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# Journal of Technical Invention

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## Presentation of the content

In Issue 20 as the first article we present, *Dry cleaning analysis for photovoltaic modules*, by ESCOBEDO-MÁRQUEZ, Diana Laura, RENTERIA-RAMIREZ, Rodolfo Enrique, CASTILLOCAMPOS, Nohemí Alejandra and ÁLVAREZ-MACÍAS, Carlos, with adscription in the Tecnológico Nacional de México, Campus Laguna; in the next article we present, *Ergonomic evaluation of work sites in an aerospace maquiladora company*, by RAMIREZ-CARDENAS, Ernesto, NARANJO-FLORES, Arnulfo, LOPEZ-ACOSTA, Mauricio and CORRAL-VELASQUEZ, Cristian Aarón, with adscription in the Instituto Tecnológico de Sonora; in the next article we present, *Analysis of the mechanical behavior of a heat diffuser for electrical cells made of natural fiber-reinforced composite materials*, by SÁNCHEZ-ROMERO, Ricardo Emmanuel, RODRÍGUEZ-DAHMLOW, Jesús Ernesto, MENDOZAMIRANDA, Juan Manuel and SALAZAR-HERNÁNDEZ, Carmen, with adscription in the Instituto Politécnico Nacional; in the last article we present, *Design of an adjustable prop made of Polymeric material*, by PÉREZ-PÉREZ, Arnulfo, HUERTA-GÁMEZ, Héctor, TÉLLEZ-MARTÍNEZ, Jorge Sergio and MORENO-REYES, José Miguel, with adscription in the Universidad Politécnica de Juventino Rosas.

## Content

Article
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# Dry cleaning analysis for photovoltaic modules

# Análisis de limpieza en seco para módulos fotovoltaicos

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**Abstract**

For a photovoltaic module to work in optimal conditions, it is necessary a correct cleaning, as electrical power losses due to dirt on the module´s surface are estimated to be as high as 30-40% in dry and sandy climates. In this work, the design and construction of a dry cleaning system was made using a cylindrical brush with nylon bristle of 100 cm in length and 12 cm in width, the bristle have 0.3 mm diameter. The angular speed of the system is 10.58 $\pi$ radians per second. The objective is to analyze the impact of the cleaning system on the electrical properties of a photovoltaic module. For the experimental analysis, the brush was adapted to a conventional electric motor, and the cleanings was on the frontal cover of the photovoltaic modules. The module was exposed to the environmental conditions of a desert climate, to perform periodic cleanings and record temperature and irradiance variables. The result of the research shows the analysis of the electrical properties of the module to determine the influence of the type of cleaning and its impact on the conversion efficiency.

**Photovoltaic energy, Dry cleaning, Electrical parameters**

**Resumen**

Para que un módulo fotovoltaico opere en óptimas condiciones es necesario una correcta limpieza, ya que las pérdidas de potencia eléctrica debidas a la suciedad en la cubierta del módulo se estiman hasta 30-40% en climas secos y arenosos. En este trabajo se realiza el diseño y construcción de un sistema de limpieza de tipo seco usando un cepillo cilíndrico de cerdas de nylon con dimensiones de 100 cm de largo por 12 cm de ancho, las cerdas tienen un diámetro de 0.3mm, la velocidad angular del sistema es de 10.58 $\boldsymbol{\pi} rad/seg$. El objetivo es analizar el impacto del sistema de limpieza sobre las propiedades eléctricas de un módulo fotovoltaico. Para el análisis experimental el cepillo se adaptó a un motor eléctrico convencional y las limpiezas se realizan sobre la cubierta frontal de los módulos fotovoltaicos. El módulo se somete a condiciones ambientales de un clima desértico para realizar la limpieza paródicamente registrando las variables de temperatura e irradiancia. El resultado de la investigación muestra el análisis de las propiedades eléctricas del módulo para determinar la influencia del tipo de limpieza y su afectación en la eficiencia de conversión.

**Energía fotovoltaica, Limpieza seca, Parámetros eléctricos**

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## 1. Introduction

Solar Photovoltaics is a technology that generates direct current (power measured in watts or kilowatts) by means of semiconductors when they are illuminated by a beam of photons. [1] This technology has grown considerably in recent years. The Energy Regulatory Commission (CRE) estimates that by 2030 there will be an installed capacity of solar photovoltaic systems in Mexico equivalent to 6,905 MW. [2] Despite this, this technology presents variability in the production of electrical energy due to external factors that impact the electrical parameters of the photovoltaic module, reducing the generation of electrical power. These factors are the irradiance received, orientation, temperature, shading, thermal performance of the module and soiling. Flores Rivera (2018) [3] indicates that the most impactful soiling is formed on the module by environmental factors such as birds, wind, environmental pollution and dust. Dust is a determining factor that causes a reduction in the transmission of incident solar radiation reaching the PV cells [8]. A dust deposit of 4 g/m2 reduces the power conversion by 40% [4]. The effect is severe when modules are installed in desert areas with frequent dust storms, as the dust lodges on the module surface as dirt.

It has been proven by different studies that dirt on a module affects the module efficiency, an investigation by Jiang (2011) found by indoor experimentation that the reduction of a module's efficiency was increased by 26% by a dust layer of about 0 to 22 g/m2 [5]. Furthermore, Elminir (2006) reported a decrease in power output of up to 70% after exposing the panels to the elements for 6 months in Egypt [4]. Taking this into account, it is important to clean the roof of the modules, so this has become an issue that draws attention, as it seeks to maintain the efficiency of the modules, especially in desert regions, where despite having large amounts of irradiance, the climate is severe, facing most of the year hot days, and little rainfall.

Al Sheheri (2017) attributes that the constant drop in efficiency of PV modules installed in arid regions is due to dust permeating the surface and insufficient rainfall to clean them naturally, leading to the use of other cleaning techniques [6].

These techniques can be classified into two main categories: wet cleaning, which involves the use of water to remove dirt, and dry cleaning, which encompasses all methods that do not require water and are generally based on physical processes, such as brushing or vibration. The forms of cleaning that can be used for PV module maintenance can be categorised as follows: manual cleaning, mechanised cleaning, hydraulic cleaning and cleaning robots installed Al Shehri (2017) [6].

In this work, a dry cleaning system for modules based on a nylon bristle brush is constructed to analyse the impact of electrical parameters when subjected to dust and cleaning. The paper is structured as follows; in section 1 an introduction to situate the reader in the field of research, section 2 covers the construction of the prototype which is divided into: the design and construction, the coupling of an electric motor, section 3 corresponds to the experimental development of the dry cleaning. Section 4 is a review of the results obtained in the project, while section 5 shows the preliminary conclusions.

## 2. Methodology

A. Design and construction of the dry cleaning system.

For the construction of the prototype it was necessary to design it virtually. Figure 1 shows the 3D model in the SolidWorks programme.

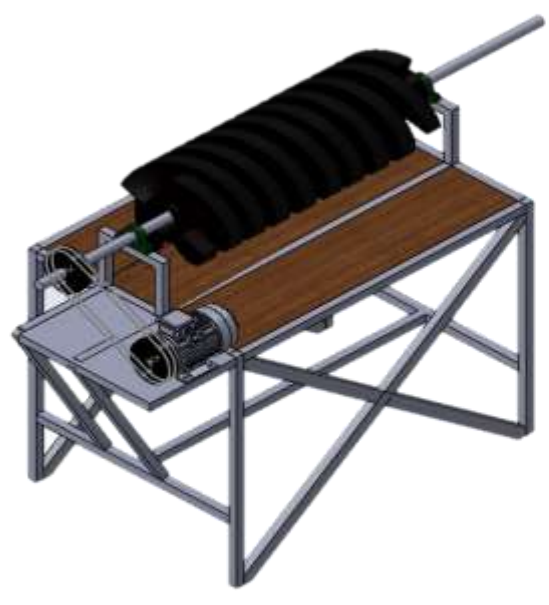

**Figure 1** 3D model of the dry cleaning prototype
*Own Source, made in SolidWorks*

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The cleaning prototype made in SolidWorks has the assembly table or base, the nylon bristle roller and an electric motor. The dimensions of the brush are 100 cm by 12 cm wide, this, taking into account the axis and the length of the bristles. The base is 120 cm long, 84 cm wide and 90 cm high. This was followed by the construction of the system. The most important aspect of a cleaning system must be that the device is able to clean the photovoltaic modules and for this reason, figure 2 shows the union of 2 cylindrical rollers with nylon bristles in the form of a spiral, which will perform the functions of dry sweeping covering the width of the module.

**Figure 2** Union of the two cylindrical rollers
*Own Source*

This roller is made of nylon bristles that have a diameter of 0.3 mm (this is the thinnest material available on the national market, to avoid scratching the module). The shaft was manufactured using one inch diameter (25.4 mm) stainless steel tubing. To support the system, diagonally arranged PTR bars were assembled and welded to provide stability to the base, as shown in figure 3.

**Figure 3** Support assembly for stability of the system base
*Own Source*

Subsequently, supports were placed along the table surface to provide support for the bases that were installed to fix two one-inch diameter bearings.

In addition, a metal base was designed and fabricated and suspended from the top of the table to house the electric motor, which will provide the desired rotation of the roller. This base has additional braces to ensure stability during operation. The complete mechanism is shown in figure 4.

**Figure 4** Roller system assembled on the stand
*Own Source*

At the end, wooden bases with a thickness of one inch were placed on top of the base structure and five castor wheels were added to support loads of up to 100 kg each. These castors will make it easier to move the modules on the table during the dry-cleaning process.

B. Coupling of a conventional electric motor to provide the brush rotation

In the system, the use of a conventional electric motor was implemented to obtain the rotation of the nylon bristle brush and to be able to apply a rotating sweep to clean the surface of the modules. In the work of Arrubla (2020), a motor rotation speed of 115 rpm was determined. Other studies show that at low revolutions for a rotary sweep it is possible to remove the most volatile dust and dirt without damaging the surface of the modules [7]. The electric motor selected is a Marathon 1075 Rpm, single phase, ½ HP, 110v single phase motor, shown in figure 5.


**Figure 5** Electric motor selected for system coupling
*Source: https://www.marathongenerators.com*

This section also presents the equations to describe the transmission of the motor power, the bristle pressure on the PV module and finally the angular and linear velocity of the system.

i) Speed reduction mechanism

The brush rotational speed setting was obtained from equation 1, to calculate the output speed generated by the motor.

$$N1\ x\ D1 = N2\ x\ D2 \quad (1)$$

Where
N1 = Engine speed
N2 = Engine output speed
D1 = Drive pulley diameter
D2 = Diameter of the driven pulley

The expected output speed is 300 rpm taking into account the research of Arrubla (2020) [7], it is expected that by increasing the rotational speed less cleaning cycles will be required and for this purpose a driven pulley of 11" diameter was chosen.

ii) Pressure of the bristles on the PV module

The pressure was determined using a horizontal board under the nylon brush to obtain the optimum height of 16 cm, from the base to the nylon bristles, sufficient to sit the module on the wood and allow the nylon bristles to rub against the module to apply the cleaning. The pressure was determined using the equation 2.

$$P = \frac{F}{A} = \left[\frac{N}{m^2}\right] = Pa \quad (2)$$

Figure 6 shows the picture of the method.

**Figure 6** Experimental tests to obtain the pressure exerted by the roller on a Surface
*Own Source*

iii) Angular and linear velocity of the system.

The angular velocity (ω) is a measure of rotation and determines the speed with which the angle can vary over a period of time.

The angular velocity (ω), which can be measured in radians per second, is a measure of rotation and determines how fast the angle can vary over a period of time. It is calculated by means of equation 3.

$$\omega = \frac{\theta}{t} \quad (3)$$

Where
$\theta\ =\ number\ of\ revolutions\ in\ RPM$
$t\ =\ tiempo\ en\ que\ el\ cuerpo\ da\ vueltas$

Linear velocity, (V), is the speed at which a point moves along a circular path. This is why angular velocity and linear velocity are related equation 4.

$$V = \omega R \quad (4)$$

## 3. Experimental development of dry cleaning in a module

A 50W polycrystalline module of the EPCOM brand (Fig. 7) was used for cleaning. The module was installed on the roof of the renewable energy laboratory of the TecNM Campus Laguna, in the city of Torreón, Coahuila. The module was placed with a southward orientation and an inclination of 25° corresponding to the latitude of the study area.


**Figure 7** Polycrystalline photovoltaic module, Epcom 50W
*Source Manufacturer's datasheet Annex 1*

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For this study, the PV module was left installed outdoors for 12 days for each cleaning. This cleaning frequency value is based on the work of Castillo (2022) [8], who used a 410 W JaSolar module in the same location, during this period of time he found a 25% reduction in efficiency, so it was decided to perform cleaning at the frequency of every 12 days [8].

All measurements were obtained near solar noon every 12 days, and environmental measurements were also taken, all before and after cleaning. Irradiance was measured with a Tenmars pyranometer (SM-206). For correct measurement with this instrument, the pyranometer must be calibrated and positioned parallel to the module surface. Wind speed was measured with an AMPROBE model TMA10A anemometer.

**Figure 8** Measurement of environmental parameters
*Own Source*

To determine the ambient temperature, the Weatherlink application was used to consult the values obtained from the weather station located at the Instituto Tecnológico de la Laguna. For the measurements of the electrical parameters of the module, an ELEJOY WS400A multimeter was used for modules and the IV curve was obtained with a Prova 200A curve tracer, equipment shown in figure 9.

**Figure 9** Equipment for measuring the electrical parameters of photovoltaic modules
*Own Source*

The electrical parameters were obtained before and after cleaning the photovoltaic module. As mentioned before, the dry cleaning was performed on the module cover after being exposed for 12 days to the weather and dirt, and the analysis showed an average power reduction of 32%. Figure 10 shows the technique performed for the dry cleaning process with the constructed system.

**Figure 10** Photovoltaic module in dry cleaning process with cylindrical roller
*Own Source*

## 4. Results

A. Design and construction of the dry cleaning system.

Figure 11 shows the final prototype built with dimensions of 1.20 x 84 x 90 cm, which allows the cleaning of modules with dimensions up to 100 cm wide, dimensions of commercial modules.

**Figure 11** Final prototype of a dry cleaning system for photovoltaic modules
*Own Source*

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B. Results of the coupling of a conventional electric motor to provide the brush rotation.

The result of the equations to describe the reduction of the transmission speed of the motor, the pressure of the bristles on the photovoltaic module and finally the angular and linear speed of the system are presented.

i) Calculation of the rotational speed.

To determine the rotational speed N2, equation 1 was used, where N1 corresponds to the speed of the motor, being 1200rpm, the motor speed reduction mechanism communicates with a 3" drive pulley with which N2 was determined, i.e.

$$N2 = \frac{N1xD1}{D2} = \frac{(1200)x(3)}{(11)} = 327.27\, rpm$$

ii) Calculation of the sow pressure on the photovoltaic module

To obtain the pressure of the roller on the module surface, equation 2 was used. The force of 9.62 N was obtained from the weight of the roller, whose mass is 0.98 kg, which is applied over a total area while the system is rotating. The total area was determined by adding the three sections where pressure is exerted when the module is placed, being 0.05 $m^2$. Then

$$P = \frac{9.62}{0.05} = 194.31Pa$$

iii) Calculation of angular and linear system velocity.

To determine the angular velocity it is necessary to know the number of revolutions the roller turns per minute, which is 327.27 rpm, which converted to radians is

$$\theta = 327.27\, rpm\, x\, 2\pi rad = 654.54\pi rad$$

that using equation 3 the final angular velocity becomes

$$\omega = \frac{654.54\pi rad}{60\, seg} = 10.909\, \pi rad/seg$$

To obtain the linear velocity, equation 4 is the relationship between the radius and the linear velocity, which is directly proportional. The radius of the pulley is 13.97cm, so that

$$V = \omega R = 10.9\, \frac{\pi rad}{seg} x\, 13.97cm = 478.77m/s$$

C. Results of the experimental development of dry cleaning in a module exposed to environmental conditions for a desert climate.

Figure 12 presents a comparison between the I-V characteristic curves of the electrical behaviour of the module before and after the cleaning process.

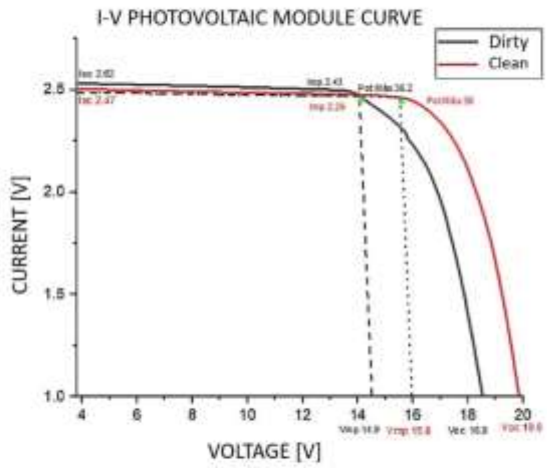



**Figure 12** Comparison of I-V curves of dirty and clean PV module
*Own Source*

From figure 12 it is possible to observe a decrease in peak power, where the peak power current decreases very slightly, showing how dirt directly affects the current generation of the modules. This suggests that cleaning the module allows the incident radiation to penetrate the module cells without being covered by dust.

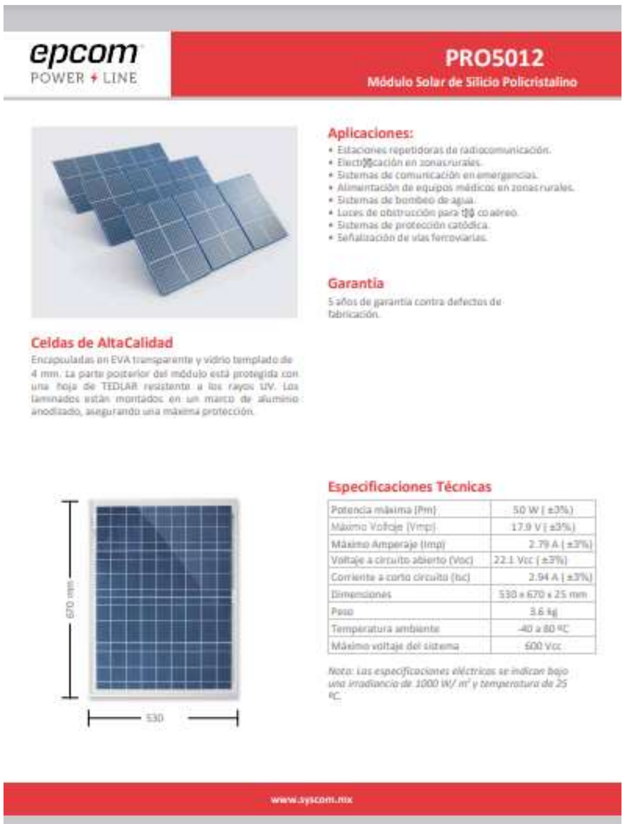
On the other hand, it can be observed that the open circuit voltage has a more noticeable variation, being more influenced by temperature. On the study day, the environmental conditions before and after cleaning were similar. The radiation was 1172 $W/m2$, the ambient temperature was 31 °C before cleaning.

After cleaning, the irradiance received in the module increased to 1200 $W/m2$ and the ambient temperature increased to 33°C, although the cleaning was done in less than 15 minutes, this time was enough to affect the measurements. The cell temperatures of the module were also recorded, before cleaning it was 58.13 °C and after cleaning it decreased to 41 °C.

From these data, it can be deduced that the accumulation of dust acts as a layer that interferes with the incident radiation on the module, which causes an increase in the module temperature. The removal of this dust layer resulted in a 29% decrease in module temperature.

## 5. Annexes

Annex 1 corresponds to the technical data sheet of the photovoltaic module used for the analysis.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Celdas de AltaCalidad
Encapsuladas en EVA transparente y vidrio templado de 4 mm. La parte posterior del módulo está protegida con una hoja de TEDLAR resistente a los rayos UV. Los laminados están montados en un marco de aluminio anodizado, asegurando una máxima protección.

Especificaciones Técnicas

| | |
|---|---|
| Potencia máxima (Pm) | 50 W ( ±3%) |
| Máximo Voltaje (Vmp) | 17.9 V ( ±3%) |
| Máximo Amperaje (Imp) | 2.79 A ( ±3%) |
| Voltaje a circuito abierto (Voc) | 22.1 Vcc ( ±3%) |
| Corriente a corto circuito (Isc) | 2.94 A ( ±3%) |
| Dimensiones | 530 x 670 x 25 mm |
| Peso | 3.6 kg |
| Temperatura ambiente | -40 a 80 ºC |
| Máximo voltaje del sistema | 600 Vcc |

Nota: Las especificaciones eléctricas se indican bajo una irradiancia de 1000 W/ m² y temperatura de 25 ºC.



www.syscom.mx

**Figure 13** Datasheet Epcom 50W module. Manufacturer's datasheet

## 6. Acknowledgements

The authors would like to thank the Tecnológico Nacional de México for the financial support, as well as PRODEP. CONAHCYT is also thanked for the support through grant 812614.

## 7. Conclusions

In this work, a dry cleaning system with dimensions of 1.20 x 84 x 90 cm was designed and built, which allows cleaning modules with dimensions up to 100 cm long up to 100 cm long and 200 cm wide, the dimensions of commercial modules.

In order to carry out its characterisation, it was necessary to couple a 1/2 HP electric motor and a speed reduction system with pulleys to reduce the rotational speed of the brush, resulting in 327.27 rpm per cycle.

The angular velocity of the cleaning system was also determined to be 10.90 πrad/sec. The force exerted by the roller on the module is 194.31 Pa, which is necessary to clean and remove the dust from the surface of the module. Its implementation showed that the cleaning of the PV module contributed to a decrease of the cell temperature by 7.13 °C.

It is concluded that the deposited dust acts as a layer that interferes with the radiation incident on the module by obstructing the radiation and causing the module temperature to rise. By cleaning and removing this dust the module temperature decreased by 29% directly impacting the open circuit voltage, this has a very noticeable variation and may be directly due to the module temperature. There was no difference between the current before and after cleaning, suggesting that the dust layer is not as thick or thick.

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# Ergonomic evaluation of work sites in an aerospace maquiladora company

# Evaluación ergonómica de sitios de trabajo en una empresa maquiladora de giro aeroespacial

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**Abstract**

Ergonomics is a discipline that contributes to the quality of life of people, through the study and understanding of interactions between humans, the environment that surrounds them and the profession. The practice of ergonomics in man-machine-environment systems is essential to eliminate risk factors associated with the presentation of musculoskeletal disorders (MSD), the reduction of occupational diseases and comply with current regulations, this being the objective of the present study. During the investigation, an exhaustive analysis of the different jobs was carried out and the ergonomic risk factors present in each of them were identified (inadequate postures, repetitive movements, excessive forces and unfavorable environmental conditions) and their level at through a specific evaluation method. Finally, specific intervention measures were proposed and applied to eliminate or reduce the level of risk. These measures included the redesign of work stations, the modification of equipment, tools, the implementation of active breaks and the training of staff in ergonomic practices. In conclusion, the results support the importance of incorporating ergonomics as an integral practice in work environments, in order to protect the health and well-being of workers, as well as improve the efficiency and productivity of organizations.

**Ergonomic, Factors, Risk**

**Resumen**

La Ergonomía es una disciplina que contribuye a la calidad de vida de las personas, a través del estudio y comprensión de interacciones entre humanos, el medio que los rodea y la profesión. La práctica de la ergonomía en los sistemas hombre-máquina-ambiente es fundamental para eliminar factores de riesgo asociados a la presentación de Trastornos musculo esqueléticos (TME), la disminución de enfermedades del tipo laboral y cumplir con la normatividad vigente siendo este el objetivo del presente estudio. Durante la investigación, se llevó a cabo un análisis exhaustivo de los diferentes puestos de trabajo y se identificaron los factores de riesgo ergonómicos presentes en cada uno de ellos (posturas inadecuadas, movimientos repetitivos, fuerzas excesivas y condiciones ambientales poco favorables) y su nivel a través de un método de evaluación específico. Para finalizar se propusieron y aplicaron medidas de intervención específicas para eliminar o reducir el nivel de riesgo. Estas medidas incluyeron el rediseño de estaciones de trabajo, la modificación de equipos, herramientas, la implementación de pausas activas y la capacitación del personal en prácticas ergonómicas. En conclusión, los resultados respaldan la importancia de incorporar la ergonomía como una práctica integral en los entornos laborales, con el fin de proteger la salud y el bienestar de los trabajadores, así como mejorar la eficiencia y productividad de las organizaciones

**Ergonomía, Factores, Riesgo**

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## Introduction

An accident at work, according to the Federal Labour Law (1970, pp 128), is any organic injury or functional disturbance, immediate or subsequent, death or disappearance resulting from a criminal act, produced suddenly in the course of or in connection with work, regardless of the place and time in which it is performed. Most accidents at work, according to the Mexican Institute of Social Security (IMSS), occur due to exposure to machinery, falls, overexertion and/or recklessness of workers (IMSS, 2023; Factorial, 2023).

The International Labour Organisation (ILO) notes that the cost of occupational accidents and diseases represents up to 4% of Gross Domestic Product (GDP) with a gradual increase in spending for IMSS from 2000 to 2017 in terms of subsidised days. These costs greatly affect the worker and the company (STPS, 2019).

In Sonora, statistics from the Mexican Institute of Social Security (□IMSS□, 2023) show that for the period 2021 occupational accidents increased by around 1500, and the average number of occupational diseases registered in the years 2020 and 2021 is 5 times higher than in previous years and the average number of incapacities amounts to 1571 cases (see Table 1).

| Year | Employees | Accidents | Diseases | Disabilities |
|---|---|---|---|---|
| 2015 | 561 756 | 15 784 | 749 | 1 472 |
| 2016 | 569 855 | 13 961 | 579 | 1 398 |
| 2017 | 587 633 | 14 848 | 679 | 1 581 |
| 2018 | 606 971 | 13 907 | 740 | 1 701 |
| 2019 | 618 880 | 13 511 | 586 | 1 739 |
| 2020 | 609 795 | 9 341 | 5 285 | 1 492 |
| 2021 | 620 718 | 10 854 | 3 042 | 1 611 |

**Table 1** Occupational diseases and disabilities in Sonora
*Source: IMSS Statistical Report (2023)*

Among the most affected sectors is the aerospace industry, which is defined as all productive activity dedicated to the construction of aeroplanes, missiles, helicopters and satellites, as well as the equipment on which they depend (Carrincazeaux and Frigant 2007, pp.264).

Aerospace production in Mexico is concentrated in civil commercial aviation. Most exports are engines, airframes, landing gear, connecting systems, doors and other components.

Table 1 shows by State the number of factories dedicated to the production of aircraft parts.

| State | Number of factories |
|---|---|
| Baja California | 97 |
| Sonora | 58 |
| Chihuahua | 52 |
| Querétaro | 50 |
| Nuevo León | 33 |

**Table 2** Number of aircraft parts manufacturing plants by State
*Source: Aguilar (2020)*

The company under study, located in Sonora, designs, manufactures and markets products for the automotive and aerospace sectors. During the last few months, it has been recording information related to occupational risks in three categories: Risks by month (figure 1), Risks by area (figure 2) and Risks by disease (figure 3).

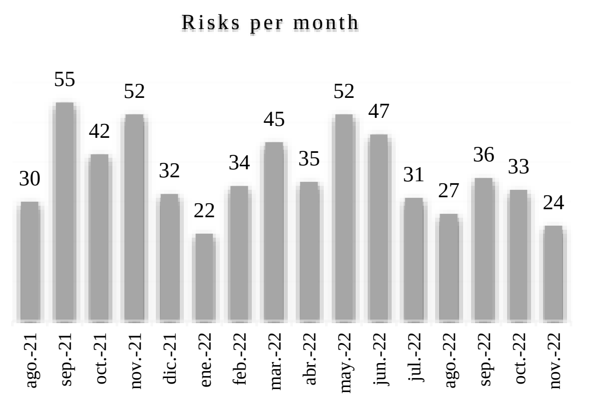


**Figure 1** Risk register by month of consultation

Figure 1 shows the record of consultations related to occupational risks month by month, period August 2021- November 2022, averaging 37 per month with a cumulative total of almost 600.

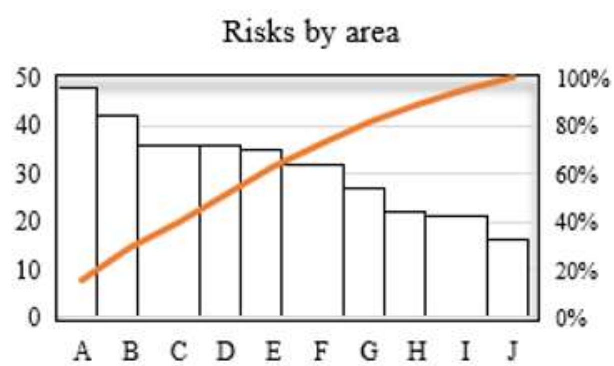


**Figure 2** Risk register by work area

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Figure 2 shows the accumulated risks by area, of which the first place and with the greatest opportunity for improvement is the process under study (A).

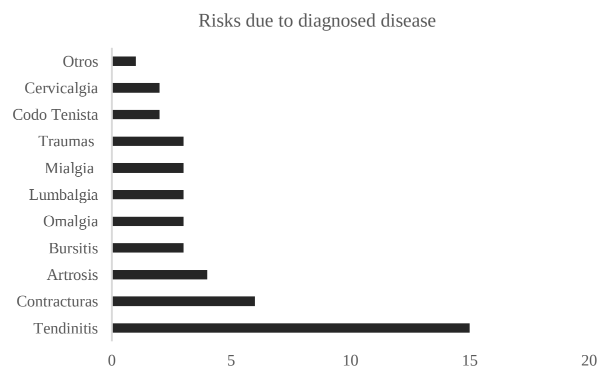


**Figure 3** Number of probable risks in the process under study

Finally, Figure 3 shows the different work-related illnesses, where 15 people presented tendinitis, 6 contractures, 4 arthrosis and some others related to Musculoskeletal Disorders (MSD).

According to Llaneza (2009) MSDs are injuries or disorders of the muscles, nerves, tendons, joints, cartilage and upper and lower limbs, and injuries that occur in the neck, lower back, aggravated by exertion or prolonged exposure to physical factors such as repetition, force, vibration or awkward posture. Symptoms are muscle and/or joint pain, tingling, loss of strength and decreased sensation. Ergonomics is a helpful discipline to counteract this type of ailment.

Ergonomics is the scientific study of human work (Pheasant, 1991, p. 3), applying scientific principles, methods and data from a variety of disciplines (Kroemer, Kroemer & Kroemer-Elbert, 2001), to contribute to the design of all types of systems with three fundamental characteristics: (1) a systems approach, (2) it is design-driven and (3) it focuses on performance and well-being (Dul, et.al., 2012).

Ergonomic assessment of workplaces requires a broad and deep knowledge of the problems related to physical risk factors in order to understand the causes of their alterations, wear and tear and other adverse health effects (Avila, 2014).

On carrying out a tour of the company facilities under study, images were captured of two operators carrying out their work (figure 4), followed by an interview with the personnel in charge and a rapid assessment of the job was carried out using the "Rapid Upper Limb Assessment" (RULA) method based on the methodology suggested by Diego-Mas (2015), whose method focuses on the upper limbs when the activity presents excessive postural load (Mcatamney, 1993, pp.91-99).

**Figure 4** Postures subject to rapid assessment

As can be seen in the figure above, the operators' postures are not very correct at first sight, which can lead to the presence of MSDs. The risk level obtained as a result of the RULA assessment was 7, making it necessary to study and modify the activity immediately.

In this context, added to the interest of the company under study to provide better working conditions and adhere to current regulations (remember that by the end of 2018 was approved in Mexico the NOM-036-STPS-2018 Ergonomic Risk Factors at Work-Identification, analysis, prevention and control where companies are required to generate actions or studies in Ergonomic matters) the following research question arises:

What actions, from an ergonomic point of view, should be implemented in the process under study to reduce ergonomic risk factors and/or the presence of occupational diseases?

## Objective

To ergonomically evaluate the man-machine-environment system of the maquiladora company in order to eliminate risk factors associated with the occurrence of MSDs and occupational diseases, and to comply with current regulations.

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## Method

The object of study of this research is represented by the assembly line of components with the highest incidence of occupational hazards. The method used to answer the research question is the development of the ergonomic analysis through a lean approach (Womack, 2005) and thus implement the actions or proposals for improvement. The procedure is described below.

*Characterise the current situation:* This step starts with the identification of the person responsible for carrying out the process of defining the problem, who can be part of the business or an external agent. Following this, a process diagram was drawn up.

*Define the problem:* The problem was defined based on records of incidents, accidents, occupational diseases, visits to medical and/or disability services, as well as the result of interviews with workers to identify tasks or activities that they consider may contribute to MSDs.

*Determine jobs to be evaluated:* In order to determine the jobs to be assessed, the number of risk factors was considered with the aim of prioritising the activities with the highest degree of urgency.

*Characterise tasks through observation:* In this section it is necessary to describe the operator's activity, taking into account each relevant movement, to achieve this, video should be taken of at least 10 cycles of the operation or 30 minutes of it. The video should be taken with a camera and the whole body of the operator should be visible in the image in order to capture the image whose posture is considered to be the most risky. The information is recorded in a table that integrates: the number assigned to the task, the reference image, the description of the task, relevant data prior to the assessment (average age, number of employees, hours per shift, frequency) and additional information derived from the observation of the workplace or posture.

Assess method and posture at workstations: Once the characterisation of each workstation was obtained, the ergonomic assessment was carried out using the following steps:

1) Write data in the header such as name of the department, division, and name of the activity; 2) Description of force, posture and frequency; 3) Assign scores to: Neck, shoulders, back, arms-elbows, wrist, hand, legs, and static postures. The scores range from 0 to 20 points, where 0-5 is low (green colour), 10 moderate (yellow colour) and 15-20 high (red colour); 4) Add scores, the algebraic sum of the scores assigned to each limb will be used to determine if the level of risk, for this 0 to 40 is Low Risk, 41 to 85 is Moderate Risk and 85 to 100 is High Risk.

Assess lifting at workstations: The first step was to observe the working conditions, such as steps, slippery surfaces or hot and cold environments that affect the lifting task. Once the conditions were identified, scores were assigned according to: Object Weight, ranging from 0 to 30 points if the weight equals or exceeds 23. 1 kg; Horizontal Distance (HD), the distance between the worker and the object while holding it, ranges from 0 to 30 points when HD equals or exceeds 63.5 cm; Initial Height (IH), this factor is scored according to whether a worker must bend or raise the arm to grasp the object to be lifted; Lifting or Lowering Distance (LD/B), here it is scored in relation to the distance the object is lifted or lowered; Frequency, which is assigned according to the number of times the object is lifted every minute or hour; Angle of Trunk Twist, which is determined by the angle of contortion of the upper body while lifting, without the employee moving their feet; Quality of Grip, which is good when the object is shaped to grip and bad when it has sharp edges, slippery or hot objects, and; Carrying Distance, the distance the object is carried.

Generate improvement actions: In this section, a list of actions was obtained to reduce the ergonomic risk factors to which the personnel are exposed.

## Results

The first step of the study consisted of appointing the supervisor of the area as the agent of change and/or in charge of improving the process, and then identifying the staff with the highest incidence of medical service according to the report of possible risks issued by the medical staff during the period January-December 2022.

Based on this, it was determined that it is the component assembly area that has the highest incidence of risk (see figure 2) and whose assembly process and recorded incidents are shown in figure 5.

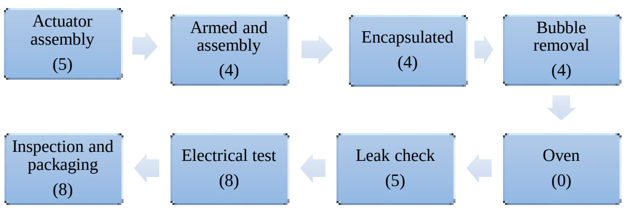


**Figure 5** Process diagram of the area under study

The figure shows the activities of the assembly process under study and the number of cases of probable risks or incidents recorded for each activity, totalling 38. Due to the small difference in the number of cases per activity, it was decided to evaluate all the posts from the actuator to the packaging of the finished product.

As a prior step to the evaluation, each task was characterised by means of observation and data recording, in order to better understand the situation and in which the following stand out: identification of the posture by means of an image, a detailed description of the activities carried out by the operator, as well as relevant data and information (see table 3).

| | Task | Task description |
|---|---|---|
| 1 | Actuator assembly<br><br>Age <45<br>No. Employees 2<br>Hours per shift 11<br>Frequency 450 /day | The operation consists of making small assemblies through pressing for which the operator operates a lever by means of a clamp-type gripper.<br><br>Additional information<br><br>It performs clamp-type gripping.<br>There is no rotation in the task. |
| 2 | Actuator assembly<br><br>Age <45<br>No. Employees 2<br>Hours per shift 11<br>Frequency 450 /day | Wrap the relay with a metal shell and place two gaskets manually and then place it in an assembly press.<br><br>Additional information<br><br>There is torsion of the trunk and raised arm.<br>There is no rotation in the task. |
| 3 | Encapsulation<br><br>Age <45<br>No. Employees 1<br>Hours per shift 11<br>Frequency 900 /day | Place epoxy resin in each piece according to a specified maximum level.<br><br>Additional information<br>Awkward postures, poor vision, elbows away from the body and elevated shoulders.<br><br>No rotation in the task. |
| 4 | Bubble elimination<br><br>Age <45<br>No. Employees 1<br>Hours per shift 11<br>Frequency Not applicable | Eliminate, by means of a hot air gun, the possible bubbles present as a result of the resin placement.<br><br>Additional information<br>This task is performed for 10 minutes, in intervals longer than 2 minutes.<br><br>Shoulder is elevated and arms suspended in the air without support.<br><br>No rotation in the task |
| 5 | Oven<br><br>Age <45<br>No. Employees 1<br>Hours per shift 11<br>Frequency Not applicable | Place the pieces with resin in the ovens to be heated for 5 hours.<br><br>Additional information<br>Handling loads up to 19 lbs (8 kg), awkward posture during lifting.<br><br>No rotation in the task. |
| 6 | leakage check<br><br>Age <45<br>No. Employees 2<br>Hours per shift 11<br>Frequency 450 /day | Verify that the product does not leak by injecting nitrogen.<br><br>Additional information<br>Raised arm during activity (very high table).<br><br>No rotation in the task. |
| 7 | Electrical test<br><br>Age <45<br>No. Employees 1<br>Hours per shift 11<br>Frequency 450 /day | Check the correct operation of the product by electrical test according to specifications.<br><br>Additional information<br>Operator remains on her feet throughout the day.<br><br>No rotation in the task |
| 8 | Inspection and packaging<br><br>Age <45<br>No. Employees 2<br>Hours per shift 11<br>Frequency 45 /day | This operation consists of packing 20 pieces per box and placing a label with the established format. Afterwards, it is verified that the pieces are not damaged, cables with resin and that there are no missing pieces.<br><br>Additional information<br>Handling of 8 to 11 kg loads in different locations.<br><br>No rotation in the task. |

**Table 3** Characterisation of the tasks of the process under study

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As a result of the observation, the following were identified: pincer-type grip, torsion of the trunk, raised arm suspended without support, uncomfortable postures, poor vision, elbows separated from the body, raised shoulders, standing operators, no rotation in the task and in some cases in particular the handling of loads of up to 11 kg. Tables 4 and 5 present the results of the evaluation of workstations and lifting of loads.

| Activity | Neck | Shoulders | Back | Arms and elbows | Doll | Hands | Legs | Static postures | Points |
|---|---|---|---|---|---|---|---|---|---|
| Actuator assembly | 10 | 10 | 5 | 0 | 10 | 15 | 5 | 10 | 65 |
| Armed and assembly | 10 | 15 | 10 | 10 | 5 | 10 | 5 | 5 | 70 |
| Encapsulated | 10 | 15 | 10 | 5 | 5 | 5 | 10 | 5 | 65 |
| Bubble removal | 10 | 15 | 15 | 10 | 5 | 10 | 5 | 5 | 75 |
| Oven | 10 | 10 | 10 | 5 | 10 | 0 | 0 | 0 | 45 |
| Leak check | 10 | 15 | 10 | 10 | 5 | 5 | 5 | 5 | 65 |
| Electrical test | 10 | 10 | 15 | 10 | 5 | 10 | 10 | 15 | 85 |
| Inspection and packaging | 10 | 10 | 5 | 5 | 10 | 10 | 5 | 15 | 70 |

> 85 = High

40 a 84= Middle

<40= Low

**Table 4** Job evaluation results

| Activity | Weight | Horizontal distance | Initial height | Lifting distance | Frequency | Turning angle | Grip | Distance charge | Points |
|---|---|---|---|---|---|---|---|---|---|
| Actuator assembly | 1 | 1 | 1 | 1 | 1 | 5 | 1 | 1 | 12 |
| Armed and assembly | 1 | 1 | 1 | 1 | 1 | 5 | 1 | 1 | 12 |
| Encapsulated | 10 | 1 | 1 | 10 | 1 | 5 | 1 | 1 | 30 |
| Bubble removal | 10 | 1 | 1 | 5 | 1 | 5 | 1 | 1 | 25 |
| Oven | 10 | 5 | 1 | 5 | 10 | 10 | 1 | 1 | 43 |
| Leak check | 10 | 1 | 1 | 1 | 5 | 5 | 1 | 5 | 29 |
| Electrical test | 10 | 5 | 1 | 1 | 10 | 20 | 1 | 1 | 49 |
| Inspection and packaging | 20 | 1 | 10 | 10 | 5 | 5 | 5 | 1 | 57 |

> 85 = High

40 a 84= Middle

<40= Low

**Table 5** Results of the assessment of the lifting of loads

According to the results of the previous table in relation to the method and postures (section 1), the activity Final inspection is the one with the highest risk level, scoring 85 points, and therefore changes must be made urgently. The rest of the activities result in moderate risk, so they must attend to the extremity whose qualification has been marked in red, as is the case of shoulders, which appears in this condition in 4 of the 8 activities.

With regard to manual handling of loads, 3 activities appear with moderate risk and the rest with low risk, with the final inspection being the one with the highest score and the one that should be focused on.

Finally, there are some actions for improvement:

Implement intervention measures: Based on the results of the ergonomic assessments, implement specific intervention measures to eliminate or reduce the identified risk factors. These measures may include redesigning workstations, modifying equipment and tools, introducing active breaks, modifying the method and improving environmental conditions. The aim is to achieve a low risk rating (green).

- Establish an ergonomic team: Form a multidisciplinary team composed of professionals in ergonomics, occupational health and safety, human resources and workers. This team will be responsible for leading ergonomic activities and ensuring their effective implementation.

- Train staff: Provide ergonomics training and awareness to all employees. It is important to educate workers about the risks associated with MSDs, basic ergonomic principles and best practices to prevent work-related injuries.

- Conduct regular ergonomic assessments: Establish a regular programme of ergonomic assessments to proactively identify and address risk factors. These assessments can include analyses of postures, movements, forces and environmental conditions, as well as staff satisfaction and well-being surveys.

- Promote worker participation: Involve workers in the process of identifying risks and finding ergonomic solutions. Foster a participatory culture in which employees feel empowered to report problems and suggest improvements.

- Follow-up and evaluate results: Regularly monitor the results of implemented ergonomic measures. Evaluate the effectiveness of interventions in reducing risk factors and in the overall well-being of workers. Make continuous adjustments and improvements based on findings and feedback.

– Keep up to date with current regulations: Maintain up-to-date knowledge of ergonomics standards and regulations. Ensuring compliance with relevant standards and legal requirements and making necessary adjustments in line with regulatory changes.

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**Conclusions**

In conclusion, according to the results, the objective of ergonomically evaluating the man-machine-environment system of the maquiladora company to eliminate risk factors associated with the presentation of MSDs and occupational diseases, and to comply with current regulations, was achieved. This study contributes to the achievement of a safe and healthy working environment for its employees, a better image and to avoid possible legal sanctions.

It is advisable to continue working on the ergonomic evaluation of all the different workstations for the timely identification of the risk factors present such as: inadequate postures, repetitive movements, excessive forces, vibrations and unfavourable environmental conditions. This will contribute to a better working environment and to the success of the organisation.

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Article

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# Analysis of the mechanical behavior of a heat diffuser for electrical cells made of natural fiber-reinforced composite materials

# Estudio del comportamiento mecánico de un difusor de calor para celdas eléctricas construido con materiales compuestos reforzados con fibras naturales

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**Abstract**

The automotive industry is currently moving towards electrification of its vehicles to reduce $CO_2$ emissions. As a result, manufacturers are striving to offer electric vehicles that can provide the same benefits as internal combustion vehicles and, if necessary, improve them. The main component in the conformation of the electric cells adapted to the vehicles requires a distribution that allows them to be balanced on the chassis platform. In addition, a very important aspect to consider is the fact that the configuration of the cells must support proper ventilation so that they can dissipate the heat generated and optimize their operation. Therefore, in this paper it is proposed to provide an alternative that can support the ventilation of the cells, trying to take advantage of the momentum of the vehicle using a diffuser capable of driving the air into the cells and then out, which could generate greater stability to the temperatures generated in the cell and extend the life of the vehicle. A CAD model of the prototype will be designed based on modifications to the one currently used; this will be done to give rise to a degree of innovation in the development of production electric vehicles. On the other hand, it is considered to evaluate the functionality of such part simulating the basic conditions of resistance and deformation with the use of modeling software considering different types of materials: aluminum alloys; polymer matrix composites reinforced with fiberglass, carbon and reinforced with natural fibers, such as coconut fiber and jute.

**Composites, Natural fiber, CAD Design, Strain distribution**

**Resumen**

Actualmente, la industria automotriz se dirige a la electrificación de sus vehículos de producción con la finalidad de reducir las emisiones de $CO_2$ que estos modelos generan. En base a ello, las empresas armadoras buscan ofrecer vehículos eléctricos que sean capaces de brindar los mismos beneficios que ofrecen los vehículos de combustión y en su caso mejorarlos. El componente principal en la conformación de las celdas eléctricas adaptadas a los vehículos requiere una distribución que permitan estar balanceadas sobre la plataforma del chasis. Además, un aspecto muy importante a considerar es el hecho de que la configuración de las celdas debe dar soporte a una correcta ventilación para que puedan disipar el calor generado y se optimice su funcionamiento. Por lo que, en este proyecto se propone dar una alternativa que pueda brindar apoyo en la ventilación de las celdas, buscando aprovechar el impulso del vehículo usando un difusor capaz de conducir el aire hasta las celdas y luego salir, lo cual podría generar una mayor estabilidad a las temperaturas generadas en la celda y alargar la vida útil del vehículo. Se diseñarán un modelo CAD del prototipo basándose en modificaciones al que actualmente se ha empleado; esto con la finalidad de dar pie a un grado de innovación en el desarrollo de los vehículos eléctricos de producción. Por otra parte, se considera evaluar la funcionalidad de dicha pieza simulando condiciones básicas de resistencia y deformación con el uso del software de modelado (SolidWorks, Ansys) considerando diferentes tipos de materiales: aleaciones de aluminio; materiales compuestos de matriz polimérica reforzados con fibra de vidrio, carbono y reforzados con fibras naturales, como lo son la fibra de coco e yute.

**Materiales compuestos, Fibras naturales, Diseño CAD, Distribución de esfuerzos**

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## Introduction

The automotive industry is moving towards the electric car as the next step [1]. The structure of these vehicles is shown in Figure 1, where different components are defined with respect to an internal combustion engine vehicle. These vehicles are driven by one or more electric motors powered by the stored energy of an electric battery [2,3].

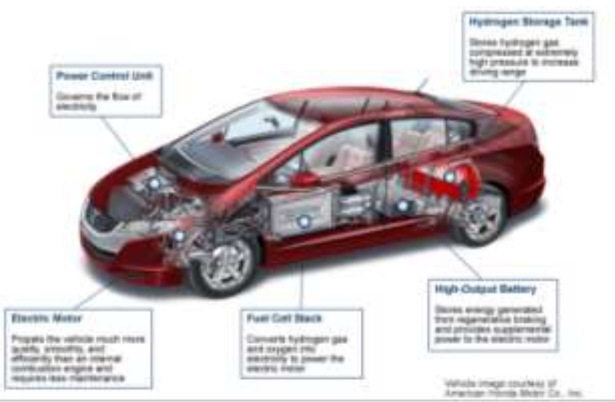


**Figure 1** A diagram of the structure of a standard electric vehicle [2]

The most important component of an electric vehicle is the battery, since the vehicle's traction depends directly on it; therefore, there are many reasons why innovations are currently being sought to optimize and improve its performance. One aspect that is rarely considered is the possibility of using the vehicle's momentum to better dissipate the heat generated in this area of the vehicle.

The automotive industry is currently using composite materials as an alternative for manufacturing various components. These materials are formed by two or more different materials without any chemical reaction between them, i.e., a mixture is formed.

All composites have two components: the matrix, which is the main phase, and the reinforcing material, which is the material added to improve the properties of the matrix (Figure 2) [3,4]. Thus, composites are the product of two or more materials joined together to form a combination with properties that cannot be obtained from the original materials.

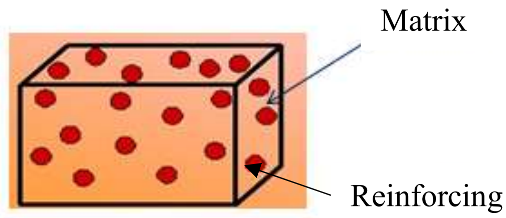


**Figure 2** Structure of a composite

Composite materials can be classified according to the scheme shown in Figure 3, with fibers or particles as the main reinforcing agent [4,5].

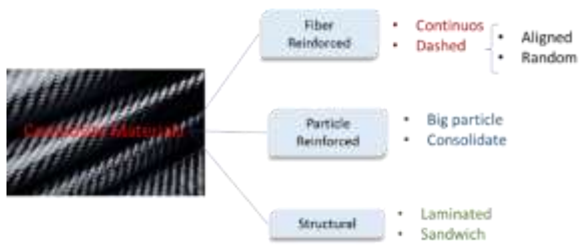


**Figure 3** Classification of composites

The aim of this research is to analyze sustainable alternatives based on the modification of the diffuser design and its construction using natural fiber reinforced composite materials, which should be able to support the heat dissipation function of the battery and optimize the vehicle performance.

## Methodology

Figure 4 shows a general diagram of the proposed methodology, which consists of the following steps:

**Step 1**. Development of the CAD model of the diffuser.

**Step 2.** Selection of mechanical properties of jute fiber reinforced composite materials. Properties such as mechanical strength, density, Young's modulus, elastic limit, percentage of elongation at break.

**Step 3.** Development of mechanical simulation using tetrahedral mesh.

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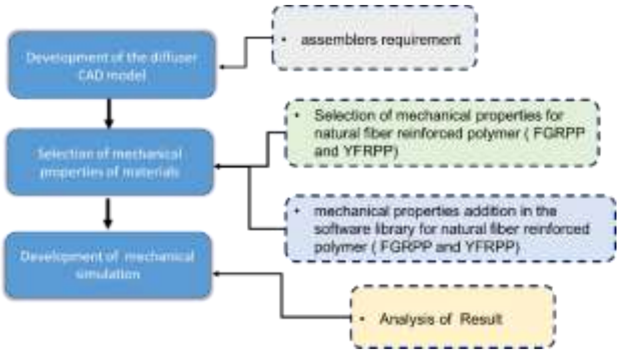



**Figure 4** General Diagram of Methodology

Table 1 shows the proposed diffuser models; Figure 5 shows the meshing of the diffuser, consisting of a tetrahedral mesh with 4016 nodes and 7832 elements with a homogeneous compressive distributed load of 22.37 kN applied.

This load was applied according to equation 1, considering a mass of 3000 kg and an acceleration (equation 2) reached when the vehicle changes its speed from 100 km-h$^{-1}$ to 300 km-h$^{-1}$ (maximum speed reached by an electric vehicle) in a time of 7.67 s [6].

$$F = ma \quad (1)$$

$$a = \frac{v_f - v_i}{t_f - t_i} \quad (2)$$

| Image | Model | Differentiation |
|---|---|---|
|  | MD-1 | Linear path model with oval inlet and rectangular outlet. Single outlet channel; 3 mm and 5 mm thickness. |
|  | MD-2 | Model with trajectory with a small ascending step. Oval shaped inlet and double outlet for air flow distribution in two; thickness of 3 mm and 5 mm. |

**Table 1** Proposed Diffuser Models

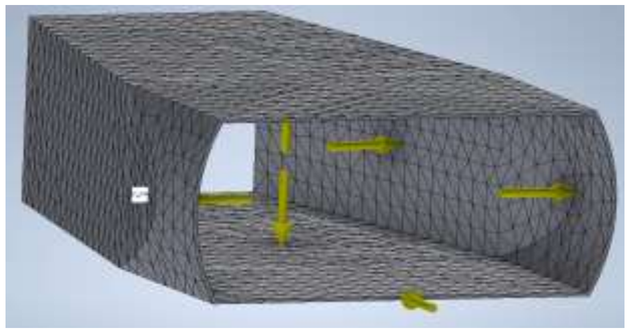


**Figure 5** Meshing and load applied for simulation

Table 2 shows the mechanical properties of the materials; three materials Al-6061T4 (conventional automotive), glass fiber reinforced polypropylene matrix composite (GFRPP) and jute fiber reinforced polypropylene (YFRPP) were compared. Table 3 shows the constraints proposed for the simulation.

| | Al-6061T4 | GFRPP | YFRPP |
|---|---|---|---|
| Tensile Strength; $\sigma_u$ (MPa) | 207 | 77 | 50 |
| Yield Strength; $\sigma_y$ (MPa) | 110 | 67 | 40 |
| Elastic Module; E (GPa) | 69 | 4.6 | 5.7 |
| Density; ρ (g-cm$^{-3}$) | 2.70 | 1.13 | 1.11 |

**Table 2** Mechanical properties required for simulation [ref]

| | MD1 | MD2 |
|---|---|---|
| Fixture 1 |  |  |
| Fixture 2 |  |  |

**Table 3** Type of Constraints Used for Simulation

## Results

Table 4 shows the von Mises stress distribution, $\sigma_V$ (Equation 3), and the displacements generated in the 3 mm thick models; Table 5 summarizes the results obtained according to the diffuser thickness and the type of restraints.

Less displacement is observed in aluminum because it is a material with higher stiffness than the composites. ($E_{Al}$= 69 GPa; $E_{GFRPP}$=4.6 GPa and $E_{YFRPP}$=5.7 GPa).

$$\sigma_v = \left[\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2} + 6\left(\tau_{12}^2 + \tau_{23}^2 + \tau_{13}^2\right)\right]^{\frac{1}{2}} \quad (3)$$

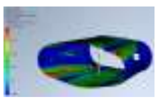
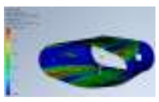
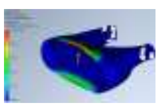
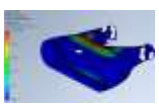
| | Al-6061-T4 | GFRPP | YFRPP |
|---|---|---|---|
| **Stress Distribution** | | | |
| MD1 Fixture 1 |  |  |  |
| MD2 Fixture 1 |  |  |  |
| MD1 Fixture 2 |  |  |  |
| MD2 Fixture 2 |  |  |  |
| **Displacement distribution** | | | |
| MD1 Fixture 1 |  |  |  |
| MD2 Fixture 1 |  |  |  |
| MD1 Fixture 2 |  |  |  |
| MD2 Fixture 2 |  |  |  |

**Table 4** Von Mises stress distribution and displacement by model and constraint type for the 3 mm thick diffuser

| | | $\sigma_v$ maximum (MPa) | δ maximum (mm) | $\sigma_v$ maximum (MPa) | δ maximum (mm) | Feasibility for build with YFRPP y/o GFRPP |
|---|---|---|---|---|---|---|
| | | t= 3 mm | | t= 5 mm | | |
| Fixture 1 MD1 | Al-6061T4/MD1 | 290 | 112.9 | 106 | 112.9 | Not feasible |
| | GFRPP/MD1 | | 1676 | | 428.8 | |
| | YFRPP/MD2 | | 1352 | | 346.1 | |
| Fixture 1 MD2 | Al-6061T4/MD2 | 581.3 | 77.93 | 240 | 21.18 | |
| | GFRPP/MD2 | | 1156 | | 313.8 | |
| | YFRPP/MD2 | | 933 | | 253.2 | |
| Fixture 2 MD1 | Al-6061T4/MD3 | 4.102 | 0.07864 | 1.98 | 0.02334 | Feasible with t=3 and 5 mm |
| | GFRPP/MD3 | | 1.144 | | 0.3389 | |
| | YFRPP/MD3 | | 0.9231 | | 0.2735 | |
| Fixture 2 MD2 | Al-6061T4/MD3 | 111 | 2.22 | 42.48 | 0.5687 | Feasible with t= 5 mm |
| | GFRPP/MD3 | | 33.31 | | 8.54 | |
| | YFRPP/MD3 | | 26.88 | | 6.87 | |

**Table 3** Von Mises stresses

The configuration of the two models with fixture one results in $\sigma_v$ higher than the ultimate strength of the material; therefore, it is not possible to use this configuration. By increasing the thickness, the stress decreases to 106 MPa; according to the material properties, only aluminum could be used ($\sigma_v$=110 MPa, for aluminum). However, it should be noted that the displacement generated is 112.9 mm; therefore, this configuration is not feasible.

The MD1 with fixture 2, gives a $\sigma_v$ of 4 MPa with displacements of less than 2 mm, therefore its construction and adaptation to the electric vehicle is possible.

## Conclusions

The choice of the fixing points in the diffuser structure allows to considerably reduce the stresses generated in the structure; a lower value of $\sigma_v$ is obtained using fixing 2, where two reactions are placed to counteract the external loads on the diffuser wall. On the other hand, the wall thickness is another element that allows to reduce the generated stresses; having that the greater the thickness, the less $\sigma_v$ will be generated On the other hand, the displacements must be analyzed to have the least impact on the structure, therefore, according to the simulation results, the most optimal configuration for the construction of the diffuser is given in MD1 with fixture 2 and thickness of 3 mm.

## Acknowledgments

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Article

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# Design of an adjustable prop made of Polymeric material

# Diseño de un puntal ajustable elaborado de material Polimérico

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**Abstract**

In this work, an adjustable prop made of polymeric material was designed. To do this, standards that refer to this element were consulted and which specify that the load that the prop must support is 6000 N including live loads and dead loads. Consequently, the selection of the appropriate polymer for this application was carried out through a comparison of the mechanical properties of these materials, with acetal proving to be better. With this information, a buckling analysis was carried out using the analytical method considering an adjustable prop length of 3 m. In addition, supported by the Solidworks® software, a simulation of the critical load and contact stress was also carried out, resulting in the fixed part of the adjustable prop being a tube with an internal diameter of 80 mm and an external diameter of 95 mm. The adjustable part must be solid with a diameter of 80 mm.

**Adjustable prop, Falsework, Buckling, Acetal**

**Resumen**

En este trabajo se diseñó un puntal ajustable en altura elaborado de material polimérico. Para ello, se consultaron normas que hacen referencia a este elemento y donde se especifica que la carga que debe soportar el puntal es de 6000 N incluyendo cargas vivas y cargas muertas. En consecuencia, la selección del polímero adecuado para esta aplicación se realizó mediante una comparación de las propiedades mecánicas de estos materiales resultando ser mejor el acetal. Con esta información se procedió a realizar un análisis de pandeo por el método analítico considerando una longitud del puntal de 3 m. Además, apoyados en el software de solidworks®, se realizó tambien una simulacion de la carga crítica y de esfuerzos de contacto dando como resultado que la parte fija del puntal debe ser un tubo con diámetro interior de 80 mm y 95 mm el diámetro exterior. La parte ajustable debe ser sólida con un diámetro de 80 mm.

**Puntal telescópico, Cimbra, Pandeo, Acetal**

**Citation:** PÉREZ-PÉREZ, Arnulfo, HUERTA-GÁMEZ, Héctor, TÉLLEZ-MARTÍNEZ, Jorge Sergio and MORENO-REYES, José Miguel. Design of an adjustable prop made of Polymeric material. Journal of Technical Invention. 2023. 7-20: 22-26

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## Introduction

The construction industry uses large quantities of standard-sized wooden poles for shoring, which are generally 2.5 m long and 76 mm square in cross-section. Nowadays, concern for forest conservation has led to a search for options in terms of the materials used for the production of these elements. For example, telescopic props made of steel can be found on the market with lengths ranging from 1.75 m to 3.5 m and load capacities ranging from 23 KN to 8.44 KN [1] [3]. Plastic dunnage with the above mentioned standard dimensions for wooden dunnage is also available on the internet. As a consequence, in this work, the structural feasibility of a telescopic prop made of polymeric material is analysed.

## General objective

To determine, by means of the analytical method and the finite element method, the dimensions and geometries of a telescopic prop made of polymeric material capable of supporting a load of 6 KN.

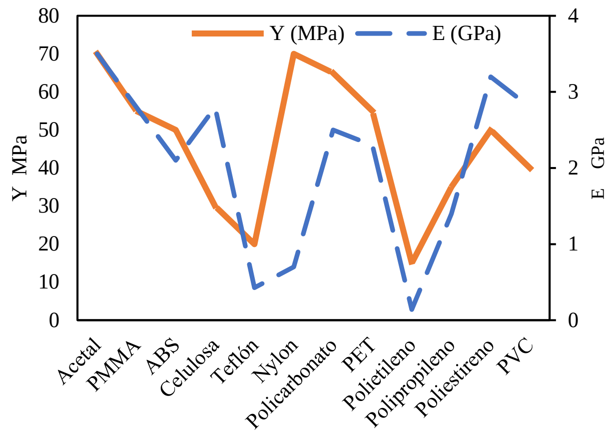
## Methodology

According to the ACI-347-04 guide, the design of a shoring system must be dimensioned to withstand the live and dead loads, whose value reaches 6 KPa with a safety factor of 2 [1]. The length of the prop, proposed for this analysis, was 3 m; and the selection of the plastic to be used was a function of its modulus of elasticity and its tensile strength since, in the buckling analysis using Euler's formula, the critical load is a function of the mechanical properties mentioned above. With respect to the tensile strength Y and modulus of elasticity E, table 1 shows the values for some of the most common plastics on the market and also shows the main applications.

| Material | E (GPa) | Y (MPa) | Applications |
|---|---|---|---|
| Acetal | 3.5 | 70 | Automotive components |
| PMMA | 2.8 | 55 | Light lenses, aircraft windows. |
| ABS | 2.1 | 50 | Tubes, office machines. |
| Cellulose | 2.8 | 30 | Clothing, cellophane paper. |
| Teflon | 0.425 | 20 | Bearings, kitchen utensils. |
| Nylon | 0.7 | 70 | Mats, clothing, tyre cords. |
| Polycarbonate | 2.5 | 65 | Safety helmets, glass. |
| PET | 2.3 | 55 | Beverage containers, fabrics. |
| Polyethylene | .14 | 15 | Bottles and tubes. |
| Polypropylene | 1.4 | 35 | Injection moulded parts. |
| Polystyrene | 3.2 | 50 | Toys, foams. |
| PVC | 2.8 | 40 | Rigid tubes for drainage and irrigation. |

**Table 1** Mechanical properties of plastics and their applications
*Source: Own Elaboration with data obtained from [4]*

In order to select the material in an objective way, graph 1 was made where the values of tensile strength Y, as well as Young's modulus E of different plastics are compared. In this graph, it could be seen that acetal is the plastic with the highest values in both properties.




**Graph 1** Tensile strength and modulus of elasticity values for different polymers
*Source: Own Elaboration with information from [4]*

Other properties of acetal, whose technical name is polyoxymethylene thermoplastic material (POM), are shown in table 2. Its high melting point allows it to be used up to temperatures of 100°C, competing with some metallic materials such as zinc and brass.

| Property | Valor |
|---|---|
| Yield strength MPa | 71.5 |
| Poisson's modulus | 0.3859 |
| Maximum working temperature °C | 100 |
| Density g/cm$^3$ | 1.41 |
| Melting point °C | 170 |
| Density kg/m$^3$ | 1410 |

**Table 2** Mechanical properties of acetal.
*Source: Own Elaboration with data obtained from [9]*

As for the props, they must be erected in such a way that they do not tilt and must be firmly supported by a square-shaped termination at the end. For adjustable models, the load values depend on their length and can be seen in table 3.

| Prop height in m | Carrying capacity in KN | |
|---|---|---|
| | Strut of 1.75 m-3.10 m | Strut of 2.10 m-3.50 m |
| 1.75 | 23 | |
| 1.9 | 23 | |
| 2 | 23 | |
| 2.3 | 20.43 | 22.14 |
| 25 | 17.64 | 20.5 |
| 2.7 | 14.21 | 16.5 |
| 3 | 9.83 | 12.17 |
| 3.3 | | 9.72 |
| 3.5 | | 8.44 |

**Table 3** Load-bearing capacity of telescopic metal props.
*Source: Adapted from [9]*

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**Strut dimensioning using the analytical method**

As a starting point, a length of 3 m and an outer pipe diameter of three inches (76 mm) was considered. With this information we proceeded to calculate the inner diameter of this tube to avoid buckling failure using the Euler's critical load equation.

The critical Euler load on an element before buckling occurs is given by equation (1) where one end is considered embedded and the other sliding (Figure 1).

$$P_{cr} = \frac{\pi^2 EI}{L^2} \quad (1)$$

And the critical stress is expressed by equation (2) as being inversely proportional to the cross-sectional area.

$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{\pi^2 EI}{AL^2} \quad (2)$$

In equations (1) and (2), E is the modulus of elasticity of the material in Pa, A is the cross-sectional area of the column in $m^2$, I is the moment of inertia in $m^4$ and L is the length of the element in m.

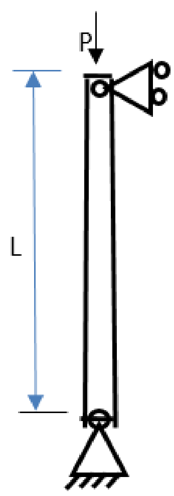


**Figure 1** Parameters involved in the buckling of an element
*Source: Own elaboration adapted from [6]*

For a tube, the equation (1) is expressed as (3).

$$P_{cr} = \frac{\pi^2 E\left(\frac{\pi\left(d_{ext}^4 - d_{int}^4\right)}{64}\right)}{L^2} \quad (3)$$

In proposing the value of dext, the unknown is the value of dint, which can be removed from equation (3).

$$d_{int} = \sqrt[4]{d_{ext}^4 - \frac{64 * P_{cr} * L^2}{\pi^2 * E * \pi}} \quad (4)$$

Given the above conditions and using the properties of acetal, the values used in equation (4) were: Pcr=6000 N, E=3.5 GPa, L=3 m, dext=76 mm resulting in dint=35 mm. Then, different values of dext were analysed to find the minimum value that complies with the load condition since a smaller diameter will be easier to handle and also represents a lower weight. The results obtained are shown in table 4.

| $d_{ext}$ mm | $d_{int}$ mm |
|---|---|
| 100 | 90.8 |
| 90 | 76 |
| 80 | 54 |
| 76 | 35 |
| 75 | There is no value |

**Table 4** Outer diameter and inner diameter values for a tubular section required for a critical load of 6000 N
*Source: Own Elaboration*

Now that the inner dimensions of the fixed tube are known, the diameter of the telescopic element was determined using equation (5).

$$d_{ext} = \sqrt[4]{\frac{P_{cr} * L^2 * 64}{\pi^3 * E}} \quad (5)$$

$$d_{ext} = \sqrt[4]{\frac{6000 * 3^2 * 64}{\pi^3 * 3.5x10^9}}$$

$d_{ext} = .0751\ m$=75 mm

**Dimensionamiento del puntal mediante el método de elemento finito**

Se utilizó el programa de cómputo SolidWorks® para realizar el modelado y el análisis de pandeo por elemento finito. En cuanto al pandeo, el análisis se realizó con las piezas de forma individual y el análisis de esfuerzos de contacto y factor de seguridad se realizó con las piezas ensambladas las cuales consisten de un tubo fijo, un redondo y un pasador. Este ultimo se le agregaron las propiedades del acero SAE 1015 tomadas de [5] y loas otras piezas con las propiedades del material acetal tomadas de [4].

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## Results

From the application of the analytical method it was determined that the telescopic part should be a round bar with a diameter of 76 mm and length of 1.5 m. As a consequence, the inner diameter of the fixed tube should be 76 mm with a fit H7 [7] and a thickness of 7.5 mm.

The finite element analysis allowed to take into account the holes in the tube that serve to adjust the height of the strut. After sufficient simulations, it was determined that the dimensions of the telescopic strut should be as shown in figure 2.

The mentioned dimensions result in a load factor of 6355 N and 6531 N for the two elements.

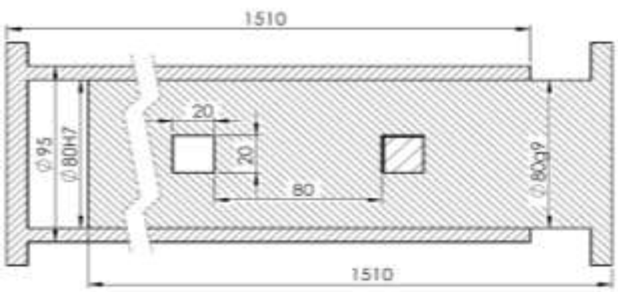


**Figure 2** Dimensions of the elements that make up the telescopic prop
*Source: Own Elaboration [SolidWorks]. Mass = 10.5 Kg*

In the contact stress analysis with SolidWorks, using a load of 6000 N applied to the assembled model, the Von Mises stresses were 34.8 MPa and thus a minimum safety factor of 2.1 was obtained as shown in Figure 3.

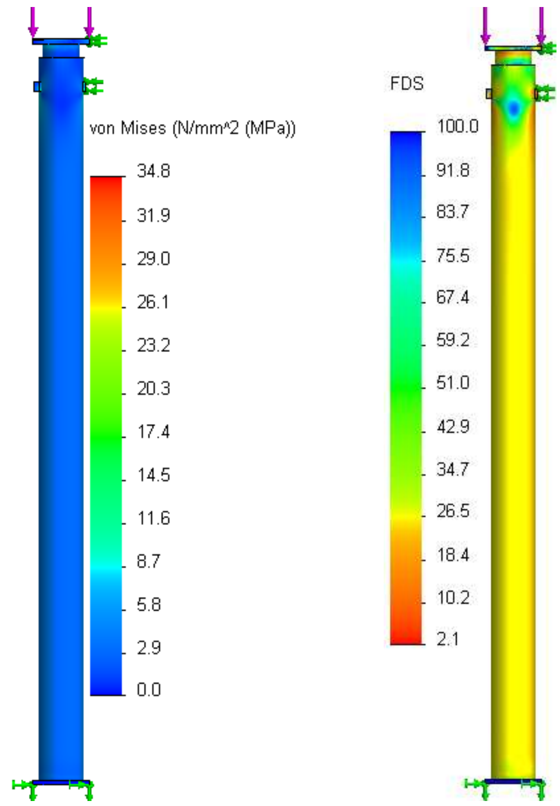


**Figure 3** Von Mises stress in MPa and factor of safety
*Source: Own Elaboration [SolidWorks]*

Therefore, if we consider a solid element, the diameter must be larger than 75 mm since we are working with a telescopic strut composed of two pieces where one slides inside the other, and the proposed dimensions, based on the calculations made, will be as shown in figure 2.

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## Conclusions

From the results obtained from the buckling analysis and the simulations for the determination of contact forces, it is concluded that it is possible to use acetal as a material for the fabrication of adjustable props used in construction for a load of 6 KN. For a prop length of 3 m, the appropriate external diameter is 95 mm with a thickness of 7.5 mm, resulting in a factor of safety of 2.1 and a von mises stress of 34.8 MPa.

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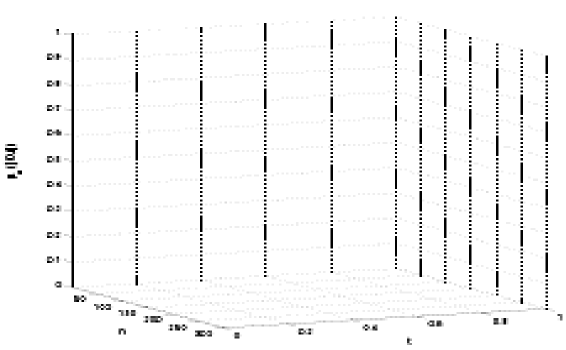

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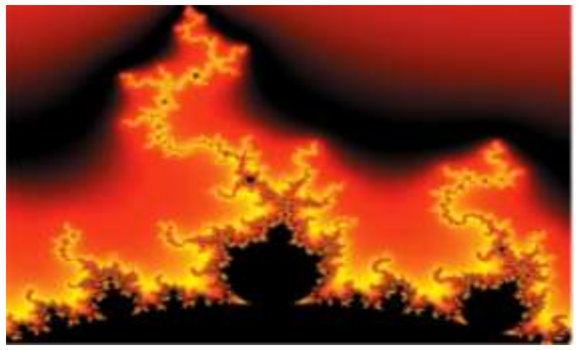

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