ESCUELA TÉCNICA SUPERIOR DE INGENIEROS INDUSTRIALES Y DE TELECOMUNICACIÓN

Titulación:

INGENIERO TÉCNICO INDUSTRIAL MECÁNICO

Título del proyecto:

IMPROVEMENT OF FLOOR TILE FEET

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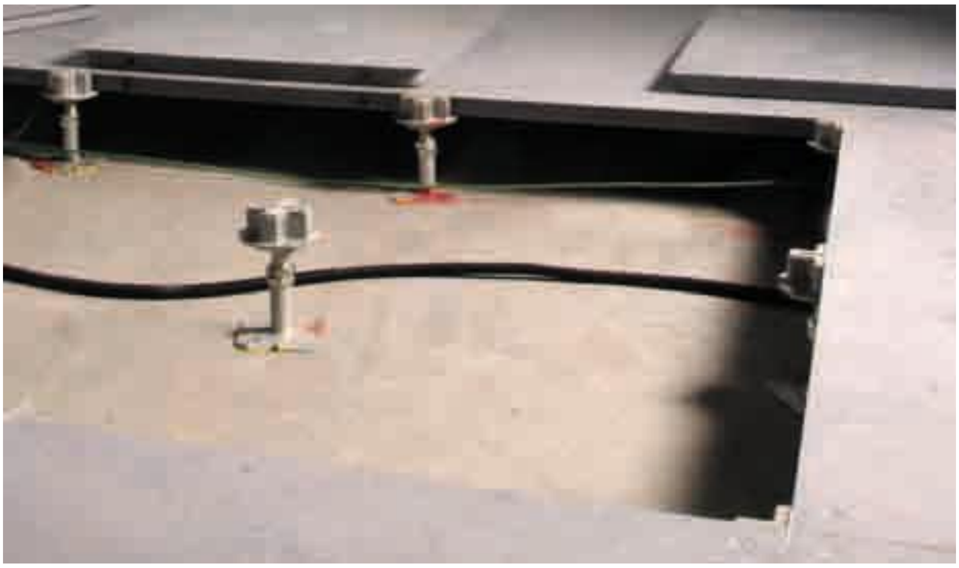
Pamplona, 27 de Junio de 2012

IMPROVEMENT OF FLOOR TILE FEET



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May 2012

Author’s declaration

Abstract

Innovation, design, implementation of new technologies and awareness for the environment and society, is the basis of this project, which aims to provide an alternative to an existing product, giving it added value, generating energy cleanly and storing for reuse.

The development of this project has been continuously linked to the need of using piezoelectric transducers to produce energy harvesting from the footsteps. This project started from an existing support, so we had to make a preliminary study of the needs required. And a comprehensive study of new technologies already existing, materials to use, as well as design and production according to the needs of the company.

During development of the project, have been designed four types of supports with subsequent analysis to see which one best to satisfy our purpose. In this way solutions have been addressed to achieve the best outcome, whether by design, by the choice of elements and their colocation or the set of all.

Acknowledgements

Thank you to Morgan Electro Ceramics and to Glyndwr University to give me the opportunity to realize this project. It has been a unique experience in which I have learned to fend for myself in different situations.

I would like to say a special thank you to my supervisor, Cedric Maranta, without whose help, guidance and their ability to point me on the right direction this project would not have been possible.

Thanks to Pablo Esteras for his support and advice, especially on a very difficult start where things were very close to not happening.

Thank you to Mr.Cedric Belloc for his guidance and good advice.

Thanks to my friends Iñigo and Eduardo for their continuous support and for cheer me up in bad moments.

Thanks to my friends Arantza and Elena for their patience, understanding and support, and for always being there.

Thanks to my cousin Isaac and my sister Clara for their support and advice.

And finally, a big thank you to all my family, specially to my parents for their love and continuous support. Although we have been separated for many kilometers during these months, I have always felt you very close.

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1. Introduction

1.1. Background to project

Energy Harvesting [1] technology has the ability to create autonomous, self-powered electronics systems that do not rely on batery for this operation. The term energy harvesting describes the process of converting ambient energy surrounding a system into useful electrical energy through the use of a specific material or transducer.

A widely studied from of energy harvesting involves the conversion of mechanical vibration energy into electrical energy using piezoelectric material, which exhibit electromechanical coupling between the electrical and mechanical domains.

Piezoelectricity [2] is electrical energy produced from mechanical pressure, including motions such as walking. When pressure is applied to an object, a negative charge is produced on the expanded side and a positive charge on the compressed side. Once the pressure is relieved, electrical current flows across the material.

Piezoelectric sensors are based on when pressure is applied, force or acceleration to a quartz crystal or other piezoelectric material develops a charge through the crystal that is proportional to the applied force. Another feature of the crystal sensors is that the signal generated by the crystal decays rapidly.

The purpose of project is to design and build an energy harvesting demostration system that will provide a renewable source of energy. This project involves the use of piezo-electric transducers for harvesting energy produced from a foot plate.

A single footsped causes pressure when the foot hits the floor. When the flooring is engineered with piezoelectric technology, the electrical charge produced by the pressure is captured by floor sensors, converted to an electrical charge by piezo materials, then stored and uses as a power source.

This project contains two parts, which will be developed by two students.
By one hand it focuses in the study of piezo-electric transductors, what is their function, that materials are made...And where is the place more efficient to put these inside of support, in the base, inside at half height...

By other hand is about redesign the existing pedestal. Researching the different types of materials to design the support as well as the possible mechanisms that can be develop to obtain that the transducers in the pedestal generates the most electrical energy. And this will be my part to develop in my project.

To throughout this study we use different techniques and technologies, which will be carried out below, in order to achieve the most optimum results.

1.2. Aim

Innovation, research, design and test a transductor piezoelectric integrated into a support, generating and storing energy from footstep for reuse.

1.3. Objectives

- Measure of support and tile, take measurements and develop drawings.
- Study of existing support.
- Research the new materials and define and design the structures of possible designs.
- Develop drawings in Catia, and analyze them through the finite element method.
- Carrying out series of tests to optimise the design.
- Improvements in design to increase energy harvesting.

1.4. Project Overview

The following figure shows the main idea of how this system generates energy from a footstep:

Figure 1.1: Energy harvesting system

When a footfall occurs, a pressure is created on the tile and this in turn transmits the presure to the four supports. The piezoelectric transducers, which are placed in the supports, are compressed by this pressure.

Piezoceramic components are the all-important part of electromechanical transducers. Are capable of converting mechanical energy such as pressure or acceleration into electrical energy or, conversely, of turning electrical signals into mechanical movement or oscillation.

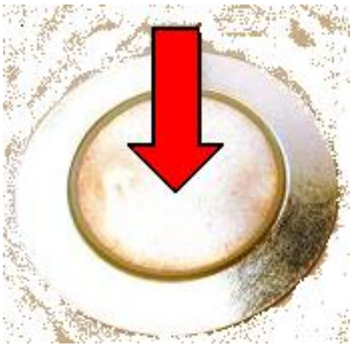


Figure 1.2: Force exerted on piezo

When this pressure is released the piezoelectric returns to its original state. This pressure variation produces electrical energy.

Piezoceramic components are used in a broad spectrum of applications covering a wide frequency range. In sensors, they enable the conversion of forces, pressures, and accelerations into electrical signals.

One feature is that the more we do vibrate, the higher the electrical current generated.

Placing a spring at the base of support, a horizontal vibration in the axis of support can be got and thus the efficiency of electrical energy produced by the piezoelectric is increased.

The generated energy is processed and converted to match the requirements of the electronics contained in the wireless sensor board. The energy is finally stored waiting to be utilised by the sensor.

1.5. Specifications

For the development of this project several elements were used:

· **Tile**

Composition: Steel with concrete core.
Dimensions: 600x600x32 mm.
Estimated weight: 12kg.

· **Force:** The analyzes were carried out considering a total force of 3000 N, whose point of application was at the center of the tile.

This force was evenly distributed among the four supports, subjecting each to 860 N. This value was chosen so to a person's weight of about 86 kilograms was reflected.

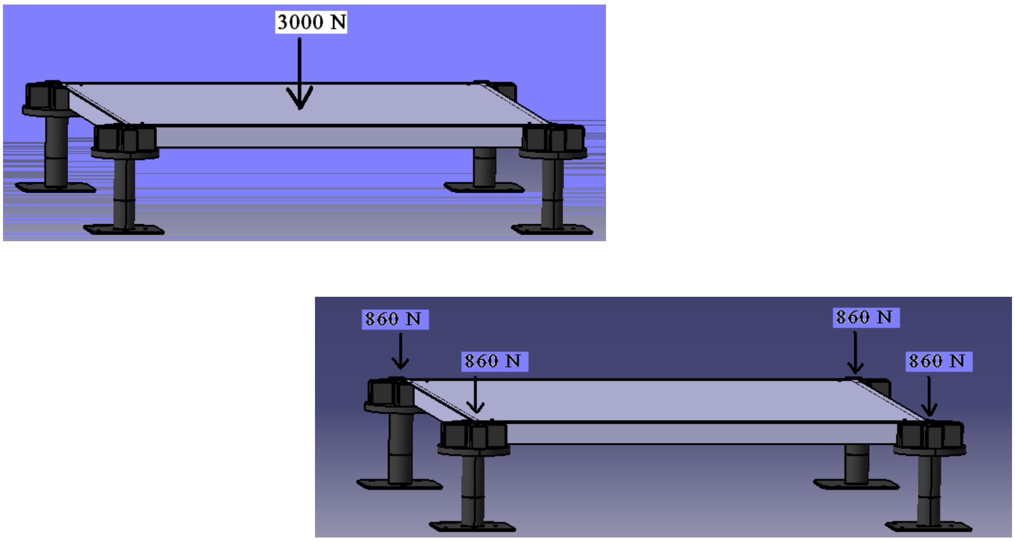


Figure 1.3: Value and distribution of force applied

· **Supports:** Were the target of the project and were specified in more detail in post chapters.

· **Transductors and Sensors** [3]: MTC ElectroCeramics is able to provide tailored solutions for some of the most demanding pressure and force sensing applications. Is a world leader in the design, manufacture and optimisation of electro ceramic materials, transducers, sensors and systems.

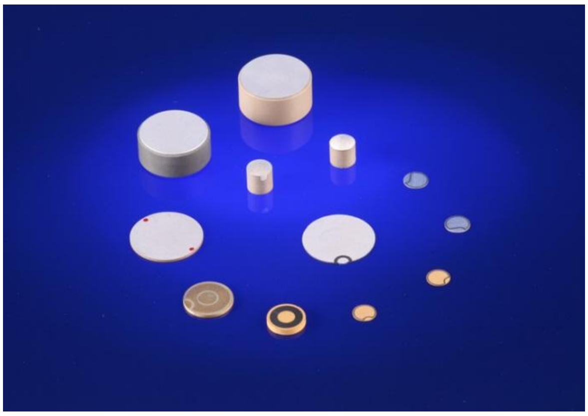
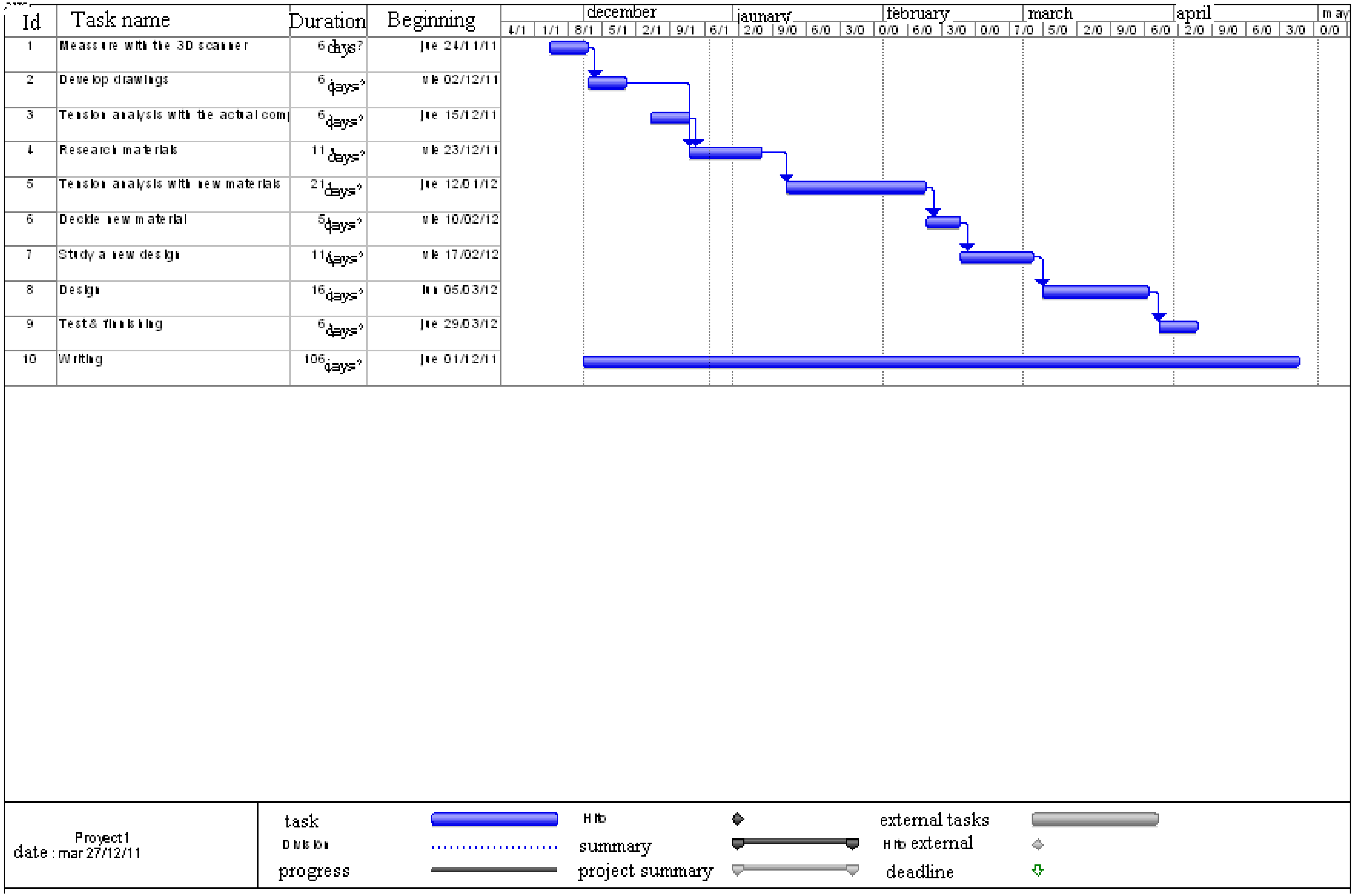


Figure 1.4: Different types of transducers and sensors

1.6. Gantt Chart



Id	Task name	Duration	Beginning
1	Meassure with the 3D scanner	6 days?	jue 24/11/11
2	Develop drawings	6 days?	vie 02/12/11
3	Tension analysis with the actual comp	6 days?	jue 15/12/11
4	Research materials	11 days?	vie 23/12/11
5	Tension analysis with new materials	21 days?	jue 12/01/12
6	Decide new material	5 days?	vie 10/02/12
7	Study a new design	11 days?	vie 17/02/12
8	Design	16 days?	lun 05/03/12
9	Test& finishing	6 days?	jue 29/03/12
10	Writing	106 days?	jue 01/12/11

2. Literature Review

2.1. Existing Product [4]

The patented T3pedestal system used with the CF Series is the only system to feature in built panel expansion, noise reduction, sound and impact absorption and positive panel locating.

T3 Pedestal

Normal finished floor height pedestal.

Field pedestal.
For use with CF,WF,CSF, and HF series bare finish panel from 150mm to 600 mm FFH.

Stringer - less Understructure.

In-built expansion System.

Noise and impact sound reduction system.

Figure 2.1: Parts of the existing support

Manufactured under Australian Standard Patent 2006200759.

2.2. Basic Understanding [5]

The aim of our project is to design a device or mechanism in a raised floor pedestals so that piezoelectric transducers generate a greater amount of electric energy.

So the first study will be the behavior of these pedestals when subjected to various efforts.

There are 6 basic tests that should be conducted on all raised floor systems to ensure maximum performance and longevity:

- Concentrated Load Test
- Uniform Load Test
- Ultimate Load Test
- Impact Load Test
- Rolling Load Test
- Pedestal Axial and Horizontal Load Test

The understanding of this test series, will help a better development of our project:

·**Concentrated Load:** A load is applied over a 25mm x 25mm steel indentor with the deflection of the panel not exceeding 2.5mm for the concentrated load specified.

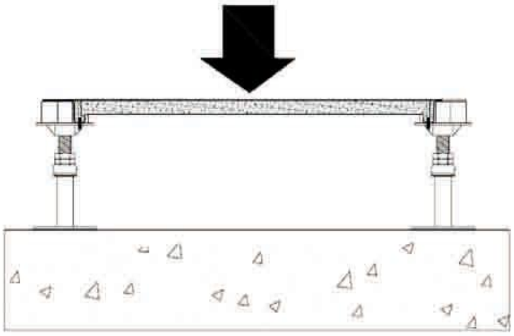


Figure 2.2: Schematic of concentrated load

·**Ultimate Load:** Similar to the concentrated load test, a load is applied over a 25mm x 25mm steel indentor until the system collapses. The ultimate load should be a minimum of 3 times the concentrated load.

· **Uniform Load:** A load is applied over a 1m x 1m area with the deflection of the panel not exceeding 2.5mm for the uniform load specified.

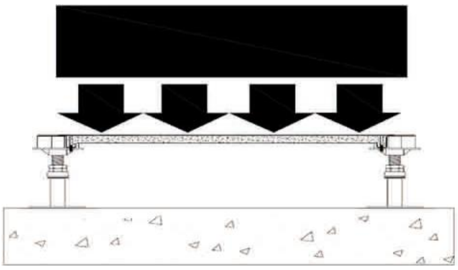


Figure 2.3: Schematic of uniform load

· **Impact Load:** A weight is dropped from 900mm onto a 25mm x 25mm steel indentor without the system collapsing.

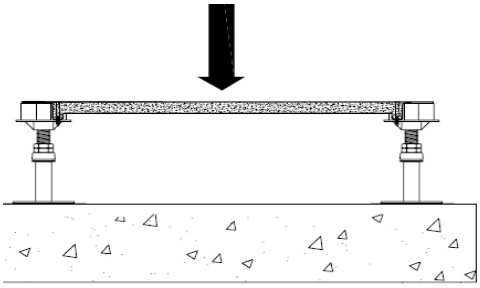


Figure 2.4: Schematic of impact load

· **Rolling Load:** A load rolled back and forth across the panel which is applied through 3 different size wheels. Deflection is measured after 10, 10,000 and 40,000 continuous cycles.

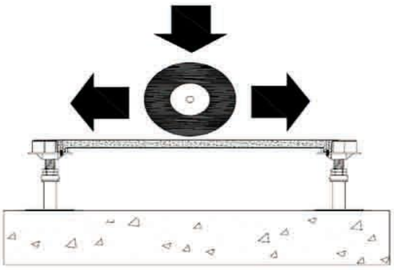


Figure 2.5: Schematic of rolling load

· **Pedestal Axial and Horizontal Load:** This is 2 tests, a load is applied vertically onto the pedestal and also horizontally. The pedestal should not show any permanent deformation after each test.

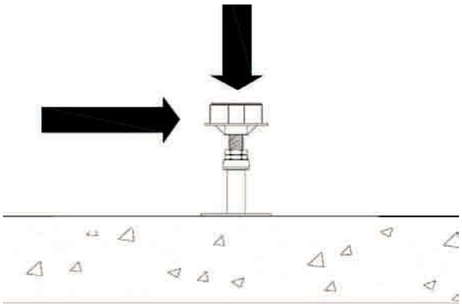


Figure 2.6: Schematic pedestal axial and horizontal load

2.3. Materials

An important factor at the time of designing a part is to define the material used for its manufacture.

The first element of the set that was taken to a study to determine the material that would be done, it was the spring.

There is a wealth of materials available for the manufacture of springs. So was required preliminary study of the functionality and features that ought to satisfy the chosen spring.

As it has been previously explained the spring was located inside the base, so that took into account that this was subjected to great efforts and repeatedly throughout its useful life.

As can be seen the following five points, the material most optimum for this type of spring was steel.

Characteristics of the steel for springs [6]

1) It is essential that steels possess a high elastic limit, that is, the coefficient of work does not exceed the limit of elasticity.

2) In industrial practice, the limit of elasticity to the traction is usually between 700 MPa and 1500 MPa, depending on use and the characteristics of size, composition, etc.

3) For that a spring can to work normally, the value the elastic limit must be very high and close to the aforementioned figures, and as the breaking strength usually ranges from 10 to 40% above the elastic limit, it must have values between 770 MPa and 2100 MPa.

4) Is important that the springs, possess resistance to fatigue, as many of the docks, in their useful life, receive efforts in a cyclic and repetitive form.

5) Is necessary avoid decarburization of the springs in their thermal processes and manufacturing, as this catalyzes the process of fatigue, because the decarburization occurs initially in the periphery and the periphery is where the spring tends to start your fails. Likewise should be take care of the presence of cracks, defects that may have the dock.

Figure 2.7: Steel springs

Carbon steels and alloy steels suitable for the manufacture of springs

· **Steel 1060**: As steel of cut used for tools of plastic works, wood and non-ferrous materials (brass, bronze, etc). This steel has good penetration of temper, even in medium size pieces and oil quenching. With induction hardening and flame hardening can get good results in pieces of not very high mechanical strength. This steel can also be used for springs.

· **Steel 1070**: As a structural steel for all types of parts requiring high strength and are subject to high mechanical stress, eg moving parts of mills and crushers, and knives for grinding soft materials. As spring steel used to make these pieces with excellent quality and with those of helical type specialty. As tool steel for all parts requiring hardness, toughness and wear resistance.

· **Steel 1095**: This is the carbon steel of greater resistance, used for the manufacture of springs of all types and for all uses. Like the other types with lower percentages of C. Can also be used in cold for the construction of special springs.

· **SAE 5160**: This steel is specially indicated for the construction of springs for cars and trucks, whether in crossbows, either to helical springs and torsion bars also.

· **SAE 6150**: This steel is used for the construction of springs of very high resistance, helical springs and torsion bars for automobiles.

· **SAE 9260**: This type of steel is the most widely used and more economical between the alloyed steels for the construction of springs, particularly for automobiles and trucks. Is tempered very easily and has good penetration of hardening. It can also be used for the construction of agricultural machine tools and other implements of the same nature.

The material chosen was Steel 1095. A summary of the main features is shown in the next tables: [7]

Category	**Steel**
Class	Carbon Steel
Type	Standard
Designations	**Germany**: DIN 1.1274 **Japan**: JIS SUP 4 **Sweden**: SS 1870 **United Kingdom**: B.S. 060 A 96, B.S. En. 44B **United States**: AMS 5121 , AMS 5121C , AMS 5122 , AMS 5122C , AMS 5132 , AMS 5132D , AMS 7304 , ASTM A29 , ASTM A510 , ASTM A576 , ASTM A682 , FED QQ-S-700 (1095) , MIL SPEC MIL-S-16788 (C10) ,SAE J403 , SAE J412 , SAE J414, UNS G10950

Table 2.1: AISI 1095

Composition:

Element	Weight %
C	0.90-1.03
Mn	0.30-0.50
P	0.04 (max)
S	0.05 (max)

Table 2.2: Composition of AISI 1095

Mechanical Properties:

Element	Weight %
Density (×1000 kg/m^3)	7.7-8.03
Poisson's Ratio	0.27-0.30
Elastic Modulus (GPa)	190-210
Tensile Strength (Mpa)	656.7
Yield Strength (Mpa)	379.2
Elongation (%)	13.0

Reduction in Area (%)	20.6
Hardness (HB)	192
Impact Strength (J)	2.7
Thermal Expansion (10^{-6}/ºC)	11.4

Table 2.3: Mechanical Properties of AISI 1095

Materials suitable for the manufacture of supports

- **Galvanized Steel** [8]**:** Is obtained from a coating process, of several layers of the alloy of iron and zinc. Usually there are three layers of the alloy, which are called "gamma", "delta" and "zeta". Finally is applied a final outer layer, which contains only zinc, called "eta", which forms by solidify the zinc bath dragged, and that confers upon the coating its characteristic look shiny metallic gray.

By being coatings obtained by immersion in molten zinc, cover the entire surface of the pieces, both exterior and interior of the hollow parts and many other parts of the surface areas that are inaccessible to other methods of protection.

Galvanized coating, grants to the steel the resistance to abrasion , because the galvanized coatings possess the almost unique feature to be metallurgically bonded to the steel base, so we have excellent adhesion.

On the other hand, being constituted by several layers of zinc-iron alloys, even harder than steel, form a system very resistant to impact and abrasion. Also to corrosion.

This last feature produces three excellent effects. The first, called "protection by barrier effect" refers to the isolation from an environment that could be quite aggressive. Second, the "cathodic protection by sacrificial anode". Finally, the "restoration of bare zones" refers to that the zinc corrosion products are able to cover those discontinuities that may exist in the coating due to corrosion or other damage, for example, a sharp blow.

In summary, among the many advantages that make of this galvanizing process something so positive and necessary is that grant to the steel a much higher durability as well as a large resistance. Noteworthy is the great protection that gives this coating, protecting it as a physical barrier, electrochemically and providing a self-curing process with corrosion products of zinc.

· **Aluminum :** Aluminum is as a storehouse of energy (15 kWh / kg), so it has a great value that can not be wasted and recycling means energy recovery. It is also a valuable material as waste, which is a strong economic incentive.

The properties that make aluminum metal as a useful are its light weight (about a third the weight of copper and steel),corrosion (very useful feature for those products that require protection and conservation), resistance, is a good conductor of electricity and heat, is not magneticand non-toxic, good reflector of light (ideal for the installation of fluorescent tubes orlight bulbs), waterproof and odorless, and very ductile. Furthermore, the greatattraction is that it is a 100% recyclable metalthat is, can be recycled indefinitely without there by losing its qualities. In Europe, aluminum reaches very high recycling rates ranging from 50% in containers, 85% in construction and 95% in transport. This translates into an annual production of around 4 million tons of aluminum recycled in Europe.

In short, aluminum is the most abundant element in Earth's crust after oxygen and silicon, and it can be recycled infinitely without losing an iota of its qualities. The applications are endless and the demand is growing every day. A suitable material for the world and respecting the environment in which we live.

Of these two types of materials that are the most common for the elaboration of these elements, the galvanized steel was chosen for our springs.

Note also that the mechanical properties of the workpiece once galvanized are the same as the starting steel.

Piezoelectric material PZT 503

The piezoelectric transducer that was taken for our study was the PZT 503, integrated with sheets of iron alloys.

Figure 2.8: Piezoelectric transducer

Ideal for use in medical sensors. This material has excellent transmit and receive constants (d and g) that result in enhanced sensitivity in any transmit/receive transducer application.

In the following table can be seen some of their properties:[9]

Property	PVDF	PZT	Units
Strain Constant	22 x 10^{-22}	-175 x 10^{-22}	(m/V)
Stress Constant	216 x 10^{-3}	-11 x 10^{-3}	(Vm/N)
Coupling Factor	0.14	0.34	
Relative Dielectric Const	12	1700	
Max Operating Temp	80	150	(ºC)
Density	1780	7600	(kg/m3)
Young's Modulus	2 x 10^{9}	7.1 x 10^{10}	(N/m2)

Table 2.4: Piezoelectric material properties, standard PVDF and PZT compounds

2.4. Stresses and Deformations [10]

The deformations of a body refer to the relative change its size or shape. This deformation is function of the molecular properties of the material and independent of their specific dimensions. The deformation of a body is the result of an applied stress.

The effort is defined as the force per unit area:

$$\boldsymbol{\sigma = F/A \quad (N/m^2)}$$

Equation 2.1: Formula of axial effort

Where F: Axial force A: Cross-sectional area

The deformation produced depends on the tension per unit transversal area over which force is applied.

Strain (ε) is the ratio between the variation in length produced and the initial length of the body:

$$\boldsymbol{\varepsilon = \Delta L / Lo} \quad \text{(unitless)}$$

Equation 2.2: Formula of strain

The deformation which undergoes an elastic object is proportional to effort or applied force and when this force is removed, the object tends to return to its original dimensions.

However, all substances have an elastic limit after which no longer return to the original dimensions. If the force continues to increase after this point, the material or substance eventually is broken or fractured. The force at this point is known as breaking strength.

When a longitudinal stress (tension or compression) is applied to an elastic body, the module that relates the stress and strain is called Young's modulus. This is a constant value for each material and is expressed in units of force per unit area.

E: Young's modulus (N/m^2)

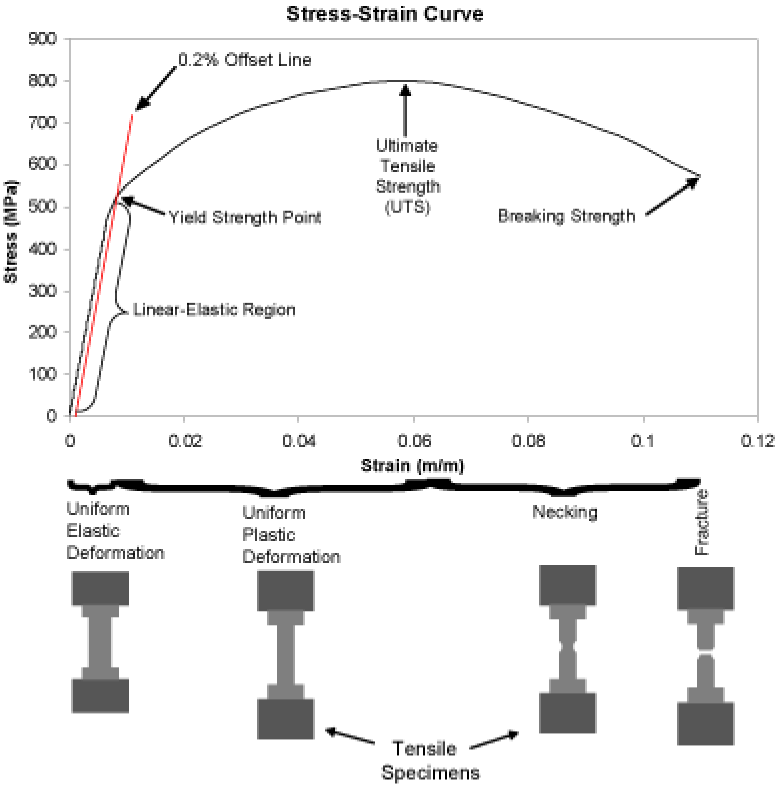


Figure 2.9: Stress-Strain curve

· Yield strength: Is the maximum value of the external forces per unit area (or stress) that the solid can bear behaving like elastic. From this value the deformations are permanent and the body behaves as inelastic or plastic.

· Limit of proportionality: Is the maximum value of the effort that the solid can supportso that the applied stress and the strain produced are proportional (Hooke's law region):

$$\sigma = E \cdot \varepsilon$$

Equation 2.3: Hooke’s Law

· Limit of rupture or breaking strength: is the minimum force per unit of section capable of producing the rupture of the body.

· Safety factor: the ratio between the maximum force per unit of section and thebreaking strength.

$$S = \sigma/\sigma_C \qquad \begin{cases} S < 1 & \text{the body does not break} \\ S \geq 1 & \text{the body breaks} \end{cases}$$

Equation 2.4: Safety factor

This table can be shown the difference between ductile and brittle material in its course to support a load: [11]

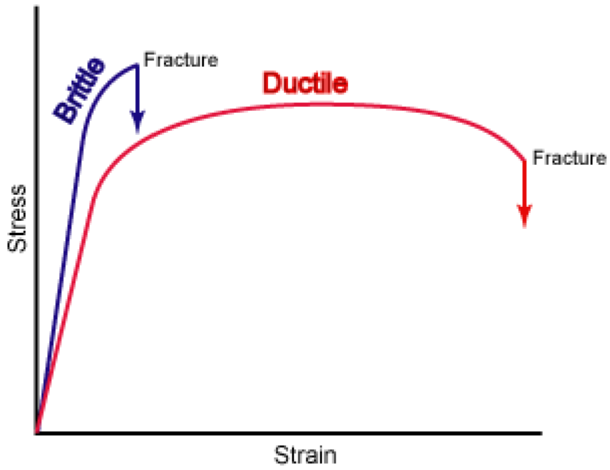


Figure 2.10: Stress-strain curve of a brittle material and ductile

The Young's modulus, also called the modulus of elasticity, represents the degree of stiffness of a material against axial and bending efforts, regardless of the shape, size and links of union the element or part that conform.

Mathematically it is the quotient of the division of a unitary effort between a unit strain.

This table shows the mechanical properties of the materials most characteristic, such as Young's Modulus , ultimate tensile strength and yield strength.[12]

Material	Young's Modulus $E(10^9\ N/m^2, GPa)$	Ultimate Tensile Strength S_u $(10^6\ N/m^2, MPa)$	Yield Strength S_y $(10^6\ N/m^2, MPa)$
Aluminum	69	110	95
Brass	102-125	250	
Glass	50 - 90	50 (compression)	
Stainless Steel, AISI 302	180	860	502
Steel, Structural ASTM-A36	200	400	250
Steel, High Strength Alloy ASTM A-514		760	690
Copper	110-128	220	70
Titanium Alloy	105-120	900	730
Nylon	2-4	75	45

Table 2.5: Young's Modulus and maximum stresses of representative materials

3. Techniques Employed

3.1. Scanner 3D

A 3D scanner is a device that analyzes a physical object to collect data such as shape and color. This data is then analyzed by specific software that allows to recreate the data collected to build a digital 3D model.

The purpose of a 3D scanner is, usually to create a point cloud of geometric samples from the surface of the object. These points can then be used to extrapolate the shape of the object (called reconstruction). If the color information meeting in each of the points, then we can also determine the colors of the object's surface.

Its operation is very simple, you only need to press the green button and start moving the scanner by the object to be analyzed. The scanner uses the geometry of the object to the alignment of the surface in real time. The result is very fast, it can capture a human face on the second 10/15.

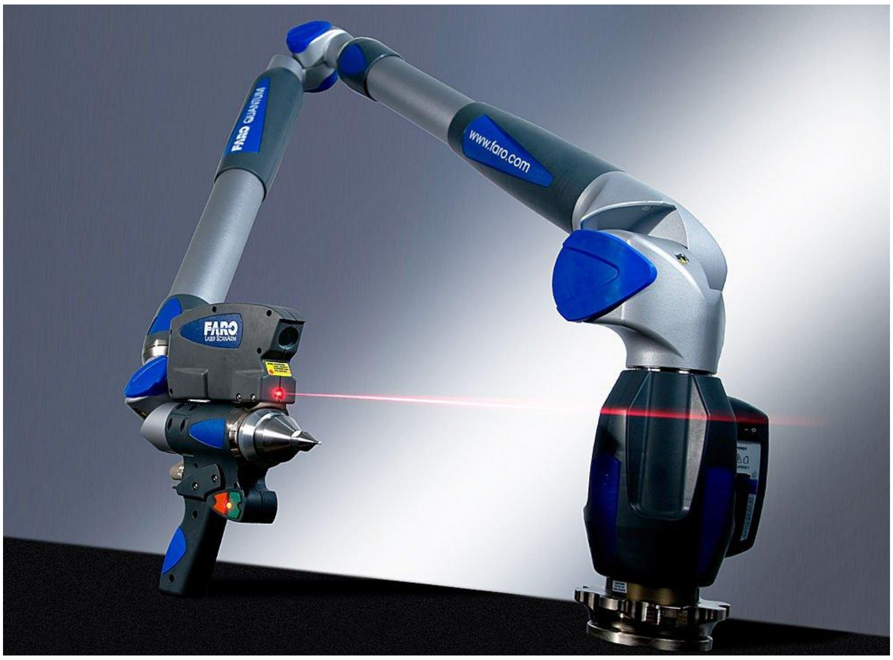


Figure 3.1: Scanner 3D

This system was used to scan the tile and the other parts of support.

In the first moment, scanner was not going to be used. Measures were to take place in the workshop with the tools needed, but the complexity of the tile made us change our mind. Because the tile was composed by a concrete core with a complex geometry of concave half spheres. And this would have taken a long time.

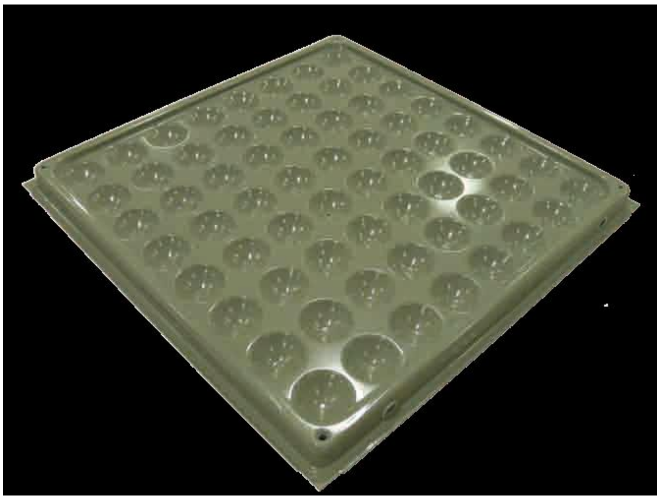


Figure 3.2: Tile

Although it was not a good idea because the 3D laser scanner was connected to a computer did not really good and it cost much time processed. Is supposed to this scan is taken in thirty minutes and it took us five hours.

And besides to the end of the scan there was not way to save the drawing.

Because of these inconveniences and considering that the tile was on the back burner in our study, was decided to simplify the geometry of the tile.

3.2. Catia's Software

My study has been conducted through the CATIA program, whose analysis are based on the finite element method, which has become the standard method currently most used for numerical simulation.

This program provides the designer with a working environment and a series of practical tasks of calculation, simply and efficiently to solve, which introduces you to the various design platforms.

The program includes various modules of work we can choose by clicking the menu 'Start'. This shows a list of all modules available, depending on the license of CATIA installed.

In this image can be seen what has been mentioned above:

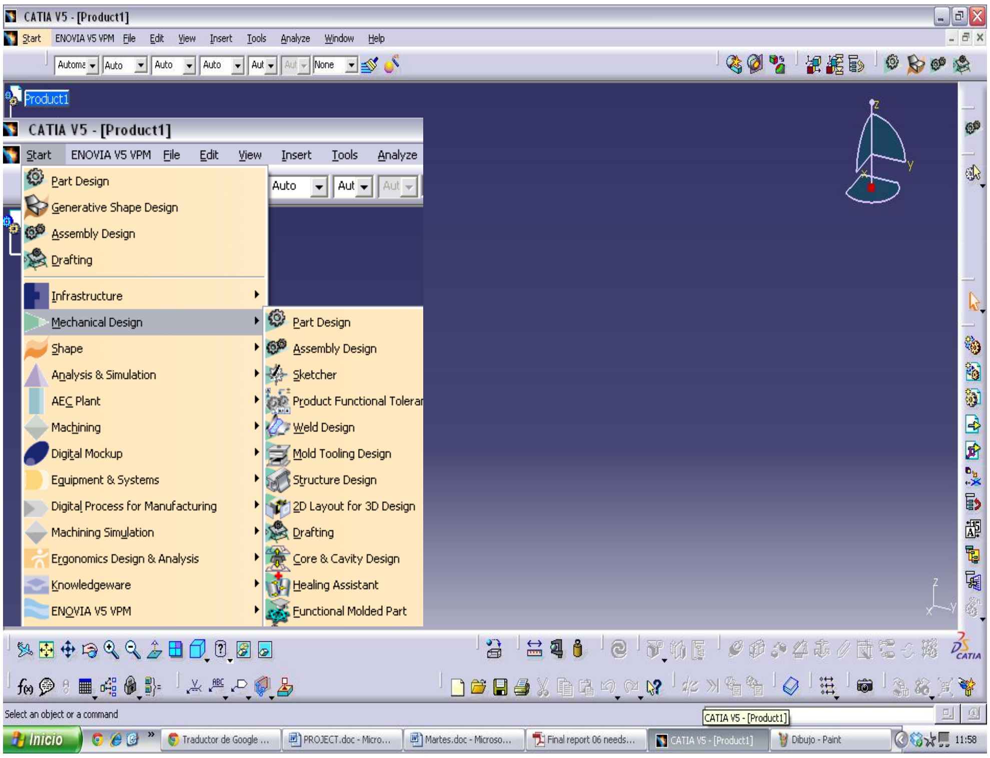


Figure 3.3: Screen of Catia Software

3.3. Finite Element Method [13]

3.3.1. Introduction

The finite element method (FEM) has acquired a great importance in solving engineering problems, physical, etc because it allows to solve cases that until recently were virtually impossible to solve by traditional mathematical methods.

This circumstance forced to make prototypes, test them and go making improvements an iterative manner, which brought with him a high cost in both economic and development time.

The MEF enables a mathematical model of calculating the real system, easier and cheaper to modify than a prototype. However it is still an approximate method of calculation due the basic assumptions of the method.The prototypes, therefore, still necessary, but in smaller numbers, since the former can approach much more to the optimum design.

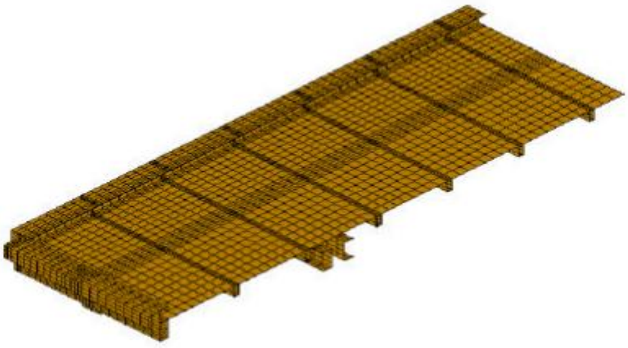


Figure 3.4: Finite Element Discretization

The finite element method as mathematical formulation is relatively new;

Although its basic structure is known since some time, in recent years has undergone a great development due to advances in computer technology.

Have been precisely these computer advances which have made available to users, many programs that can perform calculations with finite elements.

But do not be fooled, the proper handling of such programs requires a thorough knowledge not only of material you are working, but also the beginning of the MEF. Only in this case we will be able to guarantee that the results obtained in the analysis are in accordance with reality.

3.3.2. Brief History of the Finite Element Method

Although the name of MEF has been established recently, the concept has been used since several centuries. The use of methods of spatial and temporal discretizations, and the numerical approach to find solutions to engineering or physical problems is known since ancient times. The concept of 'finite element' parts of that idea.

To find vestiges of these calculations could go back to the time of building the Egyptian pyramids. The Egyptians used discretized methods for determining the volume of the pyramids. Archimedes (287-212 BC) used the same method to calculate the volume of all types of solid or the surface of areas. In the East also appear approximation methods to perform calculations. Thus the Chinese mathematician Liu Hui (300 AD) used a regular polygon of 3072 sides to calculate lengths of circles with getting an approximation of the number Pi of 3.1416.

The development of finite elements as known today has been linked to structural calculation, mainly in the aerospace field. In the 40s Courant proposes the use of polynomial functions for the formulation of elastic problems in triangular subregions, as a special method of variational method of RayleighRitz to approximating solutions.

Were Turner, Clough, Martin and Topp who presented the MEF in the form accepted today. In his work introduced the application of simple finite elements (bars and triangular plates with loads in their plane) to the analysis of aeronautics structures, using the concepts of discretized and shape functions.

Currently the method is in a phase of great expansion: it is widely used in industry and continue to appear hundreds of research in this field.

Computers have provided the effective means of solving the multitude of equations that arise in the MEF, whose practical development has progressed at the same rate that the obtained innovations in the field of computer architecture.

Among these, besides allowing the decentralization of programs of EF has helped to promote their use through sophisticated graphics packages that facilitate the modeling and synthesis of results.

Nowadays is already conceived intelligent connection between the techniques of structural analysis, design techniques (CAD) and manufacturing techniques.

3.3.3.General Concepts of Method

The general idea of the finite element method is the division of a continuum in a set of small elements interconnected by a series of points called nodes.

The equations which govern the behavior of the continuum, also govern the behavior of the element.

In this way is achieved change from one system continuous (infinite degrees of freedom), which is regulated by a differential equation or a system of differential equations to a system with a number of finite degrees of freedom whose behavior is modeled by a system of equations, linear or not.

In any system to analyze we can distinguish between:

· Domain: Geometric space where it is going to analyze the system.
· Boundary conditions: Known variables which condition the change in the system: load, displacement, temperature, voltage, heat sources...
· Unknown factor: System variables that we want to know after the boundary conditions have acted on the system: displacements, stresses, temperatures...

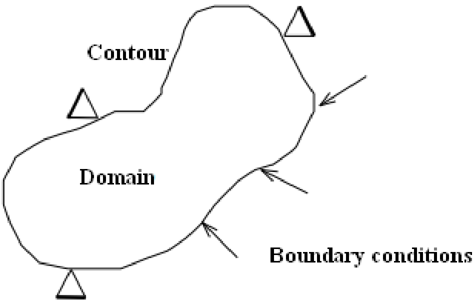


Figure 3.5: System Continuous

The finite element method supposes, to solve the problem, the discretized domain into subdomains called elements. The domain is divided by points (if linear), through lines (in the two-dimensional case) or surfaces (in the three-dimensional) imaginary, so that the total domain in study is approached through the set of parts (elements) in which is subdivided.

The elements are defined by a discrete number of points, called nodes that connected together elements. On these nodes are materialized the unknowns of the problem.

In the case of structural elements these unknowns are the nodal displacements, since from these we can calculate the other unknowns that interest us: stress, strain...These unknowns are called degrees of freedom of each node in the model. The degrees of freedom of a node are the variables that determine us the state and / or position of the node.

For example if the system to be studied is a cantilever beam with a point load on the end and a temperature distribution as shown in the figure,

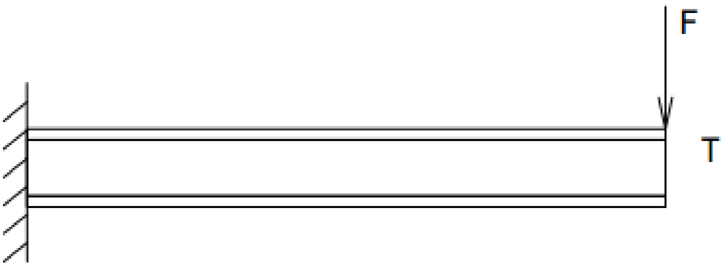


Figure 3.6: System of cantilever beam

The discretized of the domain can be:

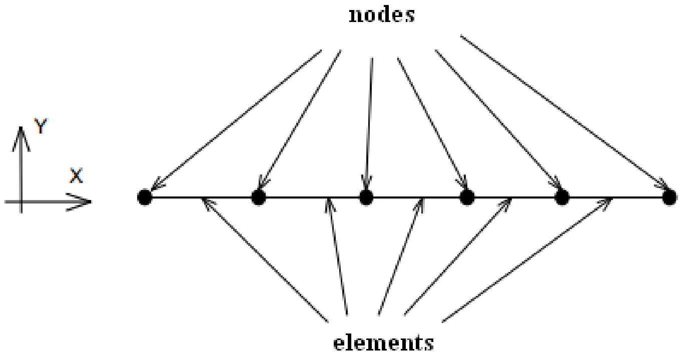


Figure 3.7: System discretized

The degrees of freedom at each node are:

· Moving in the direction X
· Moving in the direction Y
· Rotation according Z
· Temperature

The system, due to boundary conditions: underrun, force punctual, and temperature, evolves to a final state. In this final state, known values of the degrees of freedom of the nodes in the system can determine any other desired unknown: stresses, strains...It would also be possible to obtain the time evolution of any of the degrees of freedom.

Raising the differential equation that governs the behavior of the continuum for the element, you get to formulas that relate the behavior in the interior of same with the value that take the nodal degrees of freedom. This step is performed by means of some functions called of interpolation, because these 'interpolate' the value of the variable node within the element.

The problem is formulated in matrix form due to the ease of manipulation of matrices by computer. Knowing the matrices that define the behavior of the element are assembled and are form a set of algebraic equations, linear or not, that solving them give us the values of the degrees of freedom at the nodes of the system.

3.3.4. Before making a calculation by the MEF

Before starting to solve a problem by any finite element program should be reflect on a series of points.

3.3.4.1. What is intended with the analysis?

Determine voltage, obtain temperature distributions, see how the system is evolutioned, calculate frequencies and natural modes...This question will determine us the type of analysis to perform.

3.3.4.2 How will be the geometry that we will analyze?

Surely we know the royal geometry of the problem, but at the time of its analysis, we should simplify to the maximum depending on the purpose of analysis, since most of the details are superfluous and the only thing that involve is excessive consumption of computing time and storage space.

For it we must find symmetries, antisimetrías, axisimetrías the problem, problems of stress or strain flat, elimination superfluous detail: according radios, notches...

Once the geometry has been studied can be decide the type of elements to use, the characteristics thereof, as well as the properties of the materials or (modulus of elasticity, conductivity ...) to be used.

3.3.4.3. What conditions of boundary are imposed on the system to study?

Also be known, but we should study whether or not they are important or influential in the type of analysis that we will performed (may be the case, for example, that our system is subjected to sudden change of temperature, but we want to make a modal analysis to find out their natural frequencies, in which case the result is independent of this condition).

Once the boundary conditions are determined we must consider how to implement them, if they represent the actual conditions of the problem, if there balance (if it is a static analysis). The imposition of appropriate boundary conditions is one of the most complex decisions at the time of performing finite element analysis.

3.3.4.4. What results do we hope to get?

In order to know whether we have made the analysis correctly or if it represents the reality, we should have an idea of how it will to respond. For example, if we are analyzing a pipe subjected to internal pressure and the results indicate that decreases the radius we should think that we have modeled the system wrong, either in the application of loads, in the mesh, etc.

4. Rationale for the design of support

4.1. Piezoelectricity [14]

The property of piezoelectricity was first observed by Pierre and Jacques Curie in 1881 studying the compression of quartz. When subjected to mechanical action of the compression, the loads of the matter are separated and this gives rise to a polarization of the load. This polarization is the causative of these sparks jump.

For that matter present the property of piezoelectricity should crystallize in systems that do not have central symmetry (that have dissymmetry) and therefore having a polar axis. Of the 32 crystal classes, 21 have no center of symmetry. All these classes have the piezoelectric property to a greater or lesser extent.

Gases, liquids and solids with symmetry, do not possess piezoelectricity.

If pressure is exerted on the ends of the polar axis, polarization occurs: an electron flow goes towards one end and in him produces a negative charge, whereas at the opposite end a positive charge is induced.

The high voltage obtained, which is necessary for the spark jump, is greater when using narrow sheets of glass and of large surface area. The narrow sheets, are cut so that the polar axis crosses perpendicular to such faces.

The current generated is proportional to the area of the plate and the speed of variation of pressure applied perpendicularly to the surface of the plate (dF/dt is the speed of the click-clack).

The piezoelectrics are formed by two very thin sheets of different metals, or sometimes of a metal sheet on which is deposited a thin layer of ceramic. The behavior of both different layers, is such that on receiving a pressure emit an electric current, which is not nearly so high as to notice it in his hand, but enough to serve as an electronic signal for some applications. Is a metal plate and over it a layer of ceramic.

This property is somehow reversible. That means that if unlike before, what we do is apply a low electric current, the piezoelectric will vibrate. That's why we also call buzzers. So you know, if you apply electricity vibrate, and if you do them vibrating (hit it, for example) emit electricity.

One of the characteristics is that the more we do vibrate higher will be the electric current that is going to issue.

4.2. Pressure [15]

The effect of a force depends on its value, direction and sense, and the size of the surface on which it acts (walking through the snow with snowshoes to avoid sinking, using sharp instruments like the ax ....).

Pressure is the magnitude that relates the force with the surface on which it acts, ie equivalent to the force that acts on the unit area.

$$P = \frac{F}{A}$$

Equation 4.1: Formula of pressure

Where: P = Pressure ; F = Force ; A = Surface area

The unit of measurement of pressure in the International System is the Newton per square meter, which is called the Pascal (Pa). A Pascal is the pressure which exerts a force of a Newton, which acts on a surface of one square meter of area.

$$Pa = \frac{N}{m^2}$$

If we decrease the surface we will get very high pressures with low forces (eg, knives, needles, pins ...).

5. Mechanical Design

The aim of the project was to redesign the actual support to develop the most efficient energy harvesting when the piezoelectric material is placed in it. It has been described in previous sections the fundamentals of the piezoelectrics as well as the concept of pressure, from of which is posed the initial designs to improve the efficiency of energy harvesting in these supports.

One of the characteristics of the piezoelectric is that the more we to do it vibrate higher will be the electric current that is going to issue. So in addition to pressing the piezoelectric materials, we need to make it vibrate to increase the energy produced.

The first idea was to place a spring at the base of support. The starting position of the spring would be one millemeter more extended of its natural position.

Figure 5.1: Spring introduced into the support

Another feature of these elements is that the voltage obtained is greater when using narrow sheets of glass and of large surface area.

So the second concept which was taken into account was that the surfaces of the piezoelectrics would be extended. Thus will be achieved greater energy.

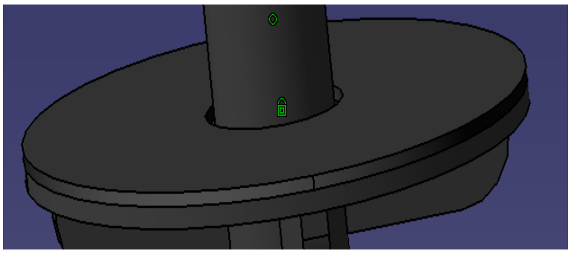


Figure 5.2: Work area of piezoelectric

There is a great variety of springs available on the market, so that was done a previous study on the features and functionality of these instruments:

5.1. Springs

The springs are mechanical components which are characterized by absorbing considerable deformation under the action of an external force, returning to recover their initial shape when it stops the action of the same, ie, have a high elasticity.

For their manufacture are used highly elastic steels (carbon steel, silicon steel, chrome vanadium steel, chrome-silicon steel, etc..), although for some special applications can use the copper and hardened brass.

The springs are used with great frequency in the mechanisms to ensure contact between two parts, to accelerate movements that need great rapidly, to limit the effects of shock and vibration, etc...

In our case the goal of putting a spring in our support is another. Besides of pressing the piezoelectric material, is need to make it vibrates and thus to increase efficient.

Can be put different types of springs to improve efficient:

5.1.1. Springs of Helical Compression:

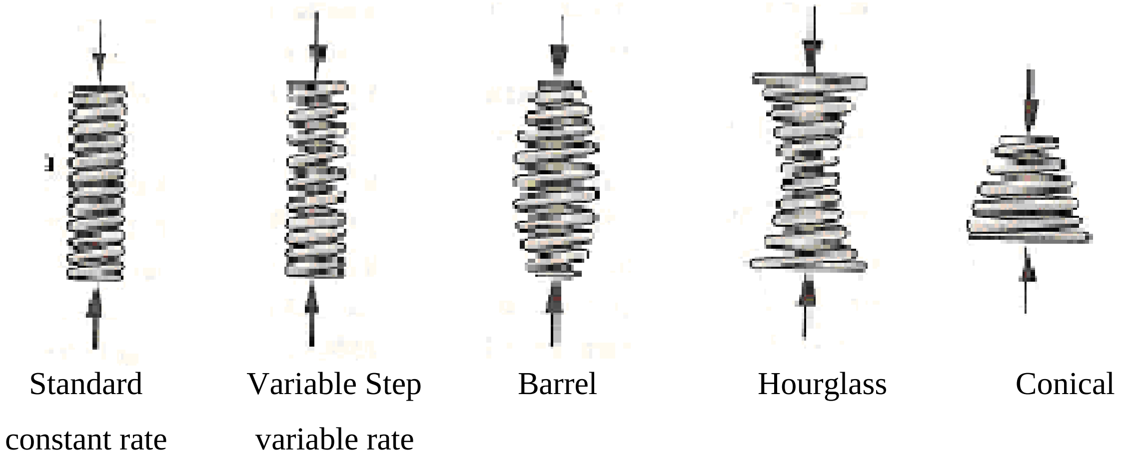


Figure 5.3: Helical Compression Springs

The **Helical Compression Spring** provides a pushing force and makes large deflections. Their standard form has turns of constant diameter, constant pitch (axial distance between turns) and constant rate.

This is the configuration of spring most common and there are numerous sizes. They are usually of round wire although there are also of rectangular wire.

It possible to change step to create a **Variable Step Spring**.

The **Barrel Springs** and **Hourglass** are usually considered as two conical springs attached. Its form is used to modify natural frequency of the spring.

The **conical springs** are manufactured for constant or increasing rates, no linear, increasing with the deflection. (The turns of smaller diameter have greater resistance to deflection).Varying the step, K can be done constant.

Its main advantage is the ability to close at a height as small as a wire diameter.

5.1.2. Springs of Helical Extension :

Figure 5.4: Extension Springs

- It has hooks on both ends.
- Provide a force of traction and is capable of large deflections.
- Are used in closed doors and balances.
- The hook is more endeavored that the turns, and usually fails first.

- Disadvantage: Anything suspended from the hook will fall by the break, so the design is not safe.

5.1.3. Bar of Extension Spring :

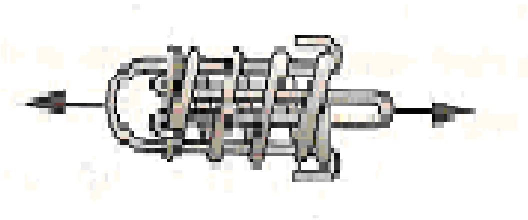


Figure 5.5: Bar of Extension Springs

The **Extension Bars** utilize a compression spring in traction mode so that even if it breaks can support load safely.

5.1.4. Torsion Spring :

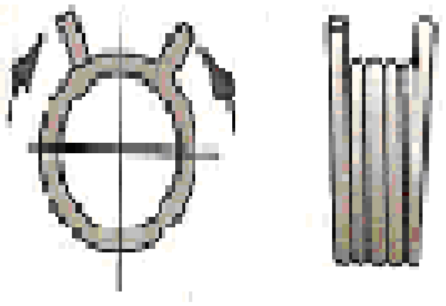


Figure 5.6: Torsion Springs

-The **Torsion Coil Springs** are wound in a manner similar to the tension springs.

-They are of round or rectangular wire and constant rate.

-Are applied as counterweights for garage doors, mousetraps, among others.

-There are many configurations in their terminations or limbs.

5.1.5. Spring Washers :

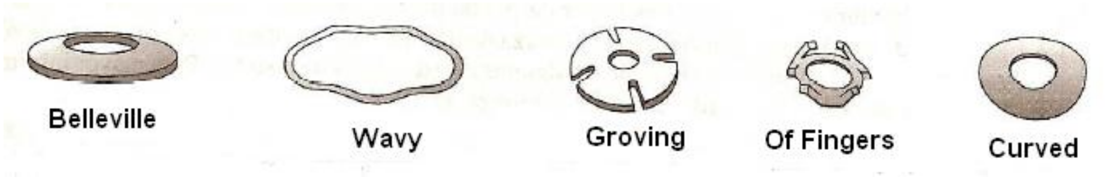


Figure 5.7: Springs Washers

The **Washers or Sheaves of Springs** (Pressure washers) provide a compression force in the axial direction.

Are used to eliminate axial play in bearings. Usually have small deflections and light loads.

The **Belleville** configuration supports higher loads.

5.1.6. Conclusion:

The springs are made depending on the type of effort that going to be submitted, either torsion, tension or compression. Should also be take into account the load is applied and the failures that may occur by the spring constant use in machines that perform cyclic work.

After performing this study, it was determined that the springs that best met our expectations were the Springs of Helical Compresion.

A compression spring is a type of spring characterized in that its length at rest is greater than the working length, so that when it is compressed exerts a reaction-compression force in the direction of its axis.

The compression springs can be constant or variable:

·The **constant compression springs** are those which force F is proportional to the displacement X, means that the ratio F / X is a constant.

·The **variable compression springs** are those that applying the force F, the deformation is not proportional to the pitch of the spring. With this variant is possible to obtain a greater force for a given displacement compared to other spring dimensionally equal with constant pitch.

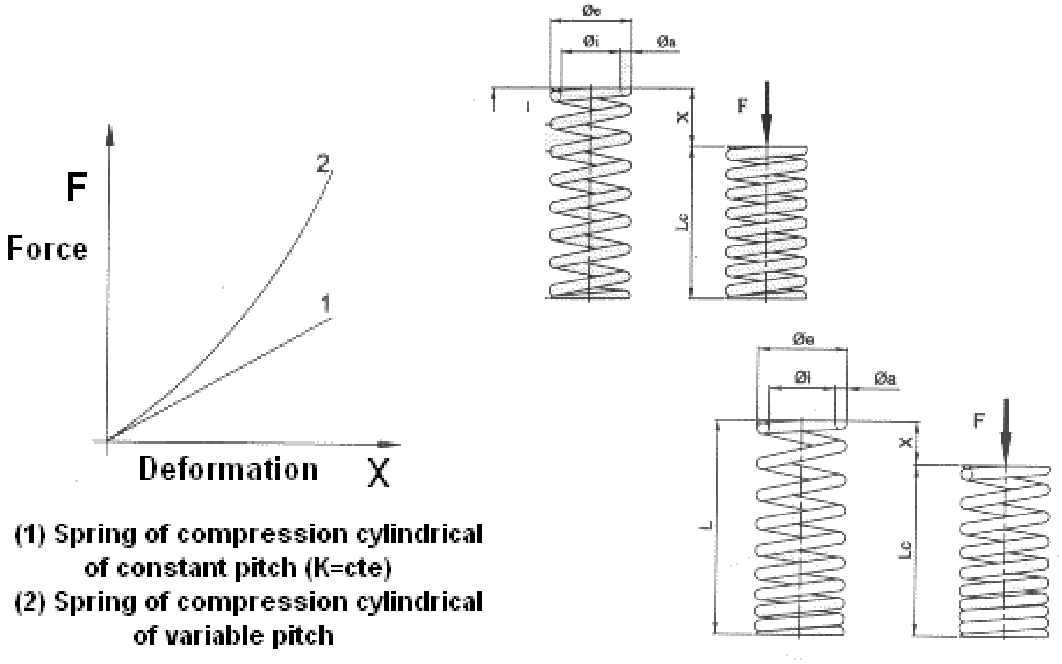


Figure 5.8: Diagram of compression cylindrical Springs of constant pitch and variable pitch

In a **Spring of conical compression of constant pitch**, the force generated by the displacement thereof is not proportional. This force is higher compared to a cylindrical spring, of diameter equal to the medium between the highest and lowest, keeping unchanged the other dimensions.

This kind of springs are used when it is required that the resulting spring length is reduced, either for reasons of space and in operation.

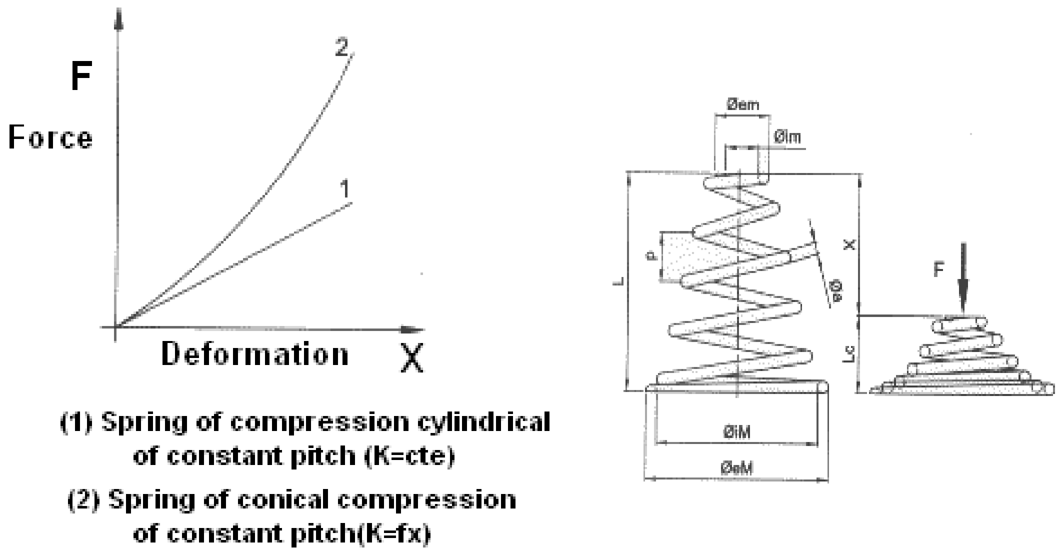


Figure 5.9: Diagram of conical compression Spring of constant pitch

The behavior of a **Spring of biconical compression of constant pitch** can be approximated by two conical springs that mounted in series form the biconical configuration, either, with the smaller outer diameter at the ends or in the center.

Therefore, the functional characteristics of biconical are similar to those of a conical spring and its application is limited to mounting considerations.

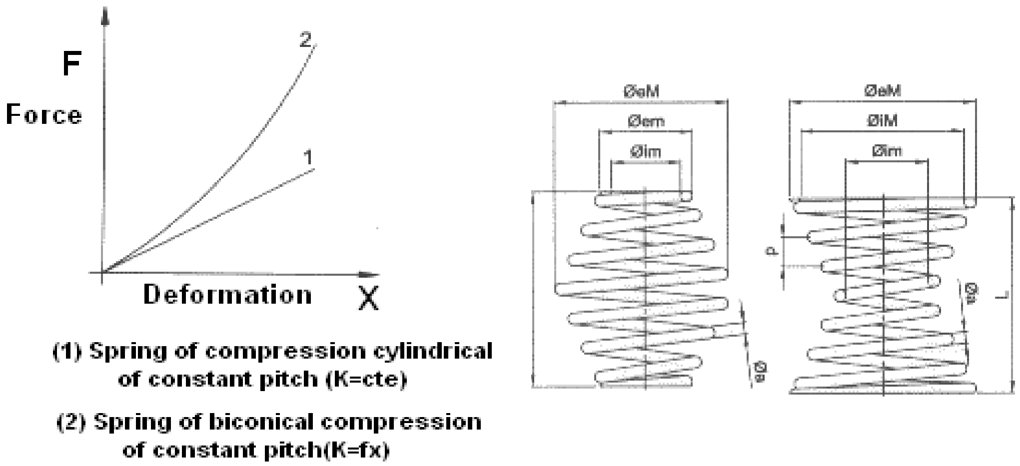


Figure 5.10: Diagram of biconical compression Spring of constant pitch

After these representations in the force-deformation diagrams, it was concluded that the springs that require less force to be deformed, are the compression cylindrical springs of constant pitch, because the force is proportional to displacement.

To higher activity of movement that the spring provides to the piezoelectric greater the energy produced by these elements. So that is what was looking for.

So it was done an analysis of deformation and stress in this type of springs, compression cylindrical springs of constant pitch, with different diameters and different numbers of turns.

This may be reflected in the following pictures:

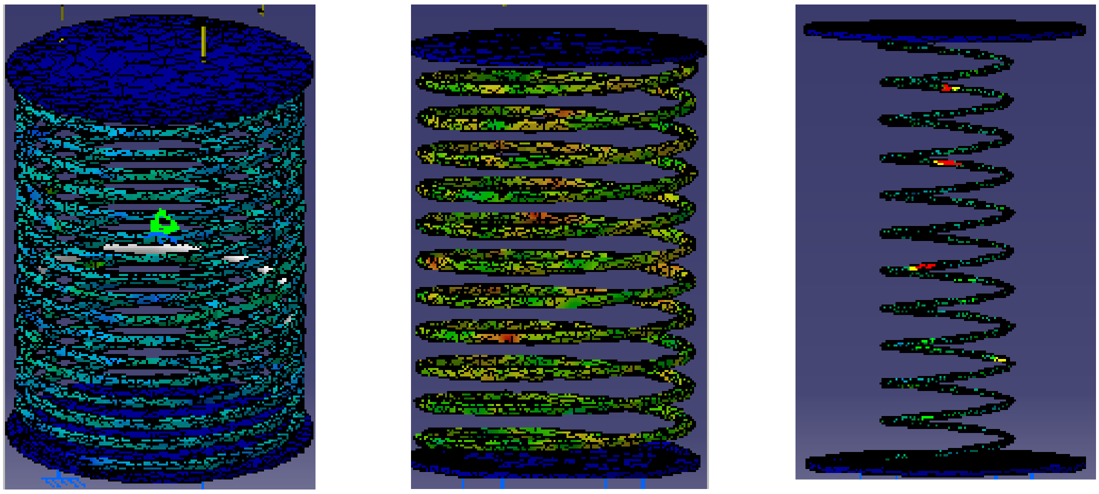


Figure 5.11: Analysis of deformation of compression cylindrical springs of constant pitch

These photos show a stress analysis in which can be observed behaviour´s springs.

In the second and third spring, may be noted the presence of red spots, which indicate danger. So the spring chosen for our design was the first, which had larger diameter and more laps. This could bear greater efforts than the others.

5.1.7. Disc type spring or Belleville: [16]

These springs are named after its inventor, who patented them in 1867. Are formed by a conical disc which rests on a plane. Springs are especially useful when are required large forces with small displacements. And furthermore are suited easily in small spaces.

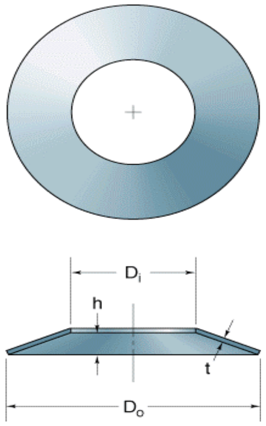
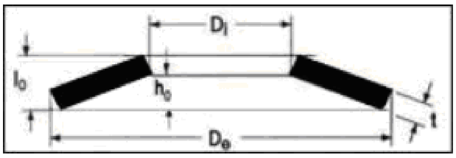


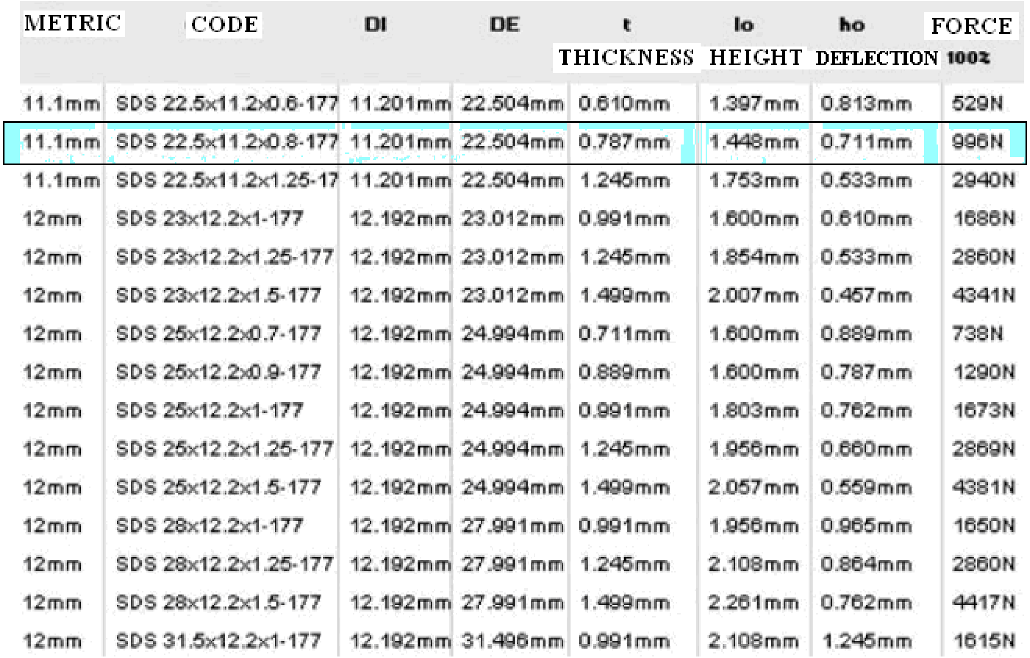
Figure 5.12: Belleville Spring

Through their combination in variable sequences, each size offers many possibilities to support loads.

In the figure that is shown acontinuacion can be appreciated a small fragment of tables that define a set of parameters for a wide possibility of different combinations of Belleville.



De: Outer diameter
Di: Inner diameter
t: Material thickness of the spring
ho: Maximum deflection of the spring
lo: Total height of spring (lo = t + ho)



METRIC	CODE	DI	DE	t	lo	ho	FORCE
				THICKNESS	HEIGHT	DEFLECTION	100%
11.1mm	SDS 22.5x11.2x0.6-177	11.201mm	22.504mm	0.610mm	1.397mm	0.813mm	529N
11.1mm	SDS 22.5x11.2x0.8-177	11.201mm	22.504mm	0.787mm	1.448mm	0.711mm	996N
11.1mm	SDS 22.5x11.2x1.25-17	11.201mm	22.504mm	1.245mm	1.753mm	0.533mm	2940N
12mm	SDS 23x12.2x1-177	12.192mm	23.012mm	0.991mm	1.600mm	0.610mm	1686N
12mm	SDS 23x12.2x1.25-177	12.192mm	23.012mm	1.245mm	1.854mm	0.533mm	2860N
12mm	SDS 23x12.2x1.5-177	12.192mm	23.012mm	1.499mm	2.007mm	0.457mm	4341N
12mm	SDS 25x12.2x0.7-177	12.192mm	24.994mm	0.711mm	1.600mm	0.889mm	738N
12mm	SDS 25x12.2x0.9-177	12.192mm	24.994mm	0.889mm	1.600mm	0.787mm	1290N
12mm	SDS 25x12.2x1-177	12.192mm	24.994mm	0.991mm	1.803mm	0.762mm	1673N
12mm	SDS 25x12.2x1.25-177	12.192mm	24.994mm	1.245mm	1.956mm	0.660mm	2869N
12mm	SDS 25x12.2x1.5-177	12.192mm	24.994mm	1.499mm	2.057mm	0.559mm	4381N
12mm	SDS 28x12.2x1-177	12.192mm	27.991mm	0.991mm	1.956mm	0.965mm	1650N
12mm	SDS 28x12.2x1.25-177	12.192mm	27.991mm	1.245mm	2.108mm	0.864mm	2860N
12mm	SDS 28x12.2x1.5-177	12.192mm	27.991mm	1.499mm	2.261mm	0.762mm	4417N
12mm	SDS 31.5x12.2x1-177	12.192mm	31.496mm	0.991mm	2.108mm	1.245mm	1615N

Table 5.1: Parameters of Belleville Spring

This type of spring was used in the final design.

5.2. First Design

This is the first design in which we have the spring integrated into the base.

The left figure is a small sketch which shows the different parts that make up the piece and provides a better understanding of how the set is assembled.

The parts of the head and base were modified in their endings, providing more contact surface to the piezoelectric translators.

The piezoelectric transducer was placed between both parties. With an inner diameter of 32mm, an outer diameter of 70mm and a thickness of 2.1mm

On the other side, in the figure on the right can be seen the restrictions of the set and the applied force.

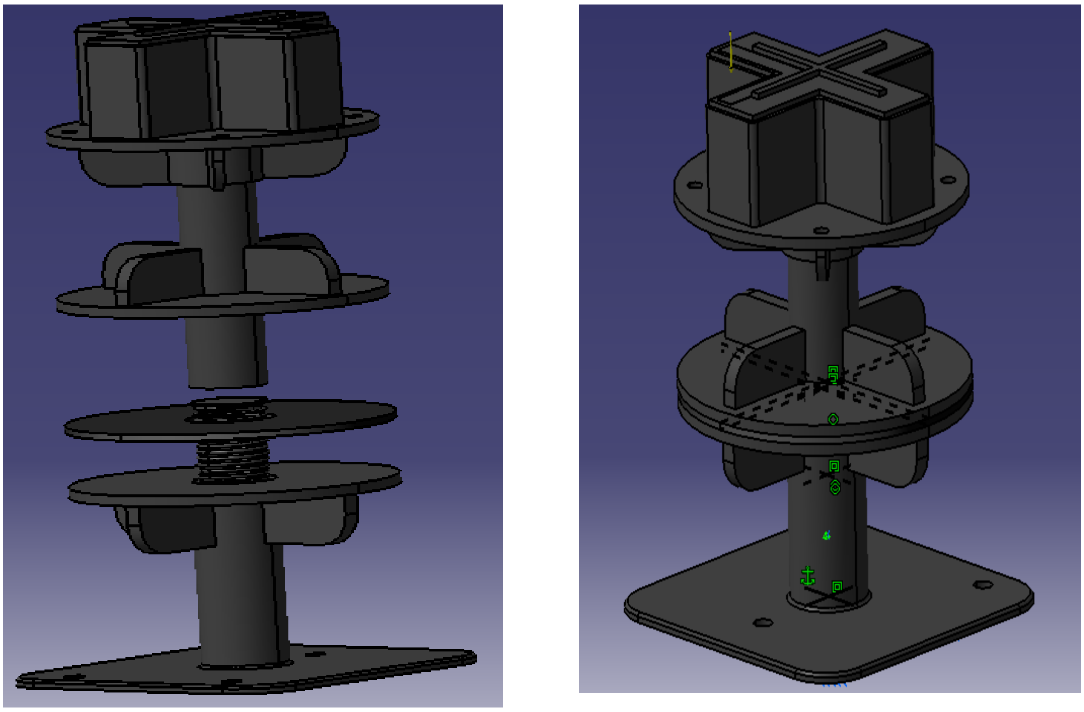


Figure 5.13: Assembly and constraints of the first design

As already explained above, the value of the applied force was 860 N, approximately a person's weight about 86 kg.

In other words our force has a modulus of 860 N, horizontal direction, downward direction, whose point of application is in one corner of the support (no matter which of them), to simulate the pressure which is transmited by the tile to the support when the analysis is performed with a single tile.

In the case of considering a support in which forces are acting on the four tiles, the point of application of this force would not be the same.

The working principle is as follows: When the pressure is exerted by a footstep, this acts on the support, the spring is compressed. With this pressure the piezoelectrics already are acting. However when the pressure ceases, the spring returns to its original position causing an oscillating movement up and down. With this simple concept the generated energy could be duplicated.

5.3. Second Design

The second design is similar to the first. It has also the peculiarities of the spring at the base and of expand the contact surface of the piezoelectric.

Although in this sketch was used the upper circular surface of the base to save material and thus obtain a more economical design.

The working principle was the same that the previous one.

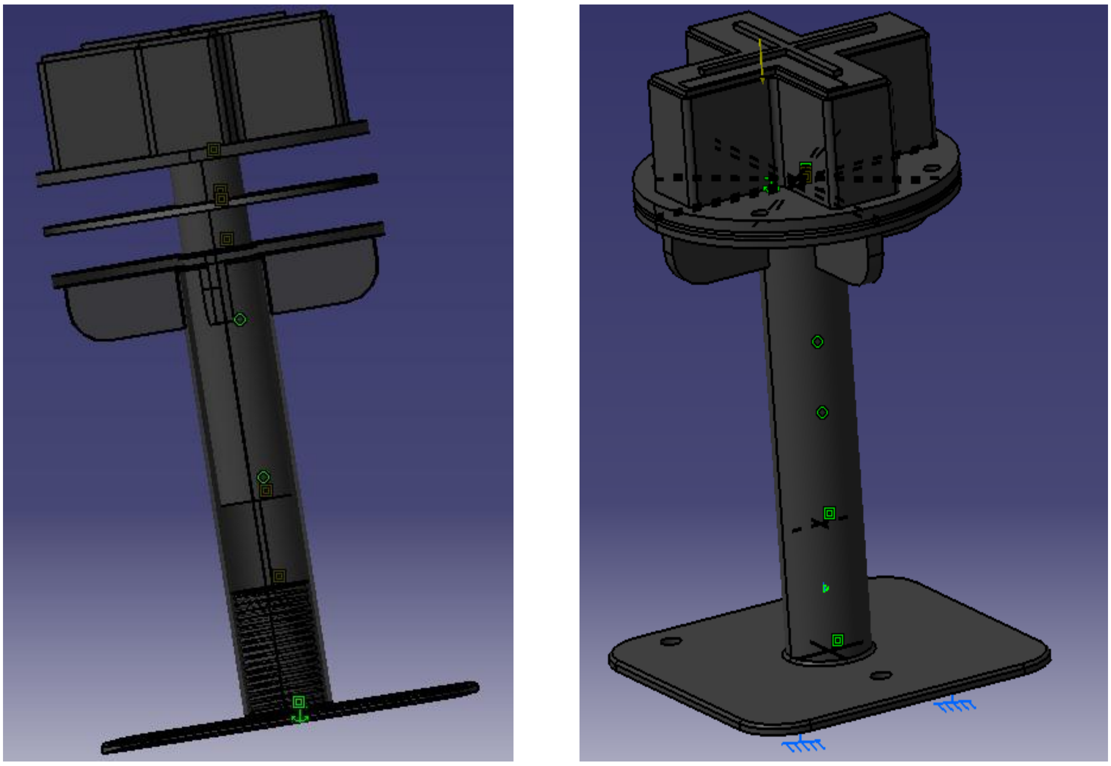


Figure 5.14: Assembly and constraints of the second design

In these first two designs, in which the main idea of design was identical, the same type of spring and equal dimensions were used.

The length of the spring with the two plates at each end was of 35mm.

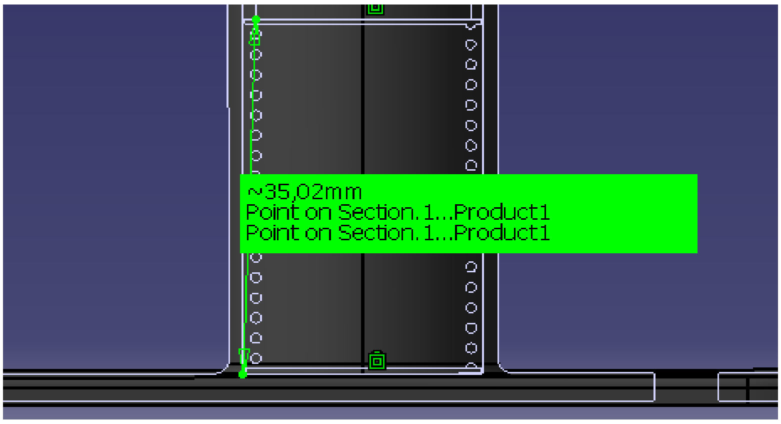


Figure 5.15: Spring length

5.4. Third Design

In this design the idea of putting a spring in the base was replaced to focus on getting more space available to place greater number of transducers.

Were placed a total of 16 transducers piezoelectric disc-shaped with a thickness of 2.375 mm each.

As can be seen the head of the support was redesigned, giving a frusto-conical with a small cylindrical cavity of about 5 mm. Thus when the force was applied, a better result would achieved at the time of pressing the piezoelectrics. And this cavity would have the function of acting as a stop.

The following figure shows a view of the design concept.

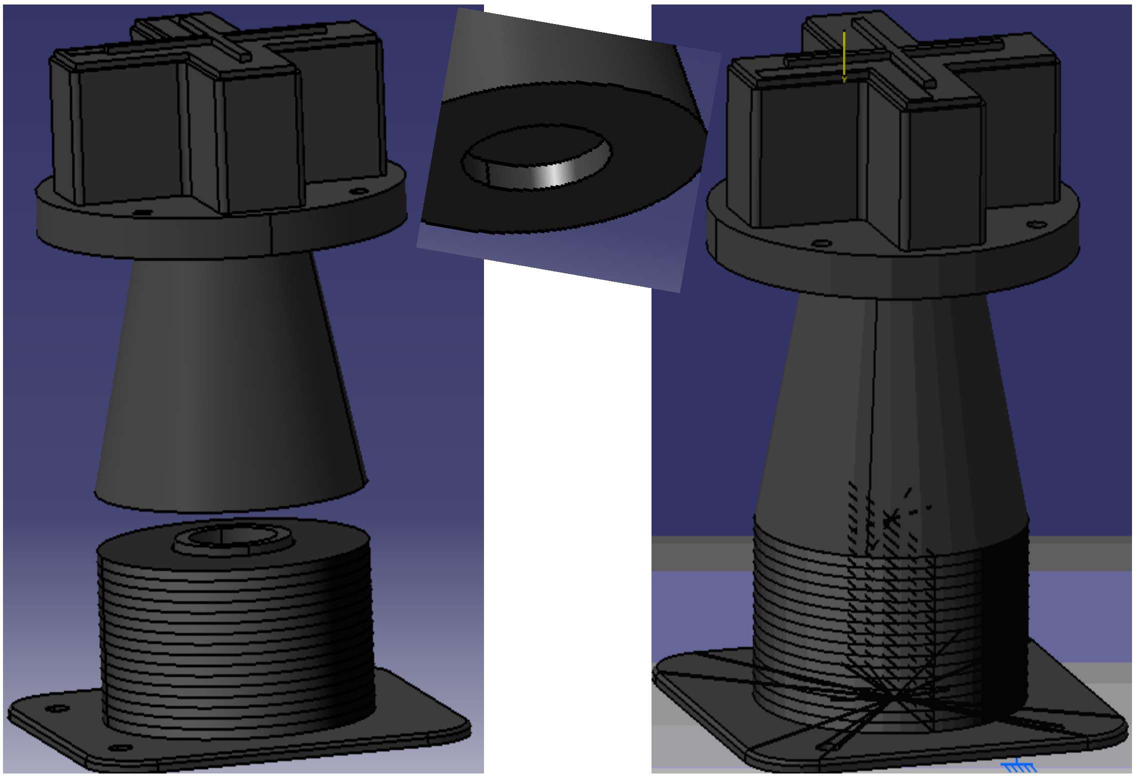


Figure 5.16: Assembly and constraints of the third design

5.5. Final Design

The final design was redesigned taking into account the following idea: with smaller surface area, higher pressures using the same force.

As the figures below show, the size of the piezoelectrics were reduced (from 35mm to 22.3mm of diameter) and were introduced inside the base.

In this study were placed a total of 9 piezos with a thickness of 2.23mm and a Belleville spring below them.

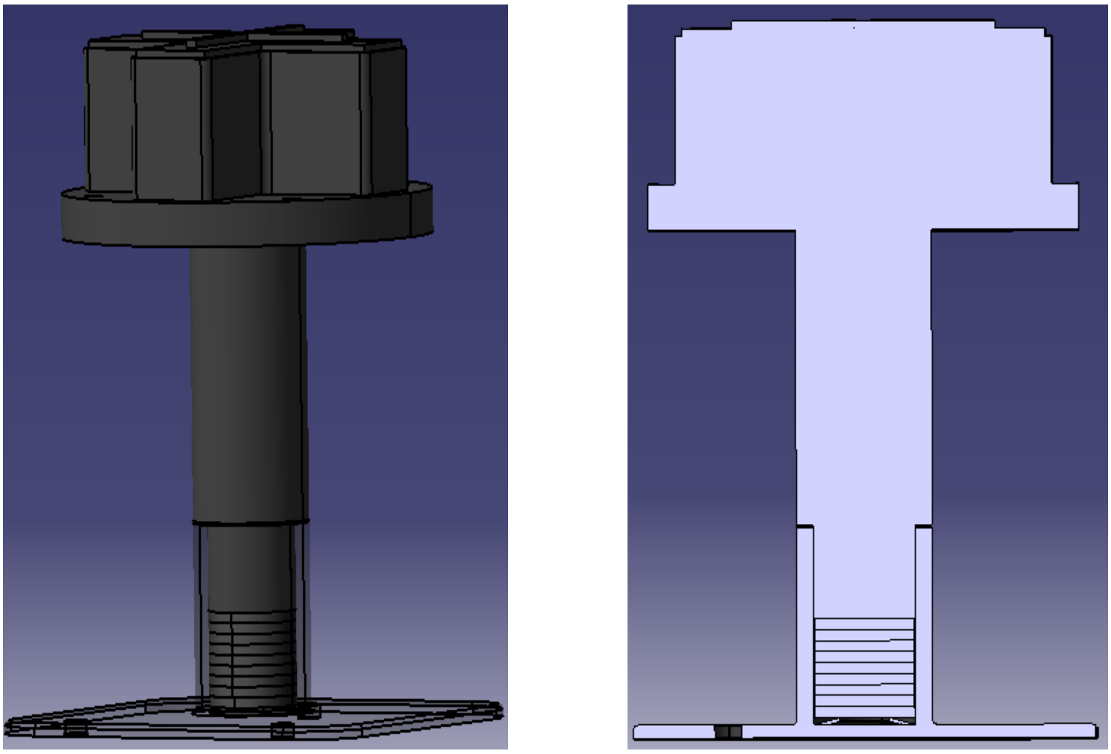


Figure 5.17: Schematic of final design

In the second figure, it can be seen more clearly that there is a small separation between the base and the head of the support.

This is so that when pressure is exerted on the support, the cylinder head is not directly in contact with the base, and thus able to act on the transducers.
And in turn, also has the function to act as a stop, if the applied force was very high. Thus although a greater pressure was applied on the support, not would occur a vertical displacement greater than said separation.

Below it can be observed a clear representation of the positioning of the transducers and the Belleville spring inside the base.

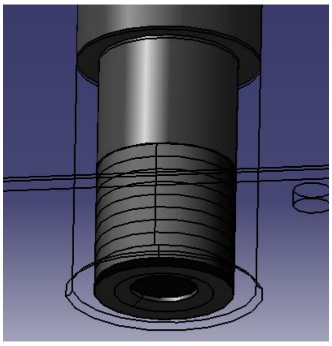


Figure 5.18: magnified view of the piezoelectrics and of the Belleville spring

6. Test and Analysis

Once drawn the designs to study and having defined the applied loads and conditions to which will be submitted the pieces are performed calculations. The calculations were performed in the Generative Structural Analysis module with the Finite Element Method in CATIA V5R 18.

All method of calculation performed with Catia V5 is based on a linear model. In this case, is assumed a linear behavior of the material, as well as the relative geometric proportionality of the structure.

There are several methods of calculation: Static Case, Frequency Case, Buckling Case...

Static analysis allows the study of stress, strain, displacement, axial and shear forces, as the result of the application of static loads.

This type of analysis is appropriate when the loads are well known and the maximum effort is evident.

In the GPS module (Generative Part Structural Analysis) found several tools that allow us to obtain the trend graph or behavior 'logic' that would represent in the work by action and reaction loads to the supporting elements.

6.1. First Design

The first tool that was used in this first design was of Deformation, to see the mesh generated in the design part, besides the graphic representation of the deformation produced by the action of loads.

In these graphics can be observed the element with the nodal graphical representation of deformation, as well as the applied load and restrictions.

In the second picture is shown, moreover, as was done a cut of the piece. For this purpose was used 'Cut Plane Analysis' tool, from which we can observe the diffusion of efforts in any court.

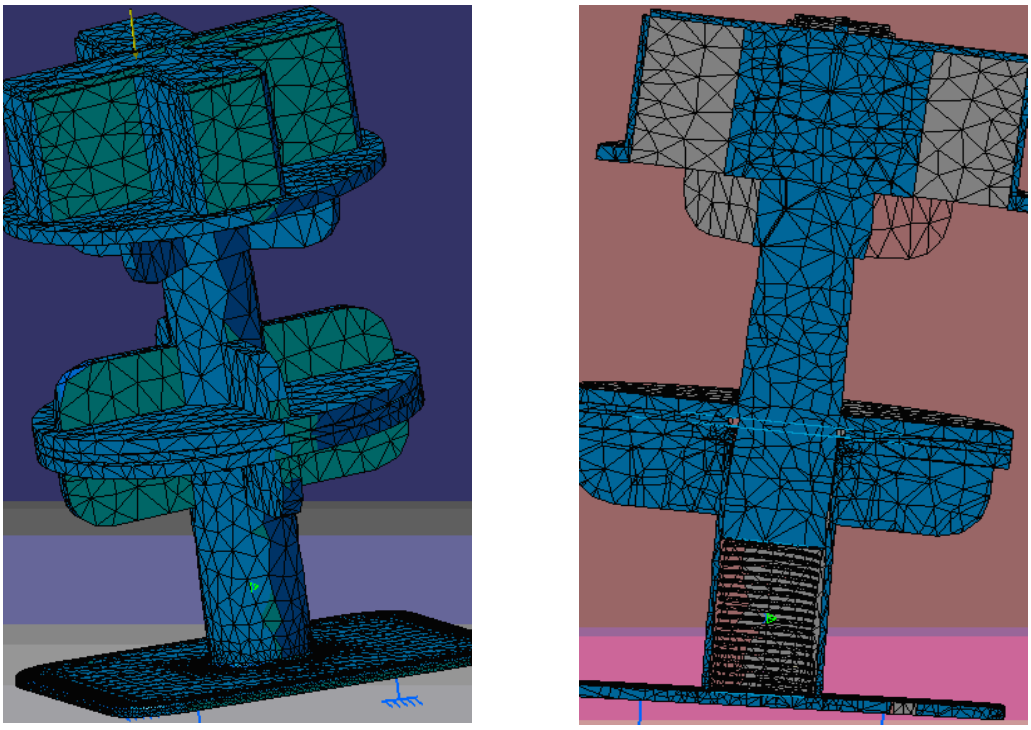


Figure 6.1: Nodal deformation of first design

The next tool was used in the analysis of study was 'Von Mises Stress'.

Von Mises Stress is a geometrical combination of all the strees (normal strees in the three directions, and all three shear stresses) acting at a particular location. Since it is a Stress, it is a measured in Pascals, just like any other type.

With the help of this tool can be viewed, in colors distribution, the different areas of concentration of effort generated by the application of loads and reactions of accommodation.

From the following graphic representation can be viewed the concentration of efforts on the piece as well as the scale of effort.

This scale indicates, in color, the value of effort illustrating it with the corresponding color on the piece.

Red color is awarded by Catia V5 as the area with greater concentration of effort.

Can be observed that the maximum concentration of effort was given at the bottom of the base tube, in the part on which the load is applied.

The value of the maximum concentration of efforts in this area was 41.4824 MPa.

This value is below the elastic limit of the material used in the piece. Our piece was made of galvanized steel, which has an elastic modulus of 190-200 GPa.As already was mentioned above, the mechanical properties of the piece once galvanized are the same as the starting steel.

So the design and material that was used in the piece is suitable for this project.

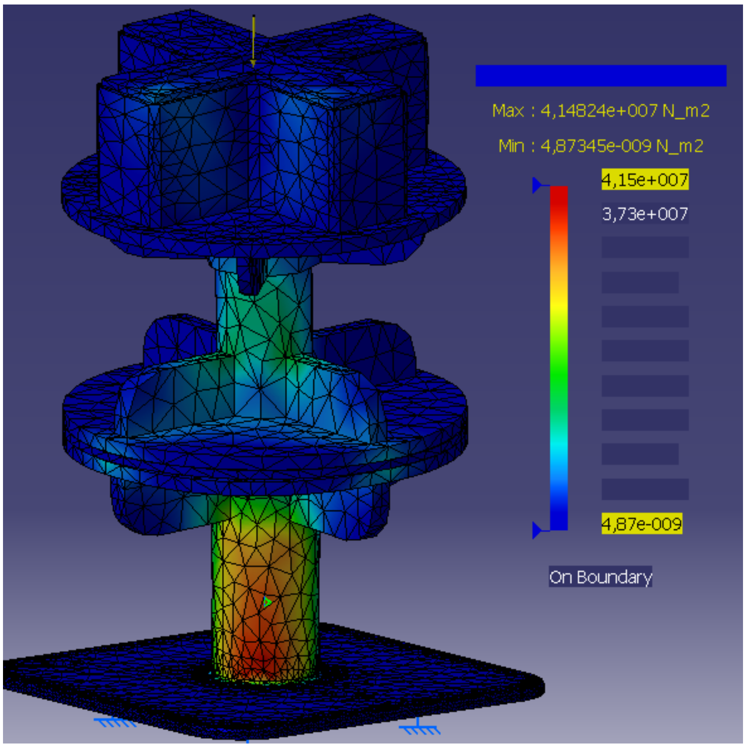


Figure 6.2: 'Von Mises Stress' analysis

Once it was seen that the piece was valid, a cross-section at the height of the piezoelectric was carried out to study the efforts in this area.

Because the study of efforts in the piezoelectric was the primary objective of this project.

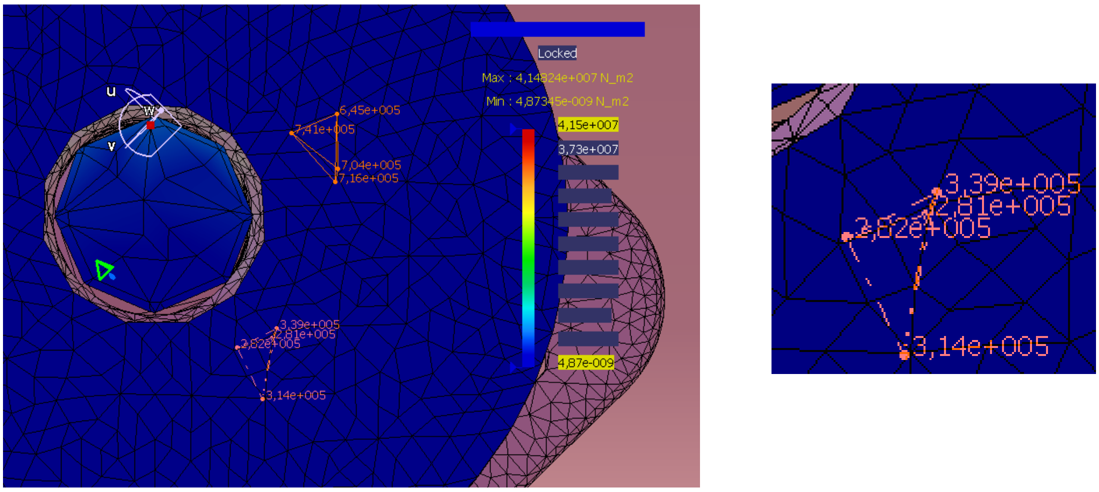


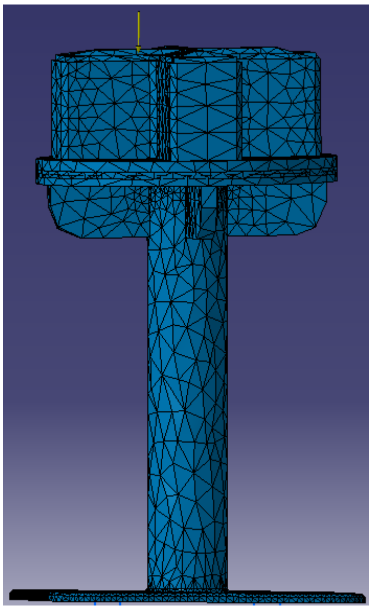
Figure 6.3: Cross-section of the piezoelectric

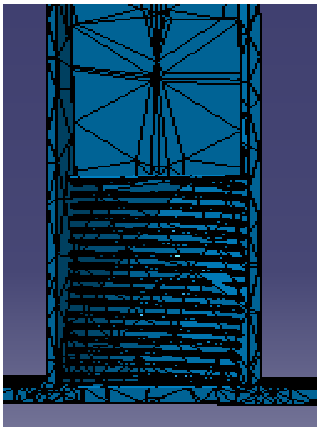
In this image dark blue was predominant, so in this design the piezoelectric was not submitted to much pressure.

The values of stress concentration included a range of 0.28 to 0.34 MPa.

6.2. Second Design

In this second analysis, as in the first, was performed a study of the deformation of the workpiece. As the picture shows the behavior of this second design was also logical.





The deformation experienced by the spring by the action of the support base can be seen in this picture.

Figure 6.5: Cross-section of the spring

Figure 6.4: Deformation analysis

The second step was to check in the same manner as in the previous one where the maximum concentarcion of effort was produced. And it was also studied whether this value was below the elastic limit. The maximum value was 35,732 MPa, so the piece could stand such efforts.

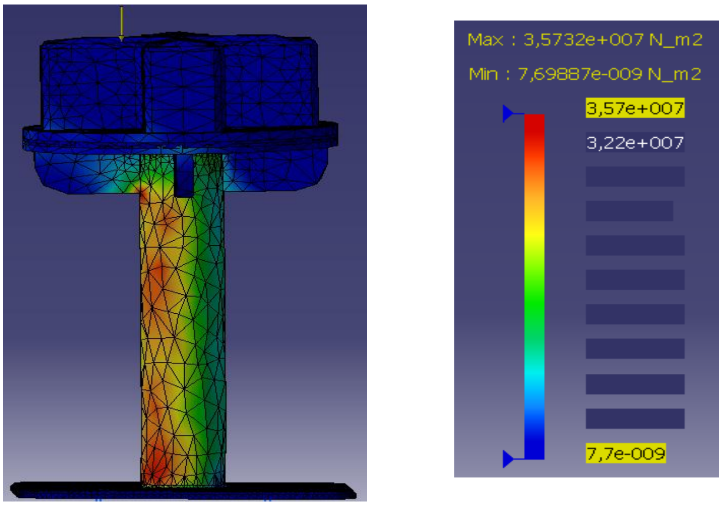


Figure 6.6: 'Von Mises Stress' analysis of second design

In this illustration can be seen the maximum value:

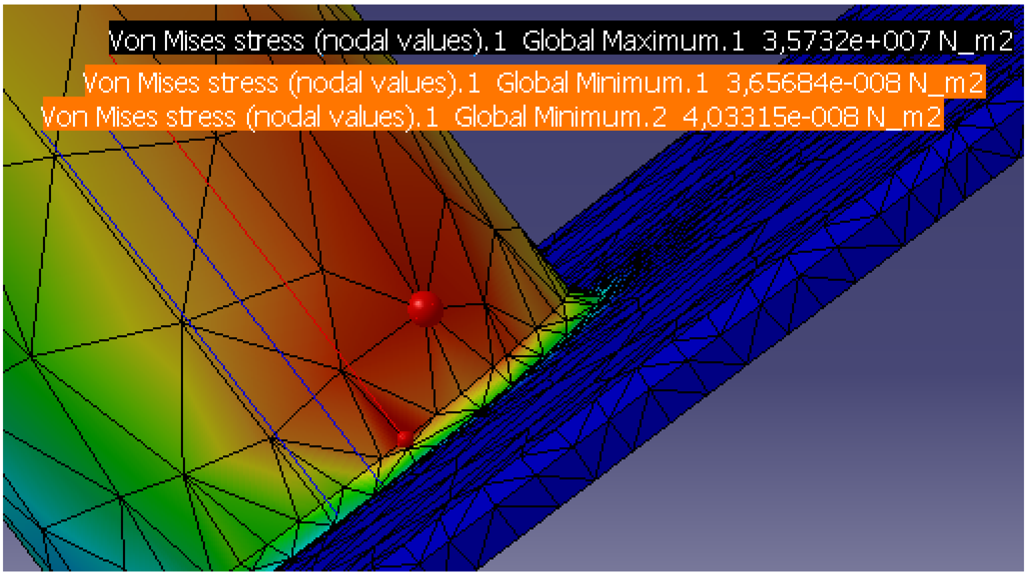

Von Mises stress (nodal values).1 Global Maximum.1 3,5732e+007 N_m2
Von Mises stress (nodal values).1 Global Minimum.1 3,65684e-008 N_m2
Von Mises stress (nodal values).1 Global Minimum.2 4,03315e-008 N_m2

Figure 6.7: Maximum concentration of effort

In the following images can be viewed as a cross-section was performed in the piezoelectric to study.

Unlike the first design, in these photos, can be seen as areas blue clearest appeared, indicating that in this model the piezoelectric was subjected to greater pressure.

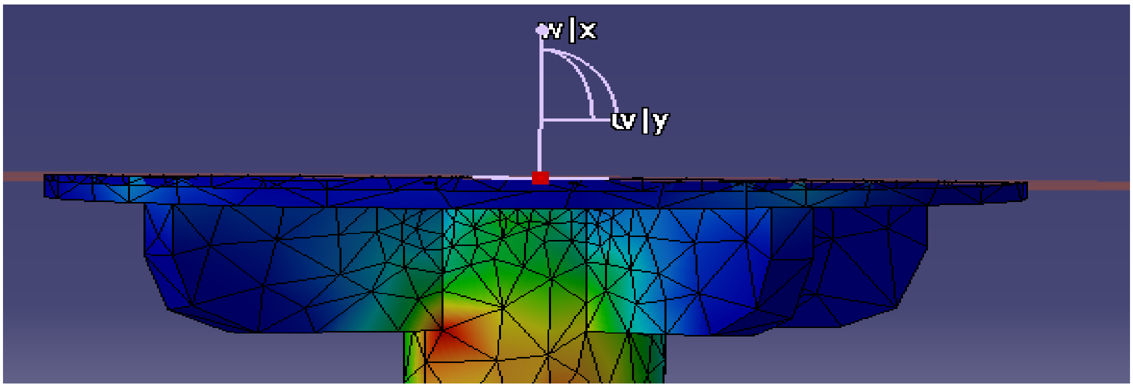


Figure 6.8: Front view of cross-section

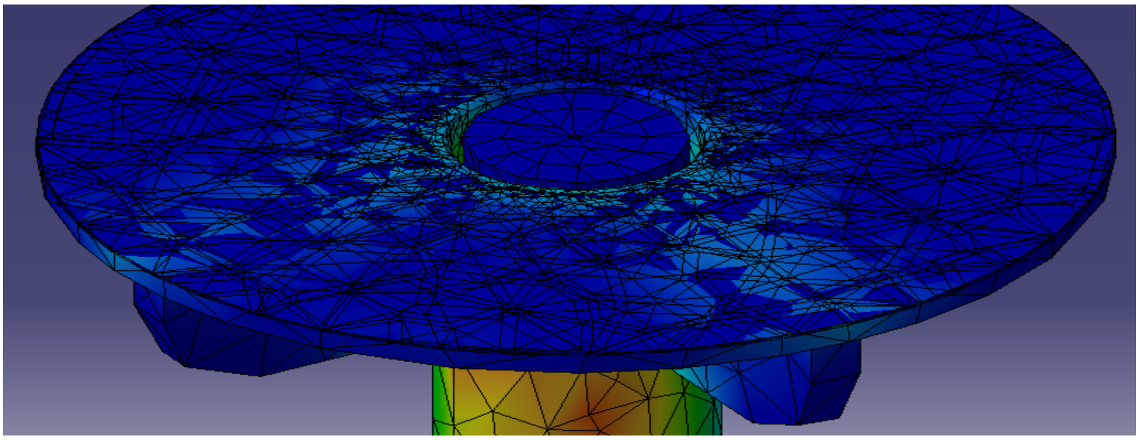


Figure 6.9: Top view of cross-section

The values of concentration of effort, achieved powers of ten to the six Pascals. The range of values was from 4 to 6 MPa.

Explained this, can be concluded that this design was more effective than the first, since the aim was to achieve maximum efficiency of the piezoelectric transducer to generate more electricity.

And as the material of piezoelectric was PZT503, with a value of Young's modulus of 71 GPa, the piezoelectric stand such pressure values.

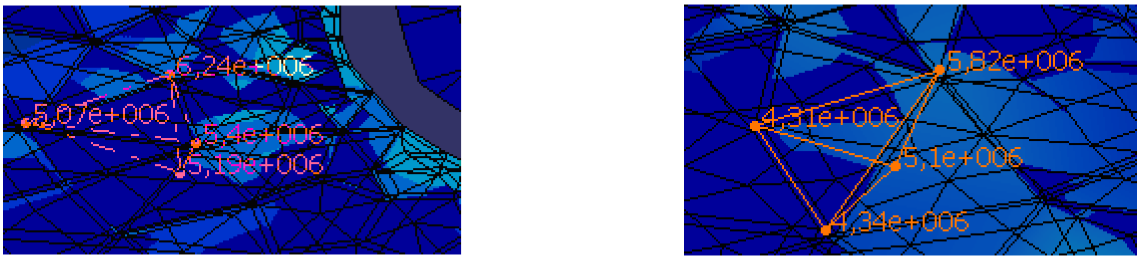


Figure 6.10: Values of concentration of effort

6.3. Third Design

As can be seen on this graphical representation, the red color scarcely was manifested. This meant that this design could withstand greater efforts than the previous two, without suffering risk of rupture or excision.

The maximum value of stress concentration was 4.11812 MPa. Although this value was lower than in the other two designs, in this was appreciated higher concentrations of areas of clear blue and green, which indicated higher pressures.

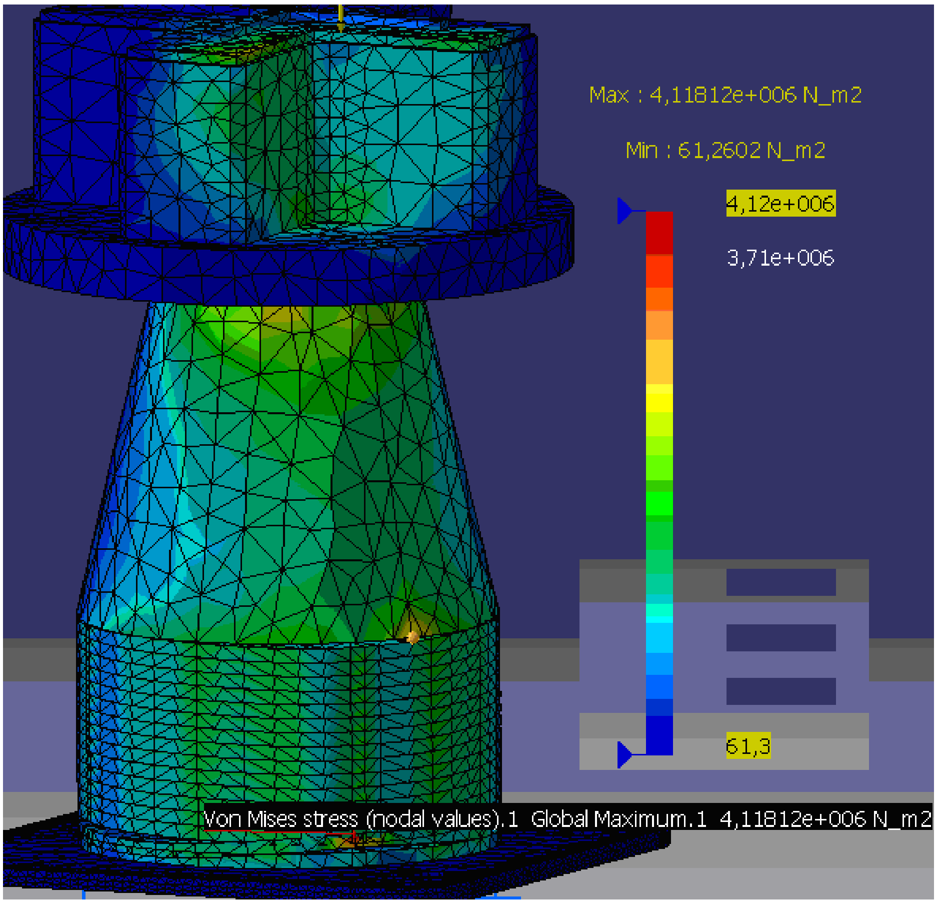
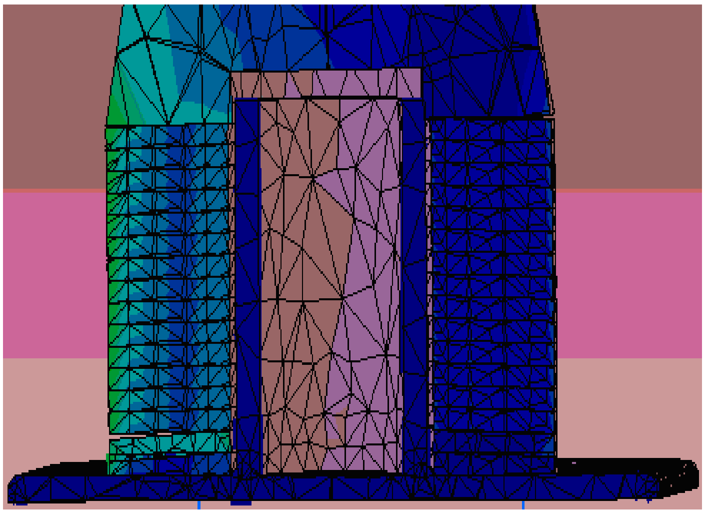


Figure 6.11: Representation of effort distribution



In this cross section is shown the 16 piezoelectrics, in which the pressure was acting.

And it can be seen, as is obvious, that in the left part lighter colors are appreciated because the force is applied on that corner.

Figure 6.12: Cross-section in the piezoelectrics

Moreover in this picture is shown as although the force was acting, there were a space between the base and the head of the support.

In this model was carried out a more exhaustive study of the concentration of efforts on the piezoelectrics to different heights, cross sections were performed at three different heights.

- The first cut was made in the second piezoelectric:

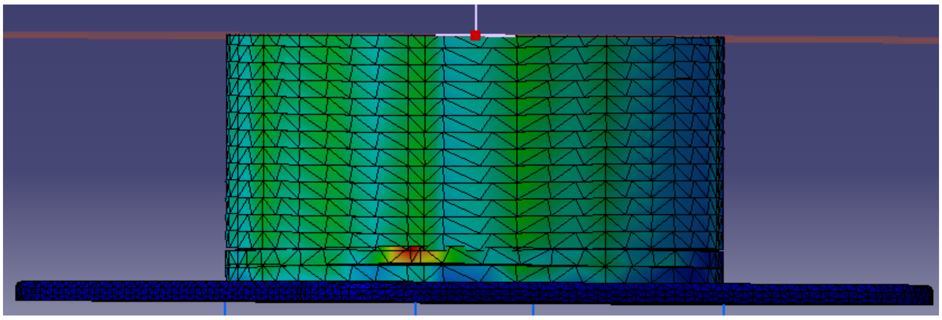


Figure 6.13: Cross-section in the second piezoelectric

In this section can be seen as bit more than half of the surface is dark blue, the rest was obtained with a blue clearer.

That unlike the cuts in the piezoelectrics of the previous designs, in this was accomplished a larger area with stress concentration values higher.

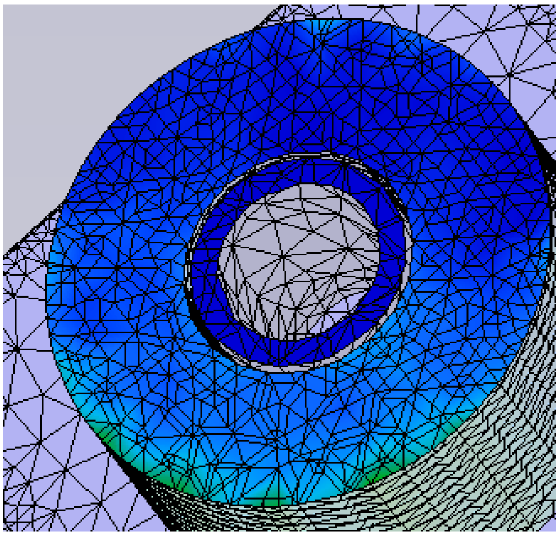


Figure 6.14: Top view of cross-section

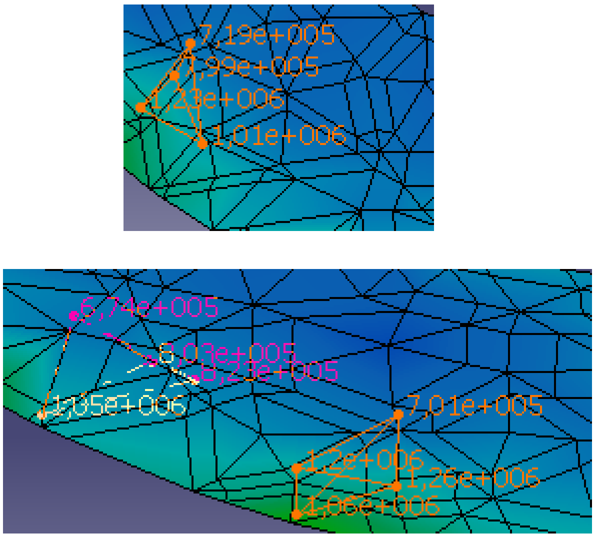


Figure 6.15: Values of concentration

Here may be seen a greater range of values ranging from 0.7 to 1.24 MPa. That although as has been mentioned in previous sections, these values are lower than the others, there is a greater proportion of area in this design.

- The second cut was made in the tenth piezoelectric:

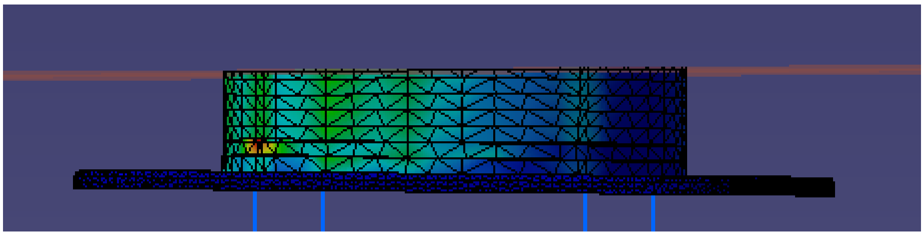


Figure 6.16: Cross-section in the tenth piezoelectric

The results that were obtained in this court were very similar to the cut made in the second piezoelectric, with values ranging between 0.67 - 1.26 MPa.

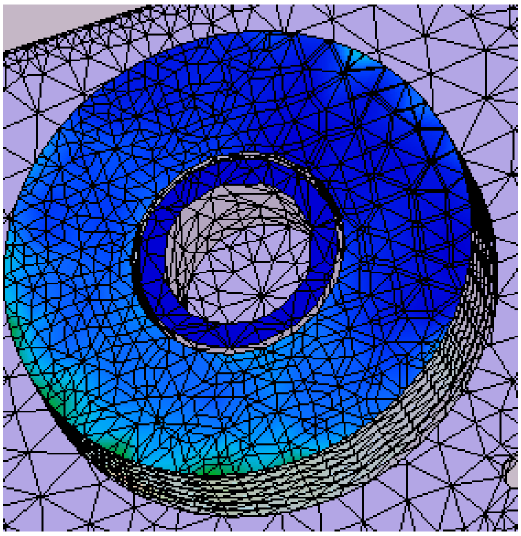


Figure 6.17: Top view of cross-section

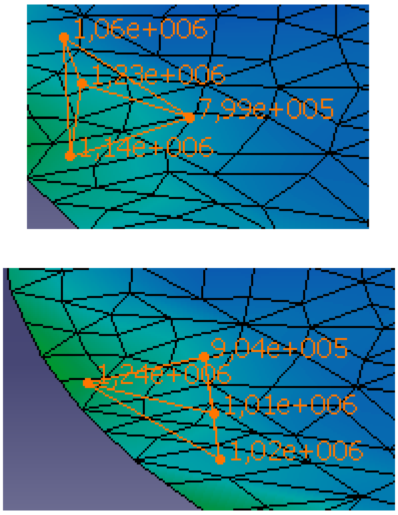


Figure 6.18: Values of concentration

- The third cut was made in the fifteenth piezoelectric:

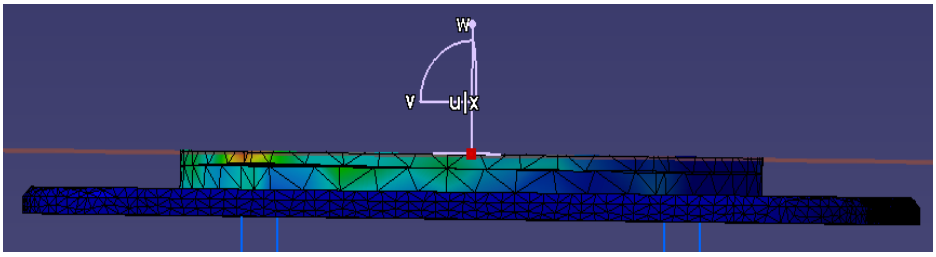


Figure 6.19: Cross-section in the fiftenth piezoelectric

In this surface can be seen that in the analysis the clear blue color was predominant over the dark blue. And in a small area appeared a concentration of effort more elevated represented by green, yellow colors ...

The values in this section were from 0.96 to 2.43 MPa.

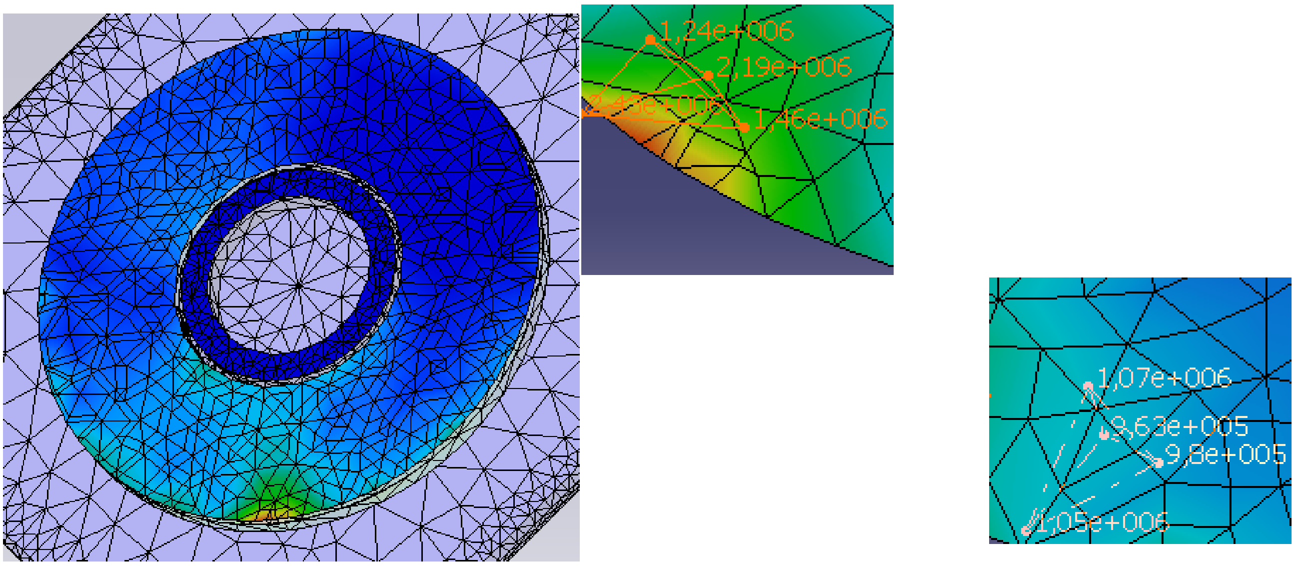


Figure 6.20: Values of concentration in the cross-section

According the cross-section was going down the pressure was greater.

6.4. Final Design

In this graphic representation can be seen the final design of the support. This design was geometrically the simplest and most effective at the time of getting greater stress concentrations on the elements to study, the piezoelectrics.

As is shown there was total absence of red in the model, so that was the most resistant to withstand higher efforts, with total absence of danger to breakage or excisions.

In this design was achieved the highest value of concentration of efforts of all the designs presented. In addition this was highly important because this value was not on the surface of the piece. As can be represented in the pictures, was in the piezoelectric.

The maximum value of stress concentration achieved was 46.0557 MPa.

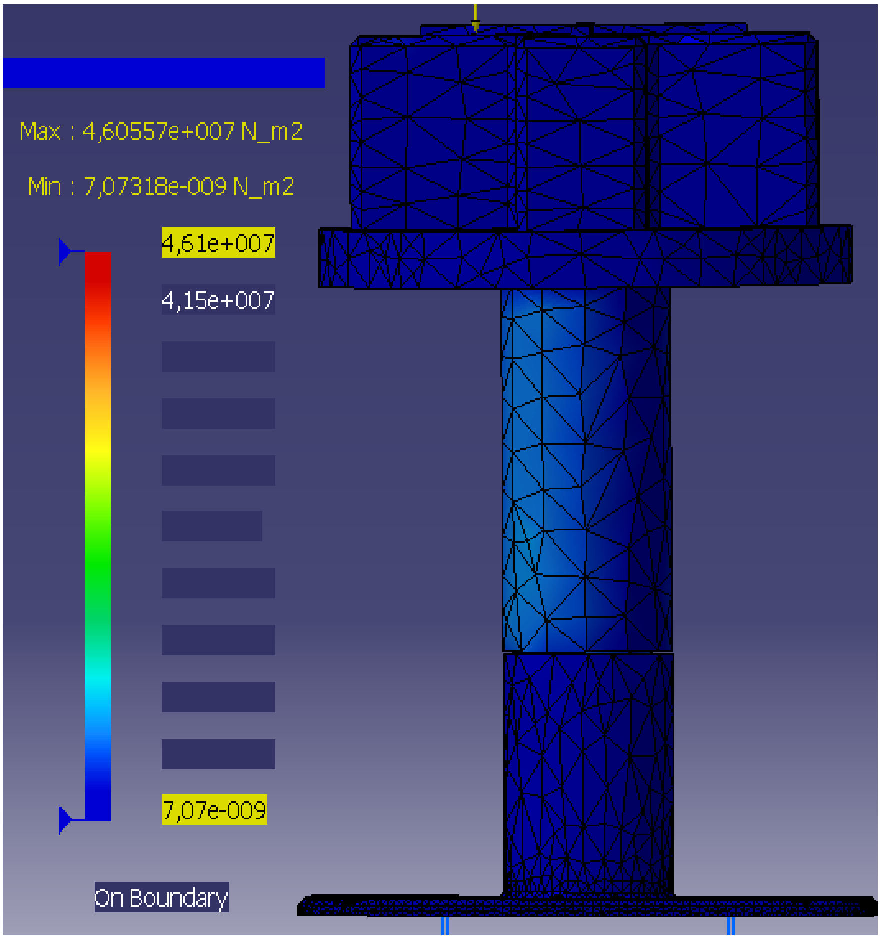


Figure 6.21: Representation of effort distribution

In this cross section can be demonstrated what has been mentioned above. It is observed as in the interior of the piece appeared lighter colors, representing greater efforts. Also in this sketch can be seen clearly the functionality of the piezoelectrics and Belleville spring.

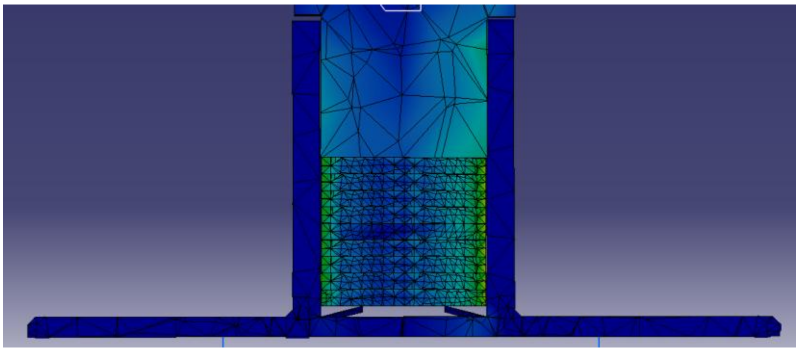
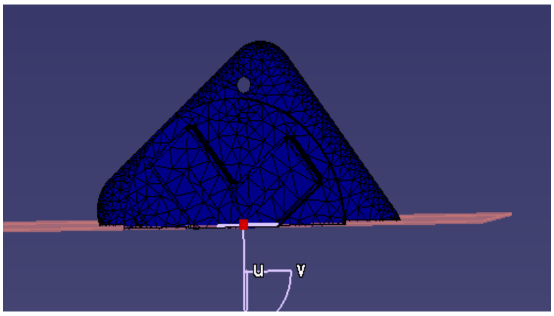


Figure 6.22: Cross-section

In the following photographs is shown a vertical cut in the part where the force was acting.

Hence the fact that the colors of greater concentration of efforts were highlighted.



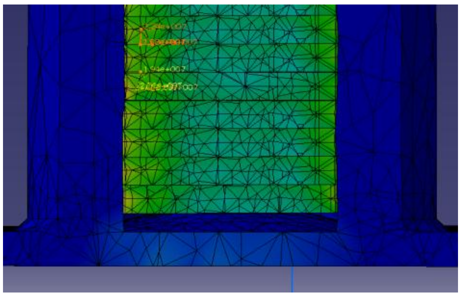


Figure 6.23: Front view of cross-section **Figure 6.24: Cross-section of piezos**

As in the third design, the analysis was more extensive in the areas of the piezoelectrics and was carried out by the same method of making cuts at different heights.

In the first court were obtained values from 4.81 to 9.68 MPa.

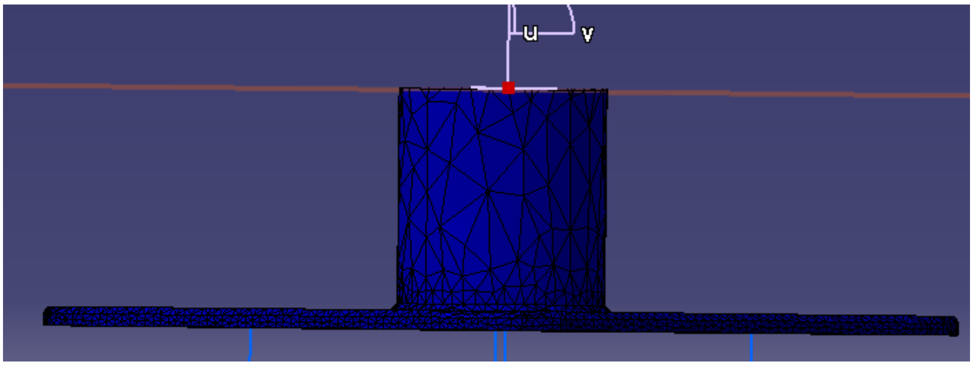


Figure 6.25: Front view of cross-section

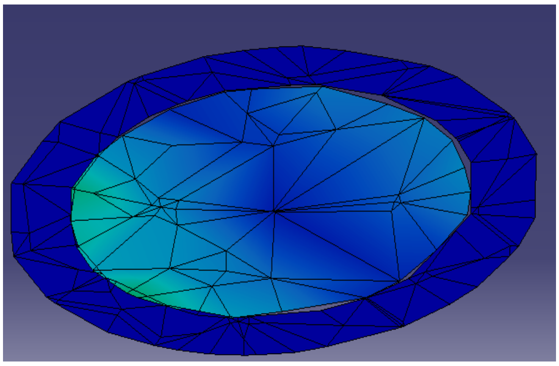


Figure 6.26: Front view of piezo's area

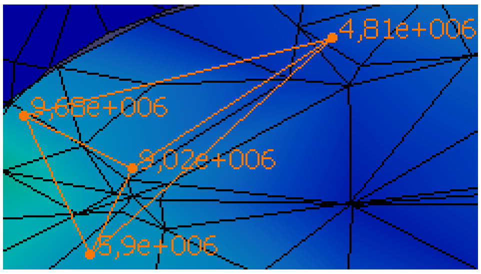


Figure 6.27: Values of concentration

In the second cross section could be observed greater variety of colors, and in this section was reached one of the highest values of stress concentrations.

Here was where for the first time in all the study, values of powers of ten to seven were obtained. The range of values achieved was from 14 to 17 Mpa.

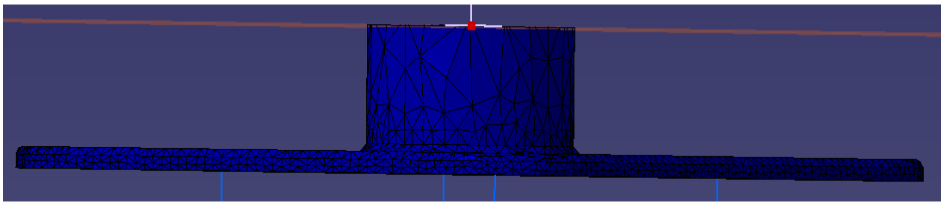


Figure 6.28: Front view of cross-section

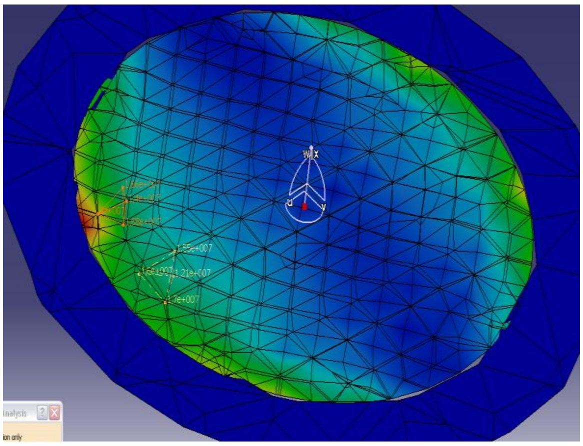


Figure 6.29: Front view of piezo's area

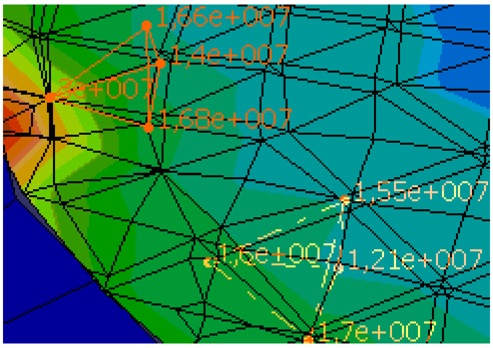


Figure 6.30: Values of concentration

And in this last cut was shown as the distribution of concentration of effort is similar to the previous one. The range of values achieved was from 16 to 29.2 Mpa.

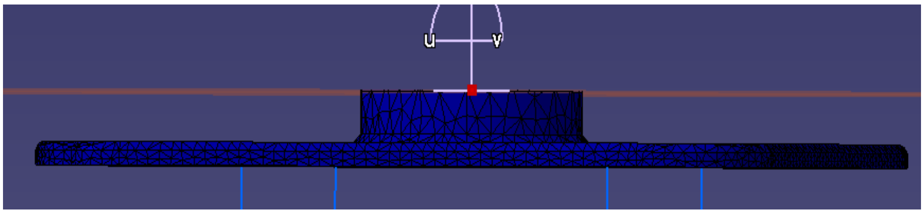
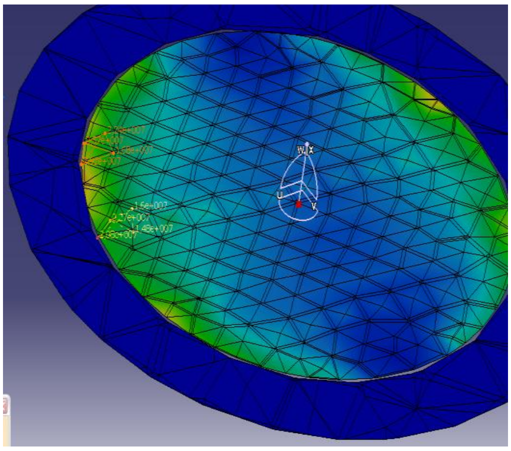


Figure 6.31: Front view of cross-section



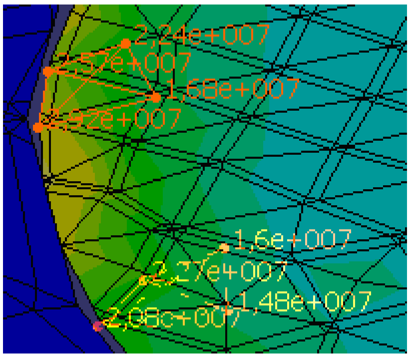


Figure 6.33: Values of concentration **Figure 6.32: Front view of piezo's area**

It has been demonstrated that in this last design, have been obtained the highest values.

As is shown, the piezoelectric transducers that were used in this model had a smaller diameter in order to place them inside the base, and therefore had less area available by piezoelectric.

On the other hand, in each piezoelectric, higher values of concentration of effort were obtained, and of remarkable difference.

And as mentioned before, the piezoelectric material was not endangered by these pressures due to that their elastic limit is higher.

7. Results and Discussions

As has been observed throughout all the analyzes made in the different designs, a pile of stress concentration values have been obtained.

To provide a better understanding and a clearer visualization, the results of the test have been compiled in the next graph:

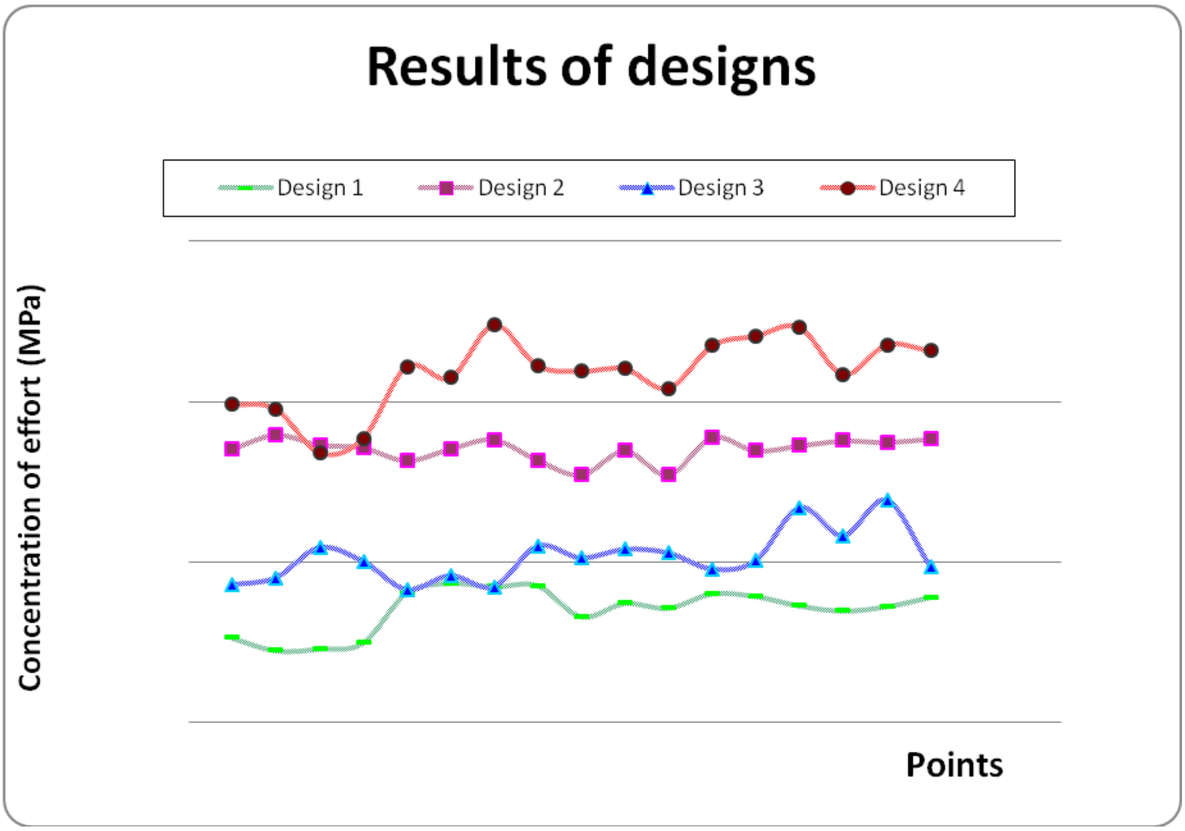


Figure 7.1: Values of concentration of efforts

This chart has been defined by a logarithmic scale on the vertical axis indicates the values of stress concentration in megapascals, and a normal scale along the horizontal axis representing the number of values taken.

Such as demonstrated in the graph, the first and third design have similar values on the order of ten to the five pascals, that is from 0.3 to 0.8 megapascals, although in the third, three points are dispersed, which can reach values of 1 to 3 megapascals.
In the second design, line remains represented more or less constant, with values of 5 to 8 megapascals.

And in the last and final design can be observed as are reached values around 16 to 29 megapascals, depending on the height of cut in the piezoelectric.

8. Conclusions

8.1. Overall Conclusion

The aim of the project was to innovation, research, design and test a transductor piezoelectric integrated into a support, generating and storing energy from footstep for reuse.

Taking into account that none of the values obtained in the stress concentration exceeds the limit of elasticity, or the workpiece material neither the material of the piezoelectric transducers, to higher values obtained, better will be the result. Since to higher pressure, greater deformation in the piezoelectric and more electrical energy will be produced.

To find this purpose, along this time, different designs have been designed and analyzed. As was illustrated in the previous section a bunch of stress concentration values have been obtained.

Is rather complex discuss at a glance which of these designs was the most effective, because there are several factors to consider. Such as the number of piezos placed, the dimensions of these (diameters, thicknesses, etc.), their placement in each design ...

Between the first two designs, which were based on the same foundation, this comparison is easier. In these was sought to expand the contact surface of the piezoelectric for so have more work area. The piezoelectric used was the same in both cases, same diameters and thickness, the only difference is its placement in the support. So between these two models, it can be concluded that the second will be more effective in increasing the efficiency of energy harvesting because it has obtained higher values.

On the other hand the second design with respect to the first has the disadvantage that in the analysis of efforts appear more reddish areas, which are dangerous.

Comparing the second and third design, which utilize piezoelectrics of the same diameter, and thus have the same contact surface for it to act force and generating energy, similar values are observed. So at this point they would be equal. But as has been seen in section 5.4, the third design consists of 16 piezoelectrics of a thickness of 2,375 mm and the second provides a single piezoelectric 2.1 mm thick. So it clearly shows that the third design is so far the most effective.

And if the results are analyzed between the third and last, can be clearly seen that the final design is the that reaches higher values. So this was the design chosen, because at higher values, more compresses the piezoelectric and more energy is generated, which is the objective of the project.

The third model consists of 16 piezoelectric, and the last has 9 piezoelectrics, and of smaller area available. But this is not a drawback, because in this latter design, the piezoelectric being placed inside the base, where the pressure strikes them in a more direct and gives rise to stress concentration values, much higher.

And furthermore if this were not enough, with modifying of small parameters of the design, more number of piezoelectric transducers could be placed inside and thus increase the electrical energy produced by the set.

Therefore, taking into account all these data and all the above study,could be demonstrated that this last design was the most effective and beneficial in increasing efficiency.

8.2. Further work

This project successfully completed the objectives, but could be invested more time and facilities to meet with greater ease the desired purpose.

One of the first observations is that the design could be improved investigating different provisions of the Belleville spring.

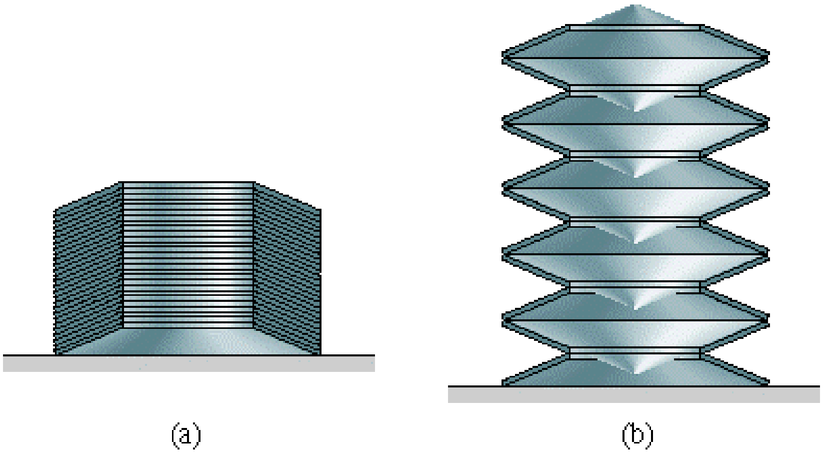


Figure 8.1: Stacked Belleville spring

As can be seen in the figure above, Belleville springs can be arranged in parallel or in series.

In parallel, stacked springs are able to increase the amount of charge that can accept. In series, either face to face or back to back, the springs are stacked to increase the deviation.

So doing testing with these two configurations could try to improve the purpose of the project.

In all cases, the Belleville springs are said to have reached its maximum capacity when they are crushed.

In the following figure, can appreciate the load variation with respect to the variation in displacement in the direction of the axis of symmetry:

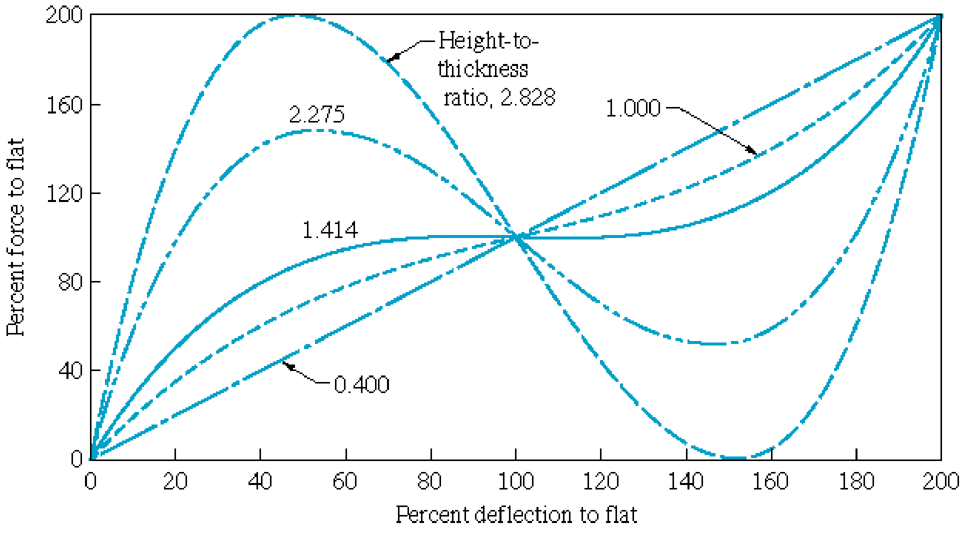


Figure 8.2: Load curves of the Belleville springs

Another recommendation would be to try to merge the concepts of the designs. We have relied on the foundations of to expand the surface of the piezoelectric for get a greater work area and that the piezoelectric are placed on the central axis of the force, so that greater pressure was exercised.

That said the idea is to make a design mixing the third and last model of my study. In this design could observe the piezoelectric of smaller diameter on the inside of the base and the larger diameter on the outside.

And once these factors were improved, the results were analyzed and studied, the next step would be to conduct a study of the supports with the tile.

In these images can be observed several graphical representations of the study that was done for the final design with the tile.

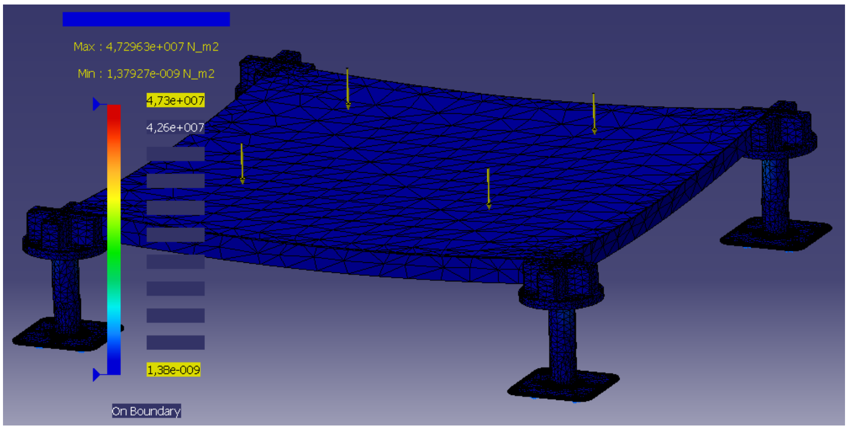


Figure 8.3: Deformation of stress analysis to the set

If cross -sections are realized at the height of the piezoelectric, we can see that the results in these sections are somewhat lower, but acceptable.

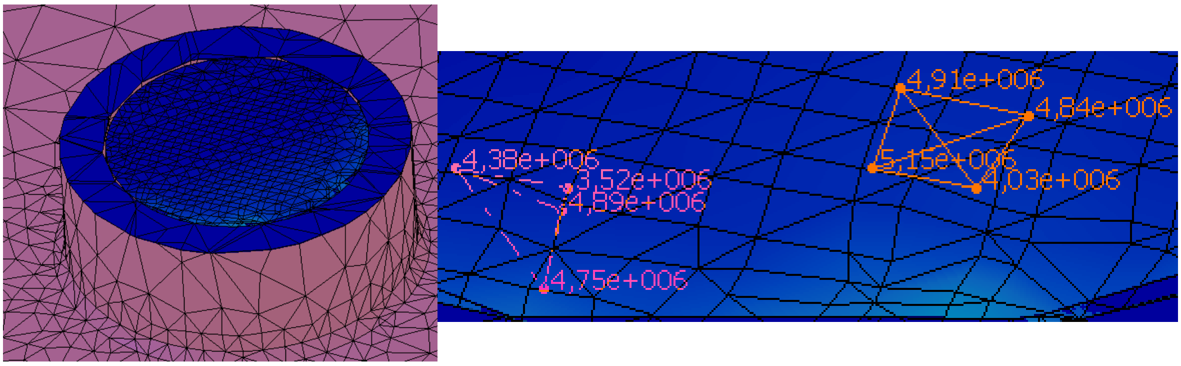


Figure 8.4: Values of concentration in piezoelectric's area

The values of concentration of effort, achieved powers of ten to the six Pascals. The range of values was from 4 to 5 Mpa.

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Appendix

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