Stress Areas

The biggest reaction forces have been observed at fixing area of soft gripper. Shown as Figure 6.3 , the reaction forces change at the Y direction.

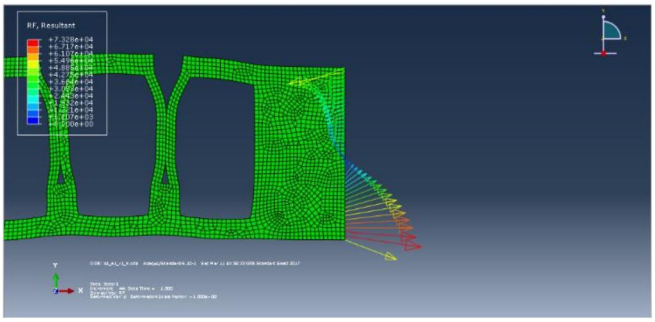


Fig. 6. 3 Changing of Reaction Force Vectors. Maximum reaction force occurred at the bottom

Displacement plot (Figure 6.4) show the total translation magnitude. The gripping process have been completed at this step. More pressure will create self-interaction problems at gripper. So , maximum pressure have been chosen properly and limited.

The aim is achieved. A target object can be wrap by soft gripper which uses pressured air.

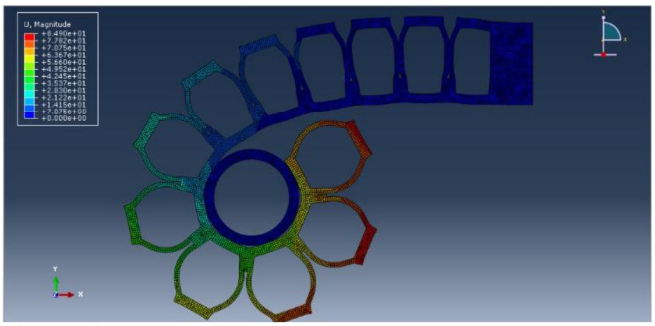
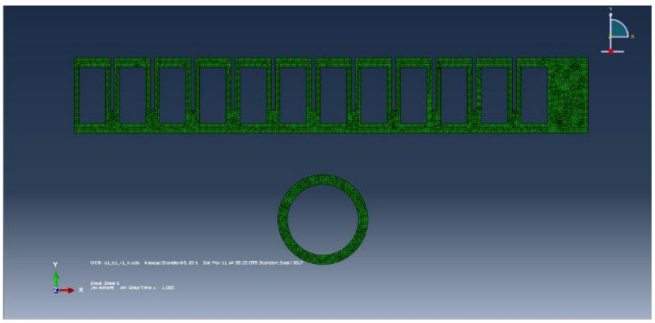


Fig.6. 4 Displacement plot



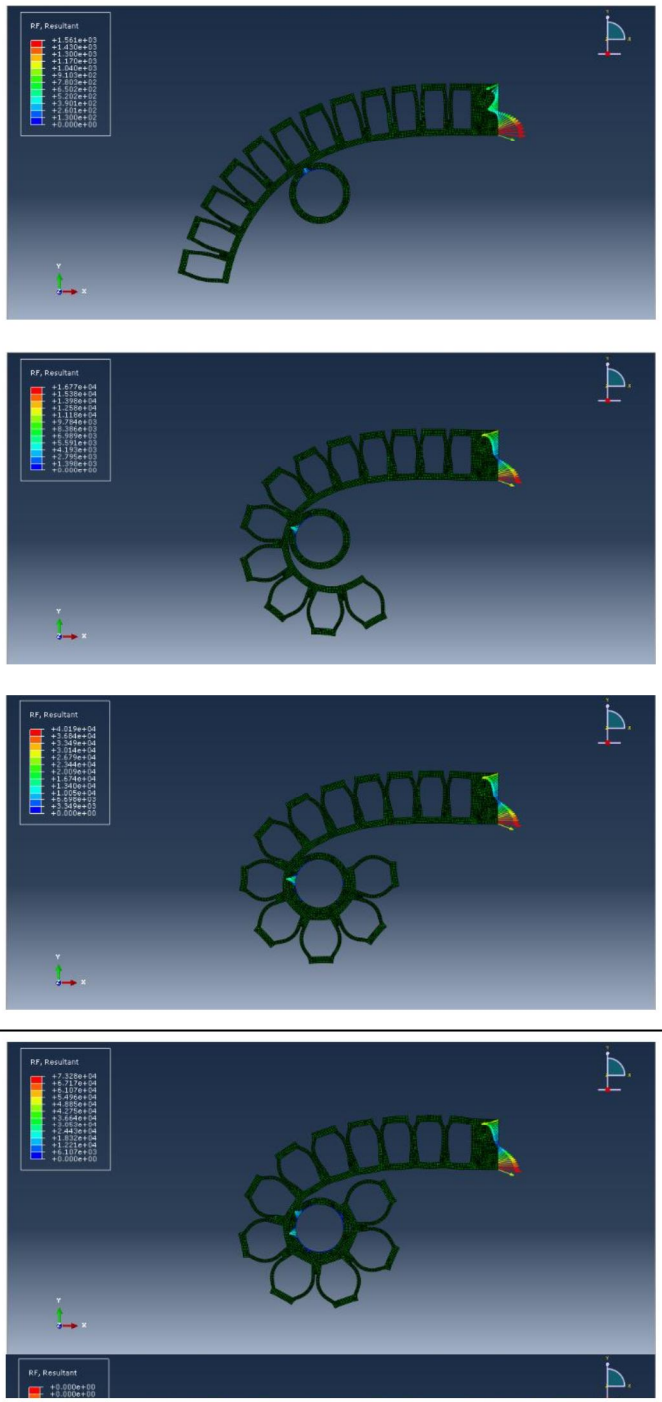
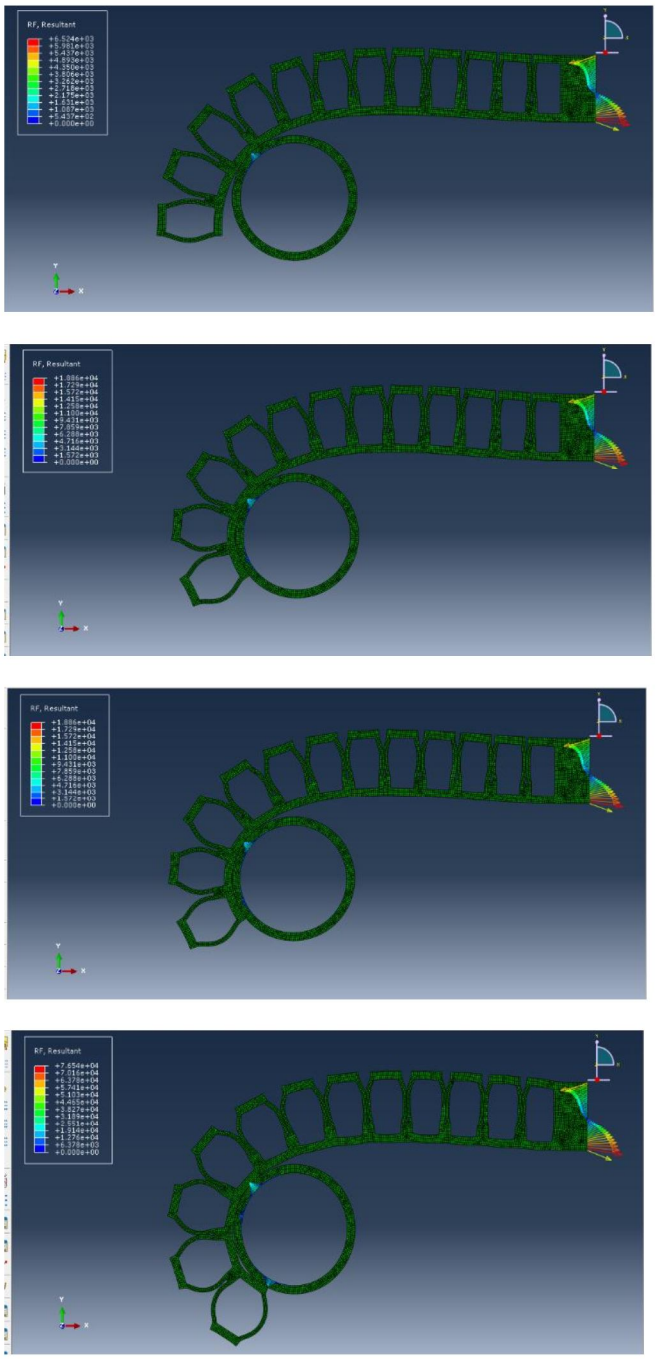


Fig 6.5 : Two different scenarios have been compared to see effect of factors. First sce , small target radius and big x coordinate of target object gravity center. Second scenar big target radius and small x coordinate of target object gravity center.



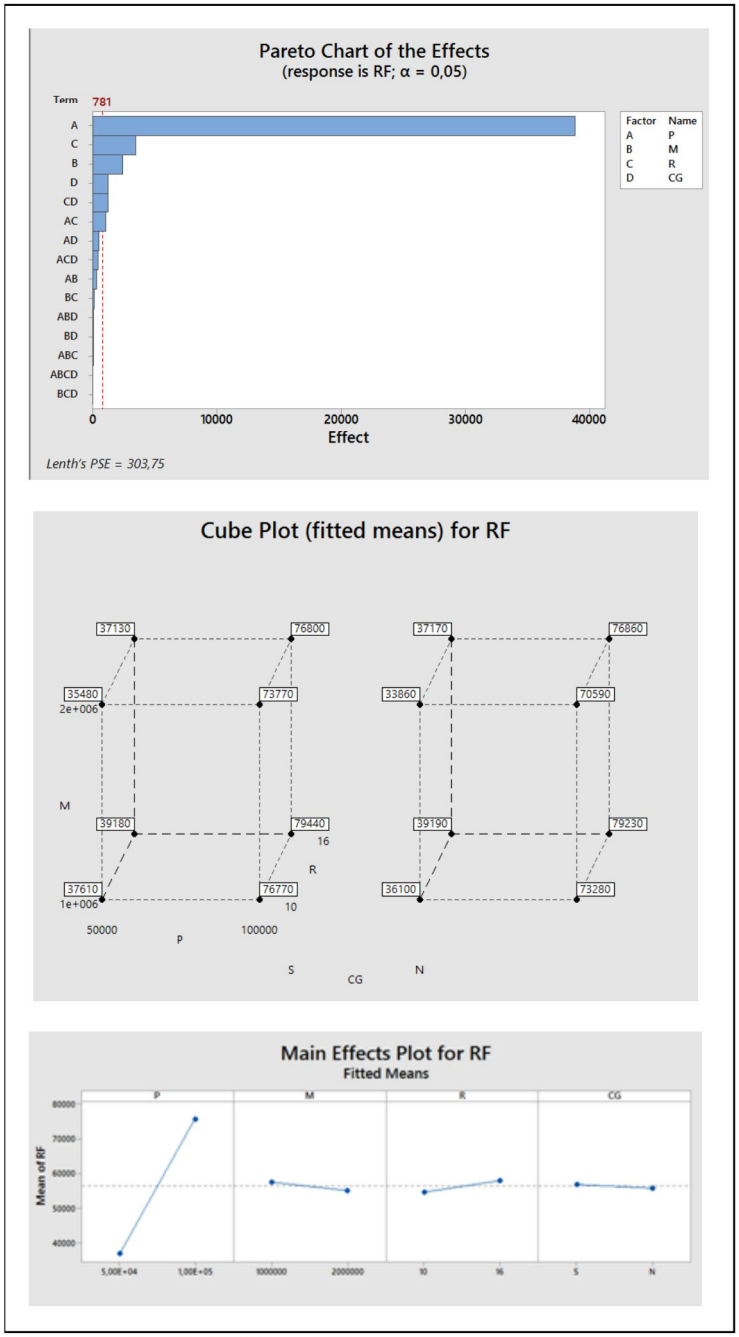


Fig 6. 6 : Result of DOE analysis

B. DOE Results

Result of CAE anaylsis have been illustrade in pareto chart , cube plot and main effect plot for reaction forces as shown below.

According to DOE results , it is clear to say that the system pressure has an important role on reaction forces. Second factor is radius of target object. The reaction forces go up while radius is increasing. But the material stiffness of gripper and position of target object show negative behavior. When material stiffness increased , reaction forces decreased.

VII. Conclusion

As a conclusion, the study has reflected the fundamental design rules of a soft grip design. The design basically use the multilayer beam technic but with some modifications. Bended beam has wrapped and held an object as expected and shown as in figures.

CAE and DOE analysis clearly show that there are different factors which play an important role on designing a soft gripper.

For reaction forces , the most important factor is the air pressure according to doe results.

As mention in first stages of study , to get maximum mechanical efficiency , factors of soft gripper should be chosen properly. So , the designers and researchers can use this study and its results as a reference.

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