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Presentation of Content

In the first article we presents, *Analysis of the properties and geometric characteristics of machined parts using computer vision* by MERAZ-MENDEZ, Manuel, REYNOSO-JARDON, Elva Lilia, MUÑOZ-LOPEZ Luis Enrique and CORRAL-RAMIREZ, Guadalupe, with adscription in the Universidad Tecnológica de Chihuahua, in the next article we present, *Mechanism validation after stress concentration analysis mathematical calculated with safety factor requirements using dedicated software with friction factor mate* by BRIANZA-GORDILLO, Gerardo, ZAMARRIPA-MUÑOZ, Miguel Ángel and HERRERA-PIAD, Luis Alejandro, with adscription in the Universidad Tecnológica de Aguascalientes, in the next article we present, *Eleven level multi-level inverter simulation platform* by PEÑA-DELGADO Adrián Fermín, JOERS-DELGADO, Carlos, GONZALEZ-MORALES, Amparo, ROMÁN-RIVERA Anette Michel, with adscription in the Universidad Tecnológica de Altamira and Instituto Tecnológico de Ciudad Madero, *in the last article we present*, Meteorological parameters monitoring system using free hardware and software with data storage and display on Nextion screen by SALINAS-AVILES, Oscar Hilario, BELTRAN-ESCOBAR, Miguel, SÁNCHEZ-LÓPEZ, Verónica and AMADO-SÁNCHEZ, Beatriz, with adscription in the Universidad Tecnológica Emiliano Zapata del Estado de Morelos.

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Analysis of the properties and geometric characteristics of machined parts using computer vision

Análisis de las propiedades y características geométricas de piezas maquinadas mediante visión por computadora

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Abstract

In milling contour profiles, tools create minute surface variations known as roughness. An algorithm is proposed to analyze the profile dimensional variation in milled parts by an artificial vision and Fourier descriptors as a measurement technique. The proposed method is based on the Fourier spectrum to analyze three profile signatures extracted from an image of a milled part with the aim of measuring the variation in three materials. It is found that when performing the profile machining process, the combination of the parameters: spindle speed, feed rate, cutting depth, and coolant fluid influence the dimensional variation of the part. The proposed approach concludes that this inspection method is faster and more efficient to guarantee the quality of parts manufactured by machining.

Artificial vision, Fourier descriptors, Inspection, Geometry, Milling

Resumen

En el maquinado de perfiles de contorno por fresado, las herramientas crean variaciones superficiales diminutas conocidas como rugosidad. Se propone un algoritmo para analizar la variación dimensional del perfil en piezas fresadas mediante visión artificial y descriptores de Fourier como técnica de medida. El método propuesto se basa en la obtención del espectro de Fourier para analizar las firmas de perfil extraídas de una imagen de una pieza fresada con el objetivo de medir la variación en tres materiales. Los resultados determinaron que, al realizar el proceso de mecanizado del perfil, la combinación de los parámetros: velocidad del husillo, velocidad de avance, profundidad de corte y fluido refrigerante influyen en la variación dimensional de la pieza. El enfoque propuesto contribuye a la implementación de un nuevo método de inspección más rápido y eficiente para medir la rugosidad de piezas fabricadas por mecanizado

Visión artificial, Descriptores de Fourier, Inspección, Geometría, Maquinado

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1. Introduction

Inspection of precision parts manufactured by computer numerical control (CNC) is a fundamental process to determine the quality of manufactured products and meet customer requirements (Meraz M. & Reynoso J., 2022). Today, the aerospace and automotive industries require the manufacture of increasingly precise components. It is necessary to inspect the geometric and dimensional characteristics of machined products for quality control. In the machining process, it is not feasible to perform a complete inspection on all manufactured products. The use of sampling techniques generates costs for companies (Prabhakar et al., 2020). Machined parts must meet a certain quality, specific surface roughness and profile accuracy. To measure these characteristics it is necessary to evaluate their geometric and dimensional tolerances because cutting tools leave marks on the contour and surface of the machined part (Seeman et al., 2010). It depends on the cutting conditions and parameters that these marks are not so noticeable.

Nowadays, machine vision (VA) systems are widely applied to perform operations that humans can hardly perform, such as object recognition, flaw detection or quality control. VAs use image processing and machine learning algorithms for image classification, object detection, object tracking, and image segmentation using deep learning techniques and convolutional neural networks.

Image processing is a physical process of converting an image signal (Russ & Russ, 2017) into data to be processed and analyzed, in order to modify the image view, add dimensionality to image data, work with masks and calculate statistics, distort images, specify regions of interest, manipulate images in multiple domains, enhance contrast, and filter, extract, and classify (C. Wang et al., 2020). The use of image processing can help produce new creations, recognize an object just by its image processing silhouette (Leon et al., 2000), and save time and cost (Tiagrajah & Razeen, 2011). Some 2-D recognition methods have relied on Fourier invariant moments and descriptors to describe silhouettes. Fourier descriptors (DF) have been applied to recognize 2-D objects with close shape boundaries (Isaza et al., 2020) and for image retrieval (Zhang & Lu, 2003).

It has been applied in automatic dimensional inspection of machine part cross sections (J. Wang et al., 2019) and implemented in 2-D partial shape classification (Fang et al., 2020).

In this correspondence, we present a method for dimensional variation inspection of milling parts using DF. The method estimates the DF corresponding to the full closed limit curve using a computer vision algorithm to analyze a 2-D image in the space domain given by transforms in the frequency domain.

2. Development

The main problem is that the measurement of roughness is a laborious process that requires specialized equipment and that it is not feasible to perform it on all machined parts. Starting from the fact that roughness can be represented as a continuous signal in space called signature, and that every signal is formed by a sum of sines and its analysis is more complex.

The analysis of the roughness in the frequency domain using the Fourier transform is proposed as a faster and easier method to analyze a two-dimensional signal. The analysis will be performed with the use of Fourier descriptors (DF) to generate the spectrum of each test and to determine which signature presents more frequency and in which material, with this the conditions that generate the roughness in the machining will be determined. The experimental method is based on the analysis of the dimensional variation produced by the contour milling process in three types of materials through a computational algorithm that transforms the spatial domain of the 2-D image f(s) in the frequency domain F(u) using Fourier descriptors called VA-DF.

The project arises since most of the theoretical and experimental studies on the machining process are based on the measurement of shear forces and stress (Soori & Asmael, 2022) and only focus on surface roughness analysis with the application of computer vision systems.

3. Methodology

The following describes the materials and methods to be employed in this research project to perform the analysis tests of the geometrical properties of CNC machined parts by DF through a VA algorithm.

3.1. Materials

For the design of the VA-DF algorithm and the performance of functionality tests, computer equipment and software with the minimum specifications for its correct performance shown in Table 1 were used.

Equipment Features	Required software and licenses
11th Generation Intel®Core™i7 processor.	Python
5.0GHz speed.	Minitab/ SPSS
Memory 8-16GB RAM.	Matlab-Simulink 2021
Free disk capacity 512GB SSD.	Visual studio
Windows 11 Operating System	SolidWorks CAD/CAM 2021

Table 1 Computer equipment

For the machining of the samples to be analyzed, a vertical CNC machining center from the laboratories of the Technological University of Chihuahua was used, with the characteristics described in Table 2.

Haas VF1 vertical machining center
3 axes X, Y, Z
Fanuc control, ISO codes
Table 650x356x300 mm
Spindle 8100 RPM, 30 HP
Carousel 20 tools

Table 2 CNC machine characteristics

3.2. Methods

Figure 1 shows the proposed methodology to obtain the Fourier spectrum and compares the results against a previously established reference standard.

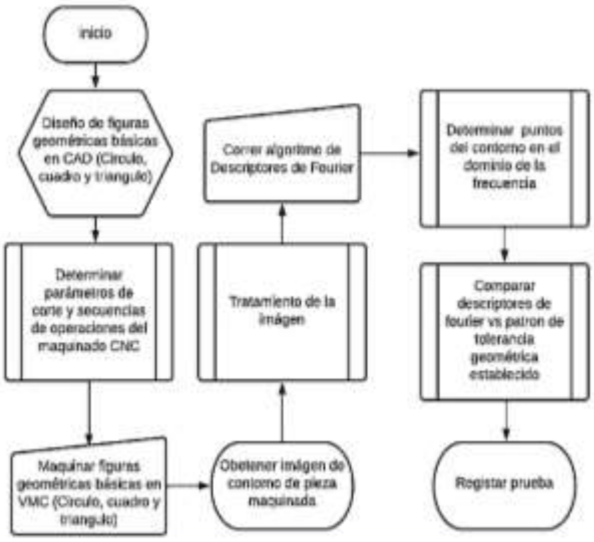


Figure 1 Methodology

3.2.1 Design

The design of the parts is carried out taking as reference a rectangular geometry of size 75 x 75 x 12 mm within a dimensional tolerance of ± 0.5 mm. The characteristics of the signatures are: curve (SG1) is a quarter circle with a radius of 20 mm, horizontal line (SG2) with a length of 25 mm and slope (SG3) of 12.5 mm length at 33.69°. Figure 2 shows the design of the test piece.

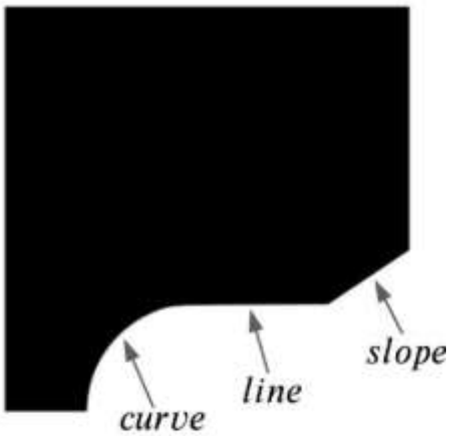


Figure 2 Test piece

The tests are performed with three different materials and their respective shear parameters described in Table 3

Materials	Vc (m/min)	Fz (mm/Flute)
Aluminum 1060	61/70	0.5/0.7
Nylacero	90/100	0.7/0.9
Plastic Delrin	27/30	0.3/0.1

Table 3 Materials and shear parameters

The parameters were obtained from the manufacturer's data taking into account the type of cutting tool and its operation in the machining process in order to evaluate the effect of the dimensional variation produced by the profile contour milling process and then compared with the *Ground Truth (GT)* reference signal of each firm shown in Figure 3.

Figure 3 Ground Truth GT1, GT2 and GT3

3.2.2. Machining of parts

The machining program is generated based on the following sequence of operations:

1. Planing cycle (1 mm depth of cut).
2. Contour roughing cycle (2 mm depth of cut) and 3.
3. Contour finishing cycle (13 mm depth of cut, in contact with the tool face).

Once the program sequence is defined, the spindle speed and feed rate are adapted for each material, then the program is simulated and verified to analyze the trajectories in order to detect collisions or anomalies in the process, finally, the G&M code program is generated on the Haas FANUC control for VMC Figure 4.

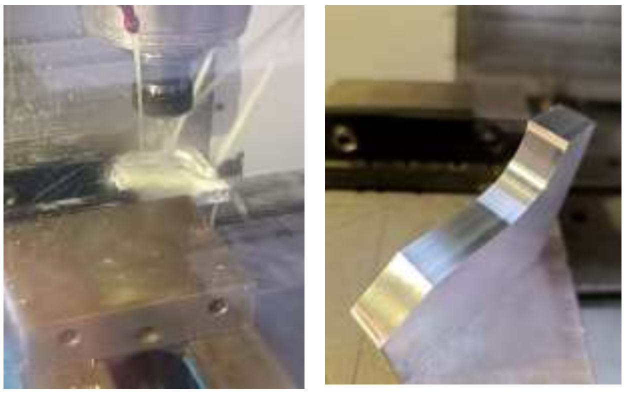


Figure 4 Machining of parts in Haas machining center

3.2.3. Generation of signatures

For the generation of signatures, first we have to capture the image of the part to be analyzed (Figure 5) with our image acquisition system since this is the input signal for the DF-VA algorithm.

Figure 5 Images captured by the acquisition system for signatures SG1, SG2 and SG3

As a next step, the signal will be subjected to a pre-processing to clean it and generate its contour through the *regionprops* function (Figure 6, 7 and 8).

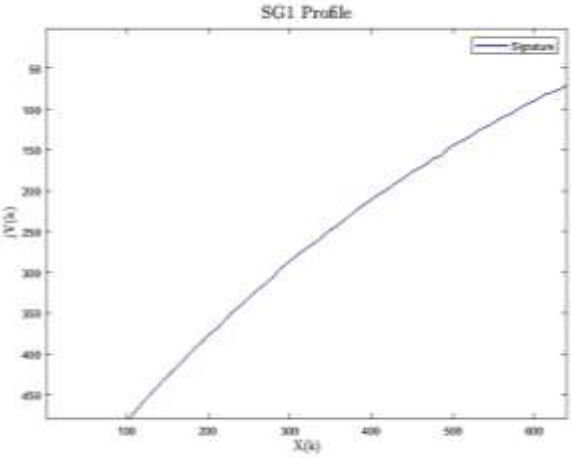


Figure 6 Contour profile for signature SG1.1

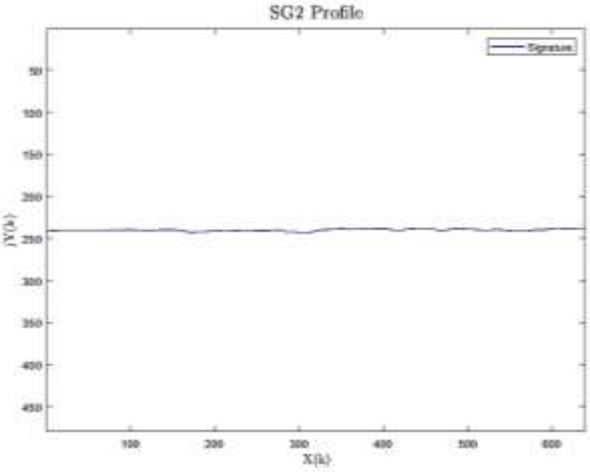


Figure 7 Contour profile for signature SG2.

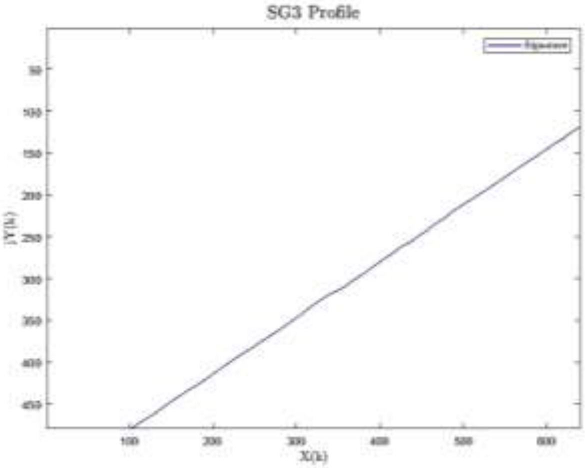


Figure 8. Contour profile for signature SG3

When the contour of the signature is already generated, the VA-DF algorithm generates a vector of 300 elements *([r(no),.....r(n-1)]* by means of the tracking function, giving a reasonable approximation with a minimum set of points on the perimeter, obtaining a compact representation compared to the large number of points that compose the original silhouette (Jasinevicius et al., 2021). This is achieved by minimizing the objective function f(n) using the algorithm that allows making good discriminations without using too much computational power or large databases.

3.2.4. DF-VA Algorithm

To process the image, the algorithm shown in Figure 9 needs the image capture as input signal to transform the 2-D continuous signal *f(s)* into a Fourier spectrum in the frequency domain F(u). The Fourier spectrum of the geometric feature will be generated as output and compared with its corresponding WG to determine the geometric variation value of the part.

Figure 9 DF-VA Algorithm

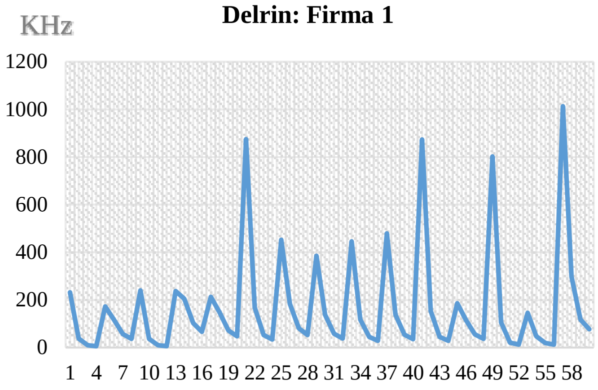
Results

Table 4 shows the results of the average Fourier spectrum (Hz) for GT1 (ξ) and its mean variation of the average Fourier spectrum (δ).

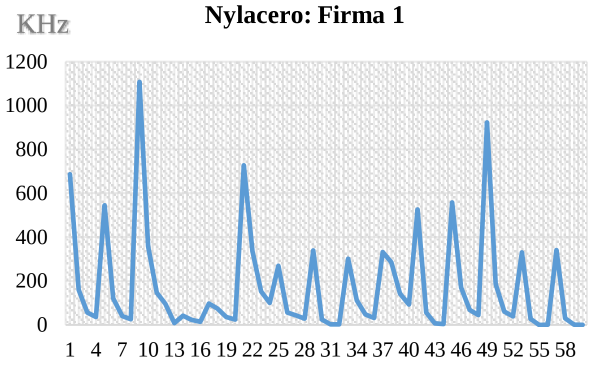
Material	Average roughness (Hz)
Black Delrin	167.9168831
Nylacero white	175.0868661
Aluminum	147.0559941

Table 4 SG1 roughness profile results

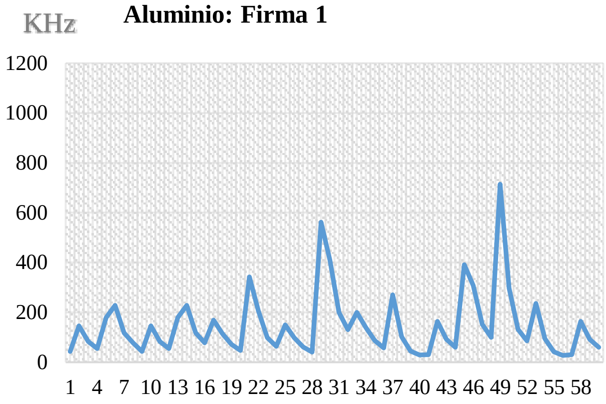
Graphs 1, 2 and 3 show the behavior of the profile as a function of frequency for the SG1 signature. In this analysis Nylon causes higher variations (*rms = 0.0039 KHz*), Delrin presents a low roughness profile (*rms = 0.0022 KHz*) and in aluminum the variation is lower (*rms = 0.0015 KHz*).



Graph 1 SG1 Delrin signature behavior



Graph 2 SG1 Nylon signature behavior



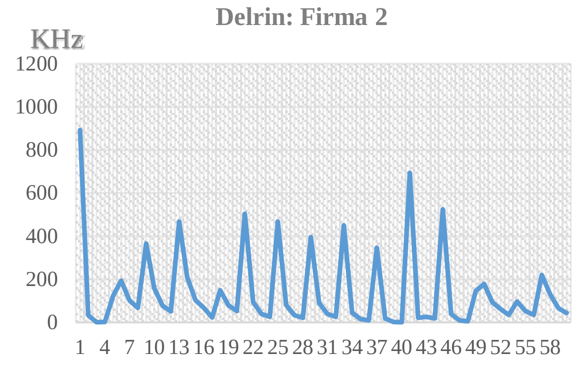
Graph 3 SG1 Aluminum Signature Behavior

Table 5 shows the results of the average Fourier spectrum (Hz) for GT2 (ξ) and the average variation of the average Fourier spectrum (δ).

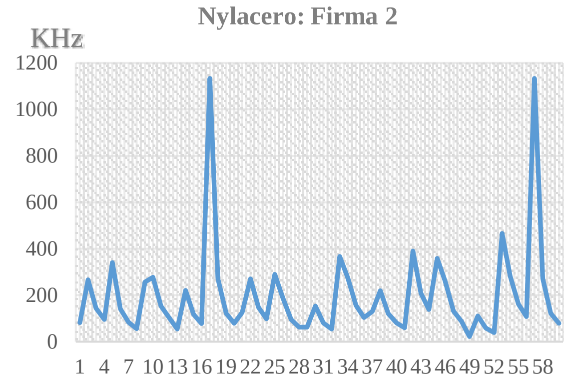
Material	Average roughness (Hz)
Black Delrin	140.462
Nylacero white	194.367
Aluminum	98.36724

Table 5 SG2 roughness profile results

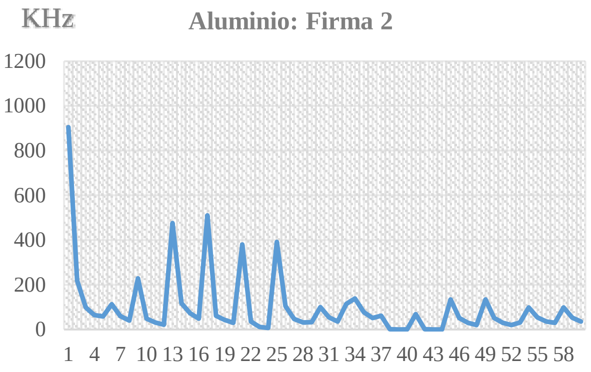
Graphs 4, 5 and 6 show the behavior of the roughness profile variation for SG2. In this analysis, we found that the dimensional variation was higher for Nylon (rms = 0.0037 KHz), lower for Delrin (rms = 0.0021 KHz) and low for aluminum (rms = 0.0007 KHz).



Graph 4 SG2 Delrin signature behavior



Graph 5 SG2 Nylacero signature behavior



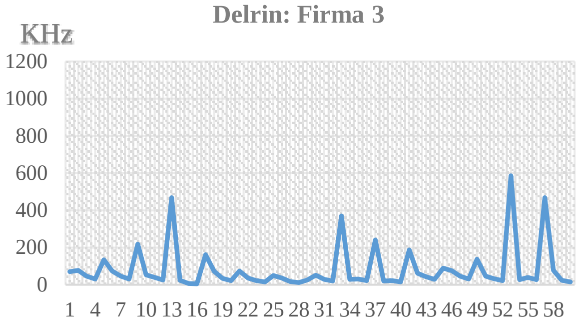
Graph 6 SG2 Aluminum Signature Behavior

Table 6 shows the results of the average Fourier spectrum (Hz) for GT3 (ξ) and the average variation of the average Fourier spectrum (δ) determined by the difference CGT3 - CGC3 in KHz.

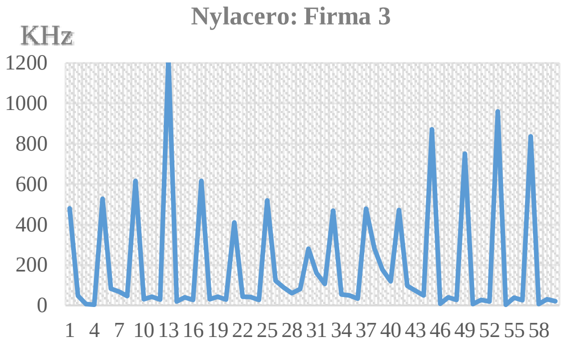
Material	Average roughness (Hz)
Black Delrin	80.40315841
Nylacero white	199.8213097
Aluminum	76.79069078

Table 6 SG3 roughness profile results

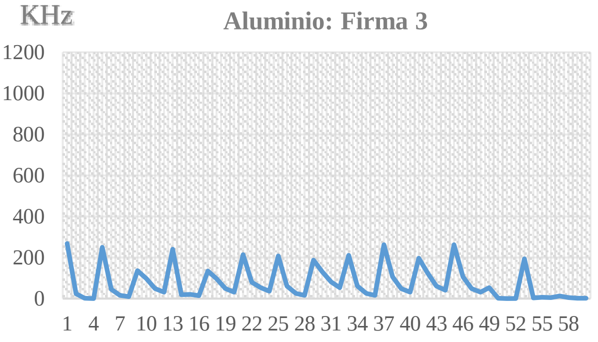
Graphs 7, 8 and 9 show the behavior of the roughness profile variation for SG3. In the analysis, we found that the dimensional variation remains higher for Nylon (rms= 0.0037 KHz), lower for Delrin (rms= 0.0019 KHz), and minimum for aluminum (rms= 0.0015 KHz).



Graph 7 SG3 Delrin signature behavior



Graph 8 Behavior of SG3 Nylacero signature



Graph 9 SG3 Aluminum Signature Behavior

Discussion

Three signatures SG1, SG2 and SG3 were compared in terms of frequency defining the roughness profile quality, each signature was machined with its own machining parameters and the same strategy tool paths.

In the results, the analyses of the signatures show that the aluminum material presents the lowest average roughness in SG1, SG2 and SG3 due to the physico-mechanical properties of the material. It was determined that aluminum presented better machinability with respect to Delrin and Nylacero. It was also determined that the roughness depends on the machining operation in each signature, resulting in a better finish in the horizontal line due to linear interpolation than in the circular signature because the machine interpolates in two axes, and this causes a little more surface chip breakage.

Milling forces were also found to be the main factors governing dimensional accuracy, profile quality, machine vibration, spindle power requirements, power consumption and cutter life. These forces that occurred during machining were determined to produce bending, breakage or other distortions of the machined part due to the tool cutting forces acting on the part (Soori & Asmael, 2022).

With this experimental project, it is determined that in general, these distortions are generated by several factors such as depth of cut, spindle speed, feed rate, vibration and type of operation. The microscopic morphology of the free machining contour cannot be measured accurately, but an approximation would be obtained using the frequency spectrum.

Conclusions

It is determined that proper selection of the cutter path strategy is crucial to achieve the desired roughness of the machined profile in combination with the proper cutting parameters for each material. Therefore, the roughness profile measurements determine the effects of the milling profile signatures on the three materials.

In conclusion, the project addresses a crucial challenge in the characterization and understanding of rough surfaces in various industrial and scientific fields. The surface roughness of mechanical parts and materials can have a significant impact on their performance, durability and efficiency, which makes the ability to analyze and quantify this characteristic of great importance.

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Mechanism validation after stress concentration analysis mathematical calculated with safety factor requirements using dedicated software with friction factor mate

Validación de mecanismo después del cálculo matemático análisis de concentración de esfuerzos con requerimientos de factor de seguridad utilizando software dedicado por factor de fricción

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Abstract

It is feasible to use Computer Aided Design (CAD) and Finite Element Analysis (FEA) numerical simulation to validate the mathematical results obtained. Testing mechanisms in real world situations, prior to manufacturing, results in optimal designs and more reliable products. Simulation software tools evaluate the behavior of a system, improve the quality of data interpretation, and even increase product innovation. The present work shows the calculation of a simple mechanical system in two dimensions, involving the mechanical properties of the materials used, obtaining the maximum allowable load due to a required safety factor. The behavior of a mechanical element while in a stress concentration is shown along with the results obtained mathematically and with the dedicated software. Once the validity of the theoretical behavior (simulation) is known, the original design will be submitted showing the assembly with non-coincident meshing, the results obtained by the friction factor, the ISO clipping showing the volumes involved in a real situation, and the acquirement of the safety factor. The designer is shown a reliable method for decision making in the development of new equipment, modifications or even changes in the geometries and materials involved.

Analysis, Calculation, Motion study, Interpretation

Resumen

Es factible el uso del diseño asistido por computadora CAD y la simulación numérica FEA para la validación de los resultados matemáticos obtenidos. Probar mecanismos en situaciones del mundo real, antes de la fabricación, da como resultados óptimos diseños y productos más fiables aun con el costo que implican los prototipos. El presente trabajo muestra el cálculo de un sistema mecánico simple en dos dimensiones, se involucran las propiedades mecánicas de los materiales utilizados, la obtención de la carga máxima admisible debido a un factor de seguridad requerido. Se muestra el comportamiento de un elemento mecánico en su concentración de esfuerzos los resultados obtenidos matemáticamente y con software dedicado. Al conocer la validación del comportamiento teórico (simulación), se someterá el diseño original mostrando el conjunto con mallado no coincidente, los resultados obtenidos por sujeción con factor de fricción, los recortes de trazo ISO mostrando los volúmenes involucrados de la situación real y la obtención del factor de seguridad. Se muestra al diseñador un método fiable para la toma de decisiones en el desarrollo de nuevos equipos, modificaciones incluso cambios en las geometrías y materiales involucrados.

Análisis, Calculo, Estudio de Movimiento, Interpretación

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Introduction

A great number of mechanisms and mechanical systems that have practical utility in the engineering field can be analyzed considering uniplanar motion. For the resolution of related problems even in the industrial field, it is necessary to have the mastery of vector algebra and skill in handling the basic concepts of particle kinematics, as well as the fundamental principles of rigid body motion where the dimension between the kinematic pairs of the mechanism under study is kept constant (Alcedo, 2018).

In a machine the synchronization of its mechanisms is critical, with the study of motion, the velocity analysis of the trajectories of interest involves defining how fast certain points travel over the links of a mechanism as a function of time, it is necessary to know all the velocities in the mechanism or machine, both for the calculation of stored kinetic energy and to determine the accelerations of the links required for the calculation of the dynamic forces that turn out to be of importance in the productive system (Orozco, 2022).

There are many approaches for the kinematic analysis of machines and mechanisms, there are graphical, algebraic, vector and matrix methods (MESA P. & DURANGO I., 2005). The graphical technique for the kinematic analysis presented in the analysis of the mechanism shown here is focused on this particular mechanism.

In the case of complex mechanisms it is desirable a general method that allows to solve the kinematic analysis in a clear and simple way (MESA P. & DURANGO I., 2005). SolidWorks Simulation is a tool available for motion study users, it provides a complete set of structural analysis capabilities to guide design decisions and improve product performance and quality, it also offers cloud-enabled solutions (Dassault Systemes SolidWorks Corporation, 2022).

An overview on the concept of optimization in the engineering field is frequently employed for a given task to enable an accurate and reliable decision on changes or adjustments made to a mechanical system, which in turn allows not losing sight of the importance of the system's power consumption.

It could also be optimized according to other parameters such as maximum deformation, maximum range, etc., in which case the dimensions of the mechanism should be optimized by modifying the thickness, length of the links, construction material or a combination of all of them. Therefore, optimization is always done with respect to one or more geometrical variables.

Methodology

Proposed solution to a mechanical system:

The following mathematical solution situation is presented for the mechanical system shown in Figure 1. Taking into account that each of the links AB and CD are connected to a support and to the ECB element by means of steel pins of 25.4 mm diameter acting in single shear. It is known that the ultimate shear stress for the steel used in the pins is 324 MPa, taking into account that the shear stress is created by the tangential stresses with respect to the part directrix. The ultimate normal stress for the steel used in the links is 579 MPa, the equivalent of a carbon steel casting. The allowable load P is determined considering a safety factor 3.

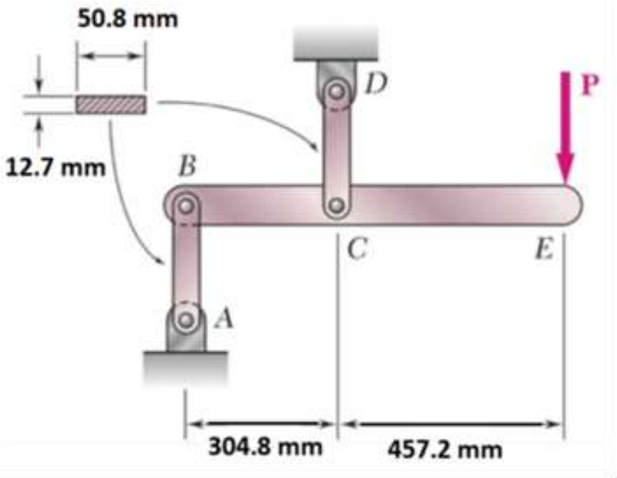


Figure 1 Schematic of the mechanical system to be solved
Source: Own Elaboration based on (BEER, 2010)

Considering that each of the links AB and CD are connected to a support and to the ECB element by means of steel pins of 25.4 mm diameter acting in single shear, we have that:

Data

The dowel diameter (d) = 25.4 mm
Ultimate shear stress for dowels (Tu) = 324 MPa
The ultimate normal stress for the links (σu) = 579 Mpa

Link width (b) = 51 mm FACT
Link height (h) = 12.7 mm FACT

The components of the tangential stresses, normal to the edge in intersection planes, of two orthogonal planes are equal in absolute value, and their directions are such that both are directed towards the edge, we can deduce the property: "The shear stress at a point on the contour is tangent to it" (Gutierrez, 2022). The ultimate shear stress (Tu) for the pins is related to the area and the ultimate load, we say that:

$$\tau_u = \frac{P_u}{A} \tag{1}$$

Where:

τ_u *is the ultimate shear stress in the pastr* (Pa)

P_u *is the ultimate load for the pin* (N)

A *is the cross section of the pin* (m^2)

We know that the area of the pin $A = 5.067\ x\ 10^{-4}\ m^2$

Therefore, from equation (1) we obtain that $P_u = 164{,}584\ N$ Considered as the ultimate load for the pin.

In the literature of mechanics of materials and structural design, the ultimate normal stress is mainly based on deformation theory and experimental tests of structural elements, although some probabilistic methodologies assume the existence of the normal stress without specifying its mode of determination (Molina, 2019). The ultimate normal stress (σ_u) for the links is also related to the area remaining from the bolt support (considered the smallest in tension) and the ultimate load, we have that:

$$\sigma_u = \frac{P_u}{A} \tag{2}$$

Where:

σ_u *is the ultimate normal stress in the link*

P_u *is the ultimate load for the link* (N)

A *is the critical trans. sec. of the link* (m^2)

We know that the critical area of the link:

$$A_c = bh - dh \tag{3}$$

And from equation 3 we obtain:

$$A_c = 3.226\ x\ 10^{-4}\ m^2$$

So from equation (2) $P_u = 186{,}825\ N$ considered as the ultimate load for the link.

From here the ultimate load for the pin can be considered as the load that will drive the design, since it is less than the ultimate load for the link.

Figure 2 shows the free body diagram for the analysis of the applied load on each element with respect to the ultimate load considered.

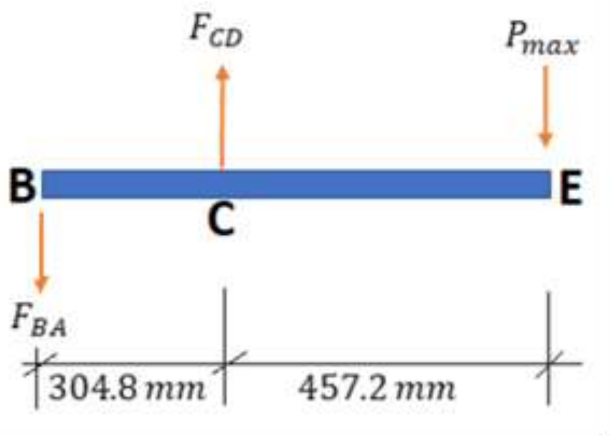


Figure 2. Free body diagram of the mechanical system.
Source: Own Elaboration

The sum of moments of the free body diagram of the member BE is considered in order to find a relationship between F_{CD} and P_{max} and between F_{BA} and P_{max}

For the sum of moments with respect to point C we have that:

$$\sum M_C = 0 = F_{BA}(0.3048\ m) - P_{max}(0.4572\ m) = 0 \tag{4}$$

And from equation (4) we obtain that: $F_{BA} = 1.5\ P_{max}$

For the sum of moments with respect to point B we have that:

$$\sum M_B = 0 = F_{CD}(0.3048\ m) - P_{max}(0.762\ m) = 0 \tag{5}$$

And from equation (5) we obtain that: $F_{CD} = 2.5\ P_{max}$

Therefore, the CD busbar is considered as the critical busbar in the design according to F_{CD}. Taking into account the ultimate load for the pin we have that: The maximum allowable load for the design will be:

$$P_{adm} = \frac{164584N}{2.5} = 65{,}833\ N$$

And with the required Safety Factor:

$$FS = \frac{P_{max}}{P_{admp}} \tag{6}$$

Then the allowable load for the pin, with a Factor of Safety of 3:$P_{admp} = 21{,}944\ N$ Analogously, taking into account the ultimate load for the link we have that:

The maximum allowable design load shall be:

$$P_{adm} = \frac{186{,}825\ N}{2.5} = 74{,}730\ N$$

And with the required Safety Factor:

$$FS = \frac{P_{max}}{P_{adme}} \tag{7}$$

Then the allowable load for the link with a Factor of Safety of 3:

$$P_{adme} = 24{,}910\ N$$

Validation and analysis with dedicated software

To analyze complex geometries, computational calculation methods have been developed. For the calculation of solid assemblies, the Finite Element Method (FEM). Founded on the transformation of continuous systems into discrete systems, i.e. the division of the real structure into small substructures (elements) of finite character, which are joined by means of nodes (Mulas, 2019). In machine components the stress concentration is important, elements exposed to the action of one or more forces in its operation, should be considered for its good performance the behavior of the stress concentration factor k which is the ratio of the maximum stress and the average stress calculated in the reduced section of the geometric discontinuity known as critical (Acosta, 2014).

Figure 3 shows the mathematical analysis of the maximum stress obtained in a rectangular steel plate with centered hole AISI 1020 subjected to axial tension load.

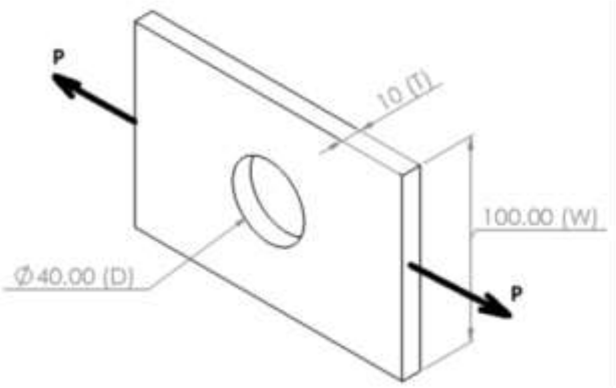


Figure 3 Centered-hole steel plate subjected to 110,000 N axial load
Source: Own Elaboration

A measure of the degree of stress concentration is given by the so-called geometric stress concentration factor k , which is defined as the ratio between the maximum local stress ("stress peak") and the corresponding nominal stress (Peru, 2022):

$$k = \frac{\sigma_{max}}{\sigma_{nom}} \tag{8}$$

Geometric nominal stress σ_{nom} towing to two stress effects: the increase due to the decrease in cross-section and the increase due to geometry (Peru, 2022):

$$\sigma_{nom} = \frac{P}{(W-D)T} \tag{9}$$

The stress concentration factor depends mainly on the geometry, not on the material except when the material deforms under load. Values of k are usually obtained from graphs and formulas and are strictly valid for ideally elastic stiff members, for brittle and high strength materials they are usually sensitive to even minor scratches hence for $0 \leq \frac{D}{W} \leq 1$:

$$k = 3 - 3.14\left(\frac{D}{W}\right) + 3.667\left(\frac{D}{W}\right)^2 - 1.527\left(\frac{D}{W}\right)^3 \tag{10}$$

From equation (8) and with the geometrical data of figure 3 we have that:

$$\sigma_{nom} = 183.33\ MPa$$

From equation (10) and with the geometrical data of figure 3 we have that $k = 2.23568$

Finally, from equation (11) the maximum stress in the plate:

$$\sigma_{max} = 409.87\ Mpa$$

SolidWorks Simulation comprises a set of structural analysis solutions, which aim to predict the actual physical behavior of a product. Using Finite Element Analysis (FEA), this group of tools makes all the work very easy, using virtual testing of CAD models (Systèmes, 2022). Meshing is a crucial step in design analysis. The automatic mesher in the software generates a mesh based on a global element size, a tolerance and local mesh control specifications. Mesh control allows you to specify different element sizes of components, faces, edges and vertices (Systèmes, 2022). The FEA analysis of the calculated plate is shown below. Figure 4 shows the initial static analysis including restraint, applied load.

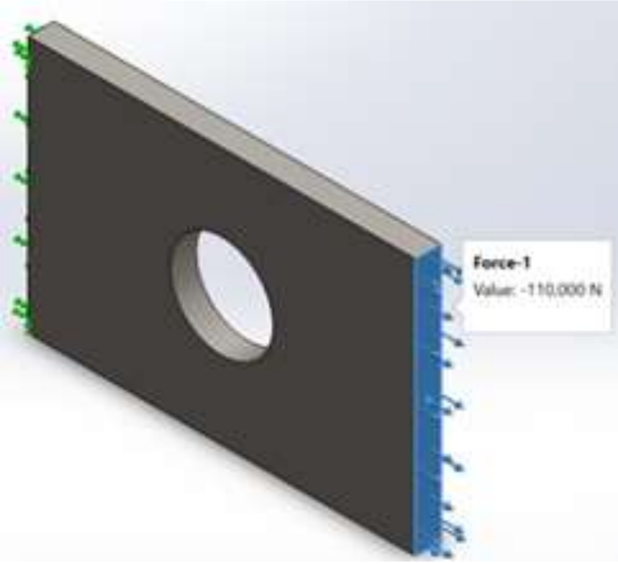


Figure 4 AISI 1020 steel plate with ultimate tensile stress of 420 MPa subjected to axial load of 110,000 N
Source: Own Elaboration

Figures 5, 6 and 7 show the fine, normal and coarse meshes showing the maximum stress value obtained from the FEA simulation study.

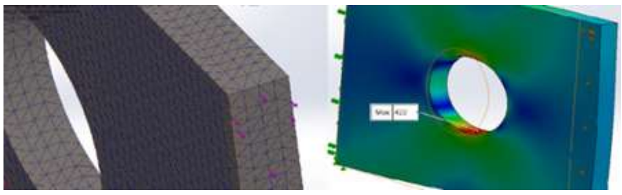


Figure 5 Maximum stress value (422 MPa) with simulation using fine meshing
Source: Own Elaboration from simulation

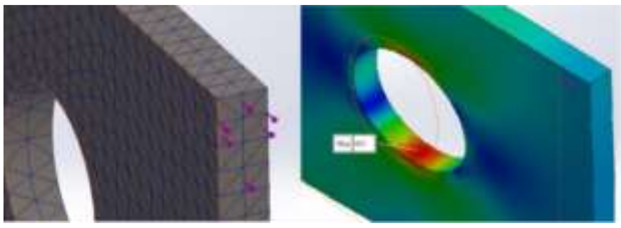


Figure 6 Maximum stress value (423 MPa) with simulation using normal meshing
Source: Own Elaboration from simulation

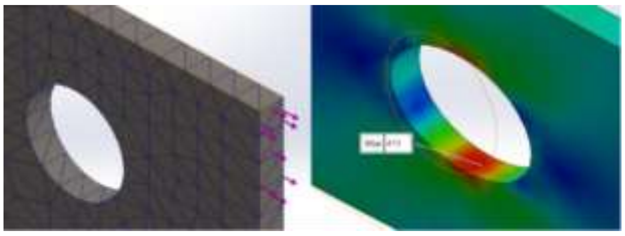


Figure 7 Maximum stress value (410 MPa) with simulation using coarse meshing
Source: Own Elaboration from simulation

The Von Mises maximum stress criterion is based on the Von Mises-Hencky theory, also known as the shear energy theory or the maximum distortion energy theory, provides a good idea in the design in determining that the element in question for its final use will or will not be strong enough. A SOLIDWORKS Simulation study allows us to understand the behavior of forces that will be applied in real life prior to production. Performing a proper finite element analysis of a system can drastically reduce prototyping time and provide design validation or justification for changes and adjustments. The most common indication of this is a Von Mises stress value (Systèmes, 2022). Table 1 shows the comparison of the results obtained by the dedicated software from the mathematical one obtained with mesh density.

Mesh density	Maximum Stress Von Mises (MPa)	Maximum Stress per Concentration Factor (MPa	Fluctuation percentage (%)
Fine	422	409.87	2.87
Normal	423	409.87	3.10
Coarse	410	409.87	0.03

Table 1 Comparison of values obtained in the simulation
Source: From values obtained

The criteria that can be obtained from the results presented in Table 1 will depend largely on the designer's needs. The Finite Element Method (FEM) predicts the behavior of the model by combining the information obtained from all the elements that make up the model. Meshing is a crucial step in the design analysis.

The automatic mesher in the software generates a mesh based on a global element size, a tolerance and local mesh control specifications. Mesh control allows you to specify different element sizes of components, faces, edges and vertices. In the early stages of design analysis where approximate results may be sufficient, however, the designer can specify a larger element size (coarse meshing) for a faster solution, if the need is for a more accurate solution, a smaller element size will be necessary.

For the mechanism proposed in the original study (see Figure 1), Figure 8 shows the model in question of only the parts in contact, bar and pin in single shear with the materials assigned with respect to the proposed ultimate stress value.

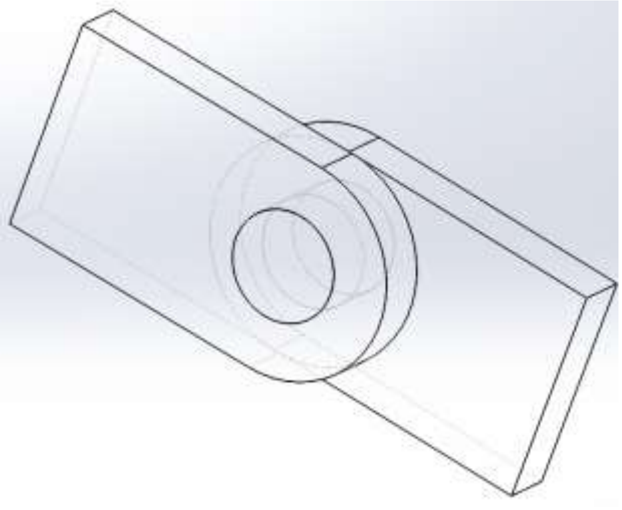
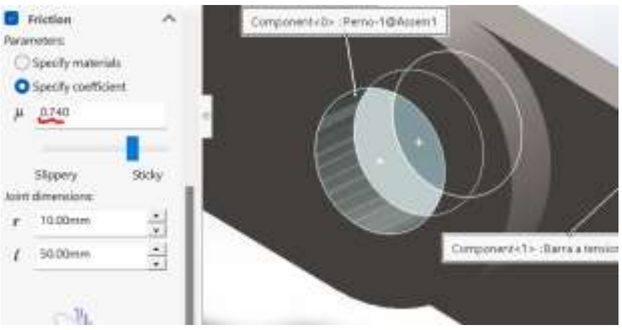


Figure 8 Assembly of the contacting parts of the elements subjected to load in the mechanism
Source: Own Elaboration based on the original model

Assembly by coefficient of friction

It is clear that in the assembly shown in Figure 8 the element is simply supported on the bolt surface and allows its mobility. Performing a geometric assembly does not allow to visualize the real behavior when the elements are in tension and shear. SolidWorks allows to include global friction. The software calculates the static friction forces by multiplying the normal forces generated at the contact locations by the specified friction coefficient. The coefficient of friction should be between 0 and 1.0 (Serway, 2008). A coefficient of friction Steel on iron of 0.74 is taken (Serway, 2008). Figure 9 shows the assignment of the coefficient of friction to the assembly.



☑ Friction
Parameters:
○ Specify materials
● Specify coefficient
μ 0.740
Slippery Sticky
Joint dimensions:
r 10.00mm
ℓ 50.00mm

Figure 9 Assembly conditions by friction coefficient
Source: Own Elaboration from the original model

Incompatible meshing

In an incompatible mesh, the entities in contact of the assembly are meshed in such a way that there is no node to node correspondence between the meshes of each entity. Nodes that correspond piece by piece cannot be merged (for a rigid joint contact) or overlapped. The results obtained with an incompatible mesh more closely resemble reality where each of the elements behaves independently in the study according to its own function. Fig. 10: shows the incompatible mesh for the study of the assembly.

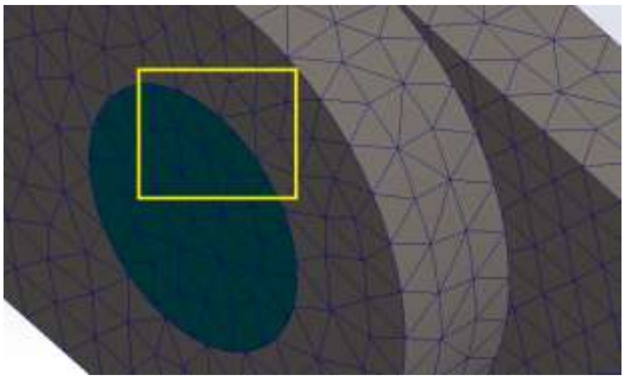


Figure 10 shows the incompatible meshing that is performed for the study of the set
Source: Own Elaboration from the original model

Testing, validation and safety factor

When loads are applied to a solid, the solid deforms and the effect of the loads is transmitted through the solid. External loads induce internal forces and reactions to render the solid to an equilibrium state. Linear static analysis calculates displacements, unit deformations, stresses and reaction forces under the effect of applied loads (Serway, 2008). Figure 11 then shows the assembly in tension situation applying the maximum allowable load for the design on the single shear pin.

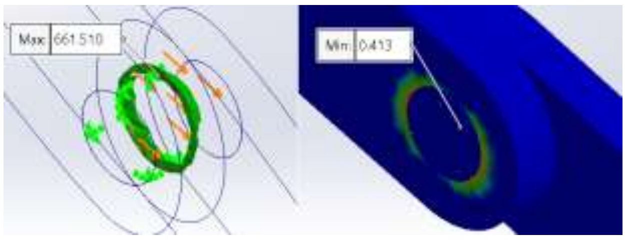


Figure 11 Element loaded to 164584 N. It shows a maximum load of 661 MPa and a Factor of Safety of 0.41
Source: Own Elaboration based on the simulation.

Since the safety factor (equation (6)) is the ratio of the maximum stress to the allowable stress, a safety factor less than 1 indicates that the element will fail.

Figure 12 shows the assembly in tension situation applying the maximum allowable load for the critical bar link CD of 65,677N, (equation (5)).

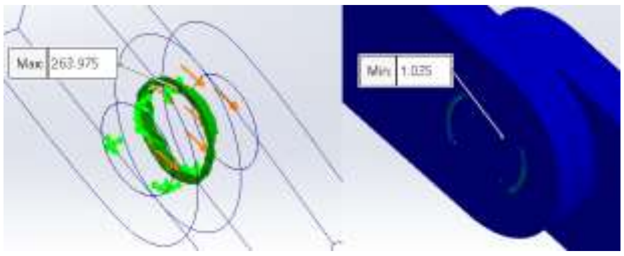


Figure 12 Element loaded at 65,677 N. It yields a maximum load of 263 MPa and a Factor of Safety of 1.03.
Source: Own Elaboration from simulation.

Figure 13 shows the assembly in tension situation applying the maximum admissible load for the pin of 21,894 N, due to the Safety Factor considered.

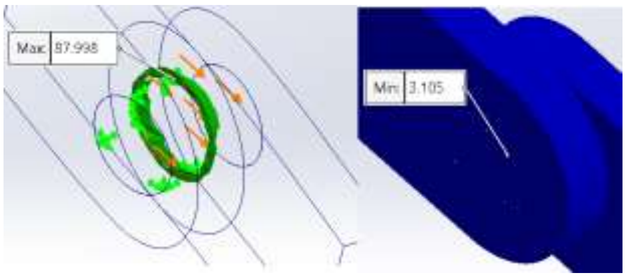


Figure 13 Element loaded to 21,894 N. It shows a maximum load of 88 MPa and a Factor of Safety of 3.1:
Source: Own Elaboration from simulation

Figure 14 shows the ISO cutout that allows to visualize by volume percentage the support with respect to the applied load of the link on the shear bolt.

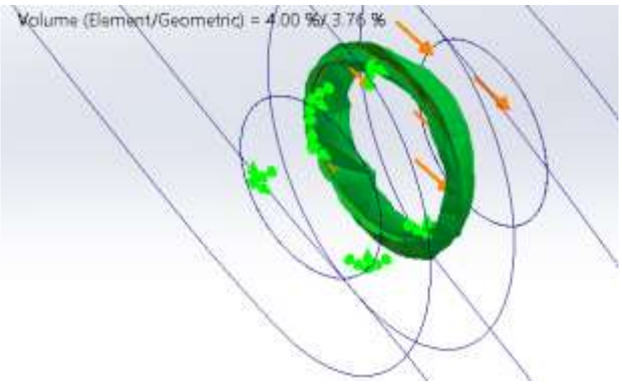


Figure 14 ISO trace cutout of the test element
Source: Own Elaboration from the simulation

Figure 15 shows the ISO trace cutout that allows visualizing by volume percentage the support with respect to the applied load of the bolt on the link.

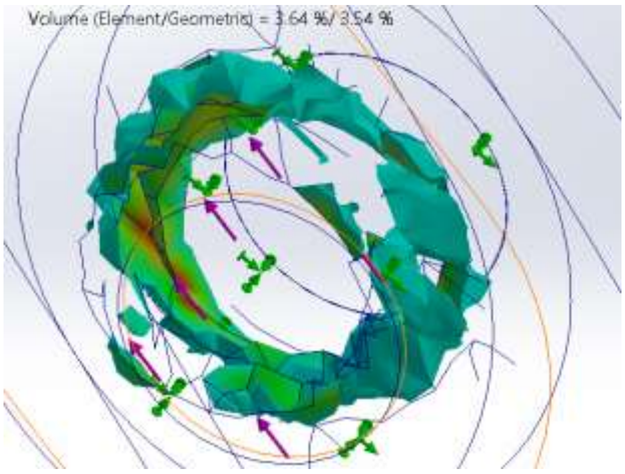


Figure 15 ISO trace cutout of the test element
Source: Own Elaboration from simulation

Results

It is interesting to be able to verify that, from the mathematically obtained calculations for the mechanical behavior of a mechanism with respect to the strength of the materials and the behavior of the solid mechanics, we have within reach dedicated software packages, which allow us to corroborate in a simple way the obtained results.

This gives the reliability in making decisions for modeled designs that result in higher complexity. With the help of SolidWorks software, the safety factor mentioned in the original mechanism is obtained. The analysis of the steel plate with centered hole is taken into account in order to generate the cofinance and reliability of the obtained graphic results.

Conclusions

It is important to consider that there is more than one simulation package for finite element, the one to be used will depend on the experience and certification level of the designer. Although the safety factor may vary with respect to the simulation load, it is important to consider that fine meshing offers results with more significant figures, but will require more computer resources. In addition, we should take into account that the proportionality limit is wider in ductile materials than in harder materials, so the value of the maximum stress should be considered for the determination of the allowable stress for the type and mechanical properties of each material or materials involved in the simulation.

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Article **Journal Computational Simulation**
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Eleven level multi-level inverter simulation platform

Software para simulación de inversores multinivel de 11 niveles

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Abstract

Finding the optimal firing angles that minimize the amount of harmonics in a multilevel inverter is an optimization problem. However, since these values are available, testing them in an inverter is not something that can always be done since there is not always a physical inverter to carry out the tests. This paper proposes the development of a Simulink script that allows, from the input angles, to determine the typical ladder output waveform, as well as the harmonic content of an 11-level triphasic multilevel inverter. This will be done by designing the inverter by implementing Simulink IGBTS modules in a configuration of 5 H-bridges in series per phase. Furthermore, Fourier analysis of these waves is carried out in order to characterize the harmonic content of the generated signals.

Multilevel Inverter, Simulation, Harmonics

Resumen

Encontrar los ángulos de disparo óptimos que minimicen la cantidad de armónicos en un inversor multinivel es un problema de optimización. Sin embargo, ya que se tienen estos valores, el probarlos en un inversor no es algo que siempre se pueda realizar ya que no en todo momento se tiene un inversor físico para efectuar las pruebas. En este trabajo se propone el desarrollo de un script de Simulink que permita a partir de los ángulos de entrada, determinar la forma de onda típica de salida en escalera, así como el contenido armónico de un inversor multinivel trifásico de 11 niveles. Esto se realizará mediante el diseño del inversor mediante la implementación de módulos IGBTS de Simulink en configuración de 5 puentes H en serie por fase. Además, análisis de Fourier de estas ondas se lleva a cabo para, caracterizar el contenido armónico de las señales generadas.

Inversor Multinivel, Simulación, Armónicos

Citation: PEÑA-DELGADO Adrián Fermín, JOERS-DELGADO, Carlos, GONZALEZ-MORALES, Amparo, ROMÁN-RIVERA Anette Michel. Eleven level multi-level inverter simulation platform. Journal Computational Simulation. 2023. 7-17:18-23

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Introduction

Multilevel inverters "MLI" are circuits capable of synthesizing an alternating voltage with low harmonic content from one or more direct current sources. They are mostly used in medium and high power industrial applications (Athimoolam & Balasubramanian, 2023).

Generally speaking, MLIs can be classified into two groups according to their power sources. The first one makes use of constant current power supplies "CSMLI" and the second one uses constant voltage power supplies "VSMLI", it should be emphasized that the latter is the most popular within the industrial sector (El-Hosainy et al., 2017). We will base the analysis for the development of the software for the simulation of an 11-level multilevel inverter on the latter. The most prominent feature that has positioned the multilevel inverter as the most attractive option in the industrial sector is its ability to achieve high voltage levels by employing low-cost power semiconductor devices (Shehu et al., 2016) (Atar et al., 2023). Among the most widely used VSMLI topologies are those based on cascaded H-bridge circuits (Colak et al., 2011).

Even though the MLI is capable of providing a voltage with low harmonic content, without the proper selection of a modulation technique, the proper use of modulation techniques guarantees an AC voltage with particular characteristics in THD, VRMS, just to mention a few (Reddy & Narayana, 2020).Figure 1 shows the three-phase cascaded multilevel inverter of "n" levels, where, the number of cells is given by S, VCD represents the supply voltage per cell, and A, B and C represent the phase voltages (Routray et al., 2018).

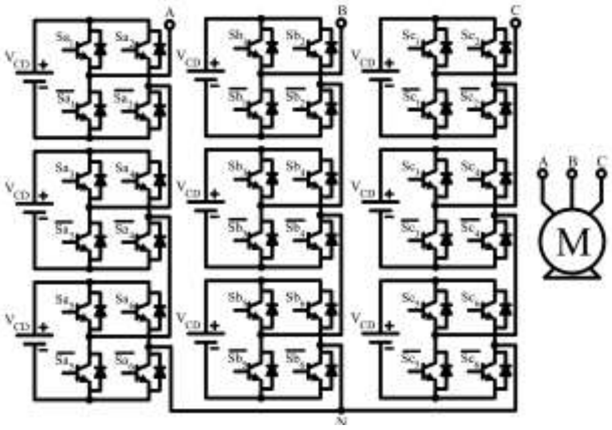

Figure 1 Typical diagram of a multilevel inverter consisting of H-bridges and their switching devices

The correct switching control of the MLI semiconductor devices lies in the use of modulation techniques for their operation (El-Hosainy et al., 2017). Figure 2 illustrates how the typical output shape of the multilevel inverter can be generated by switching the different dc power supplies at specific angles.

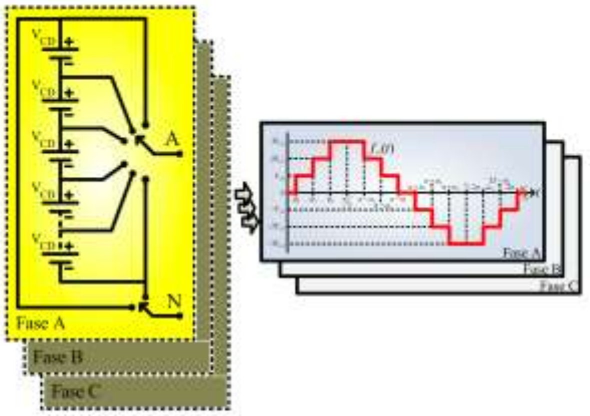

Figure 2 Generation of the staircase output waveform of a three-phase multilevel inverter

The solution of the mathematical formulation of the modulation technique is not relevant in this paper. Here it is assumed that the correct angles needed to produce the inverter output waveform are already known, taken from the literature, or previously calculated.

The interest of this article lies in the fact that once the switching angles have been defined, we will proceed by means of a simulation to obtain the output waveform of the 11-level multilevel inverter.

Although in the literature there are studies to find better ways to obtain the firing angles of multilevel inverters, there is no specific article where they focus on the development of a simulation platform to make use of the angles, determine the waveforms of phase voltage, line, as well as the harmonic content of the output waves of a multilevel inverter, see Figure 3 (Dahidah et al., 2008; Etesami et al., 2018; Reddy & Narayana, 2020). In study we will focus on performing this simulation for 11-level three-phase multilevel inverters.

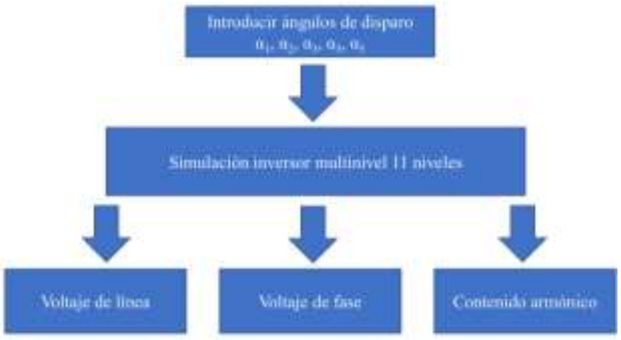

Figure 3 Experimental Methodology

Methodology to be developed

1. Establish the firing angles.
2. Implement 5 H-bridges per phase, using the IGBTS modules included in Simulink, see Figure 4.
3. Program the control logic that allows from the 5 input angles to establish the PWM signals for the switching on and off of the IGBTS per phase.
4. Establish the carrier and reference signals.
5. To record the line and phase voltages.
6. Determine the harmonic content of the phase voltage, as well as the total harmonic distortion.
7. Verify the simulator operation for 3 modulation indexes, 0.6, 0.8 and 1.

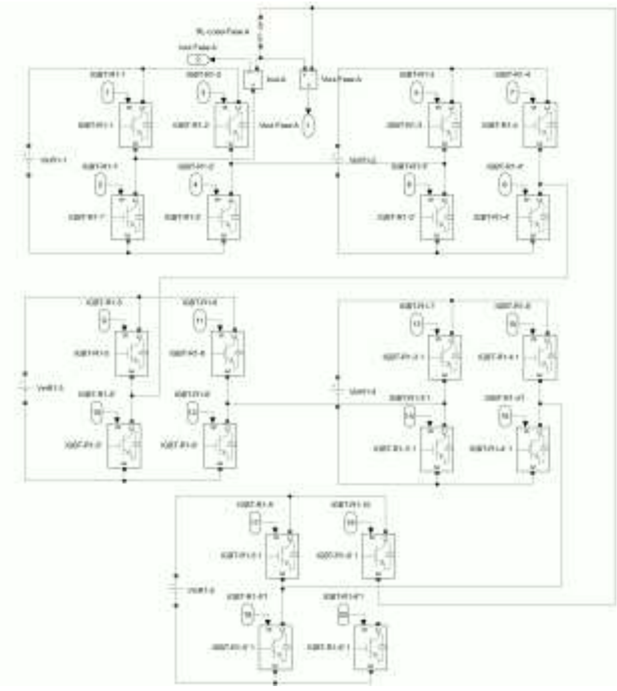

Figure 4 H-Bridges implemented with IGBTS in Simulink

Figure 4 shows the configuration of 5 H-bridges connected in series for one phase. It is important to note that the IGBTS gates have a unique label that differentiates them from the others. These are necessary to make use of them within the simulation. On the other hand, Figure 5 shows the complete simulation with the carrier signals and references for the 3 phases, as well as the PWM generators. Even though the H-bridges are not directly observed, they are found in the part where the IGBT gate labels are referenced, as previously described.

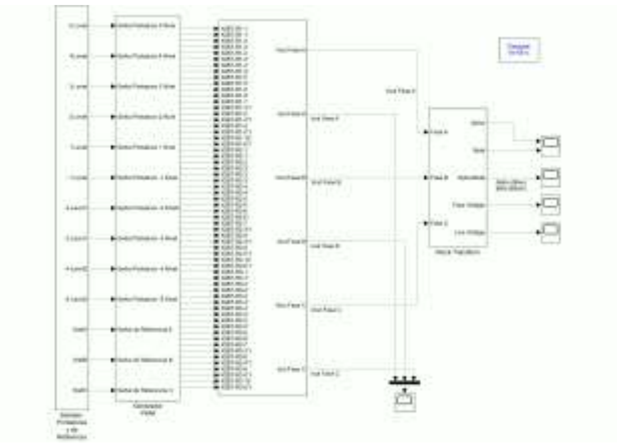

Figure 5 Simulation in Matlab Simulink

The firing angles implemented in this paper for 3 different modulation indices were calculated using a genetic algorithm "GA" following the methodology described in (Memon et al., 2018). It should be emphasized that for all calculations, in the proposed methodology, the fifth, seventh, eleventh and thirteenth harmonics were sought to be minimized. Table 1 refers to these angles, as well as their modulation index "mi". In addition to the Fourier analysis, the total harmonic distortion of the phase voltage is calculated.

m_i	α_1	α_2	α_3	α_4	α_5
0.6	35.34	46.95	58.58	72.67	87.84
0.8	22.34	39.28	52.69	59.32	70.97
1.0	7.86	19.37	29.65	47.68	63.21

Table 1 Angles used for the simulations with their respective modulation indices

Results

The results of the simulations of the line and phase voltage waveforms, in addition to the harmonic distortion of the phase waveform of an 11-level multilevel inverter can be observed in the following figures. Specifically, Figures 6, 7 and 8 show the three-phase output phase voltages.

|While figures 9, 10 and 11 include only the phase A voltage. Figures 12, 13 and 14 show the line voltages obtained in the simulation. On the other hand, the harmonic spectrum of a phase wave for modulation indices of 0.6, 0.8 and 1.0 are illustrated in figures 15, 16 and 17. In addition, these figures graphically illustrate the correct elimination of the fifth, seventh, eleventh and thirteenth harmonics, as previously established in the methodology section.

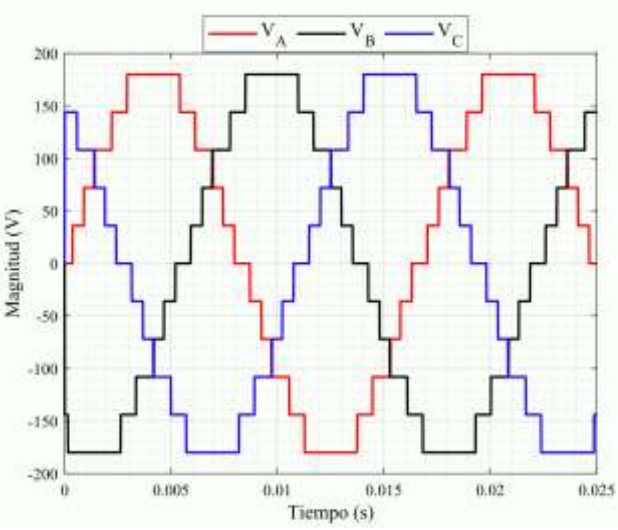

Figure 6 Three-phase phase voltages for a modulation index of 1.0

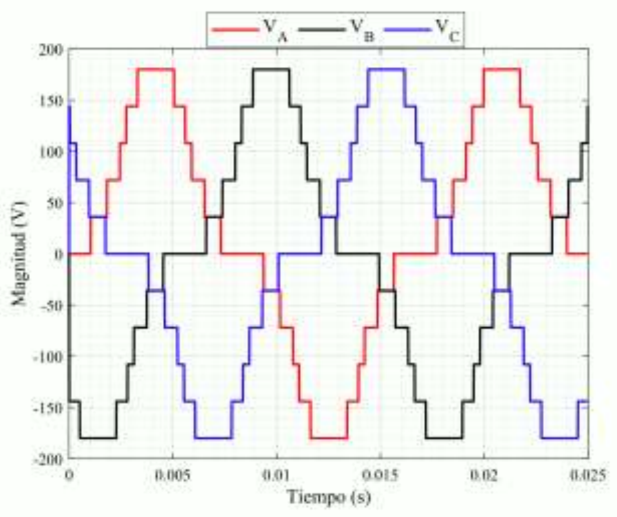

Figure 7 Three-phase phase voltages for a modulation index of 0.8

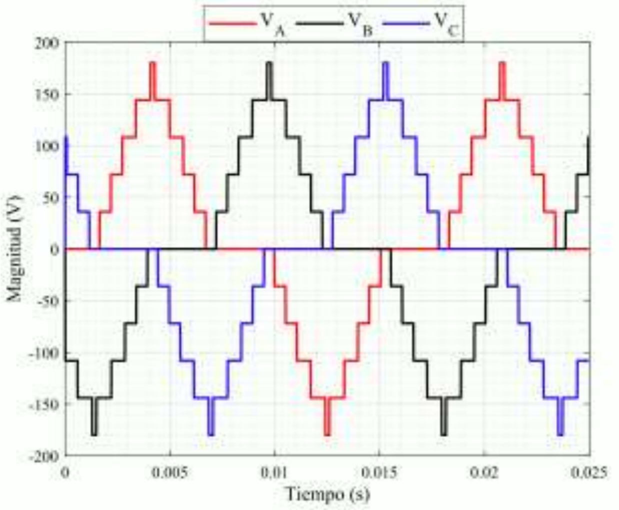

Figure 8 Three-phase phase voltages for a modulation index of 0.6

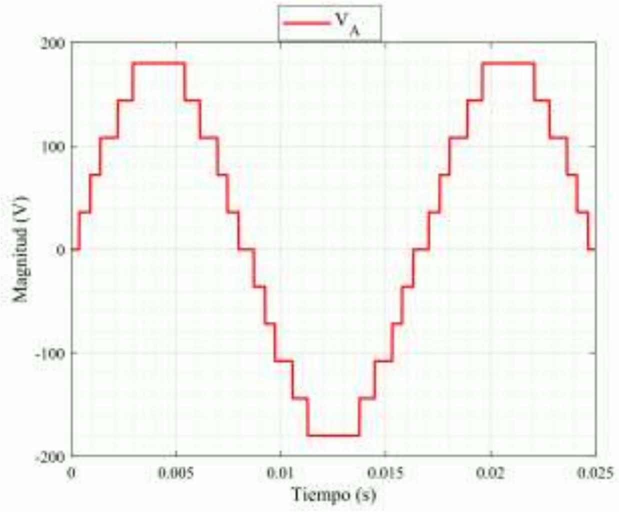

Figure 9 Phase voltage at a modulation index of 1.0

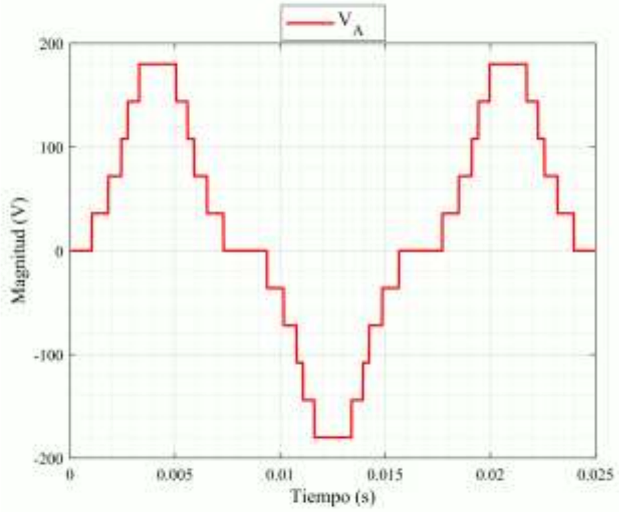

Figure 10 Phase voltage for a modulation index of 0.8

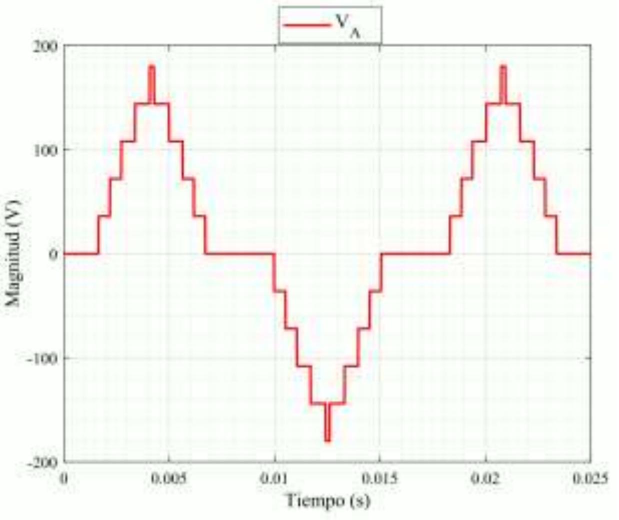

Figure 11 Phase voltage for modulation index 0.6

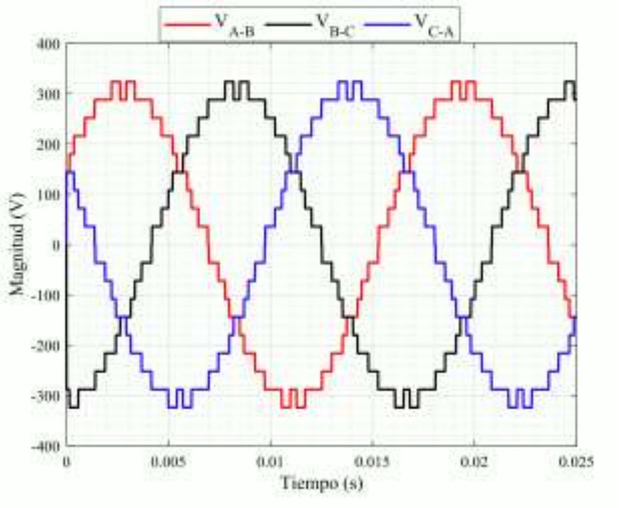

Figure 12 Line voltage for modulation index of 1.0.

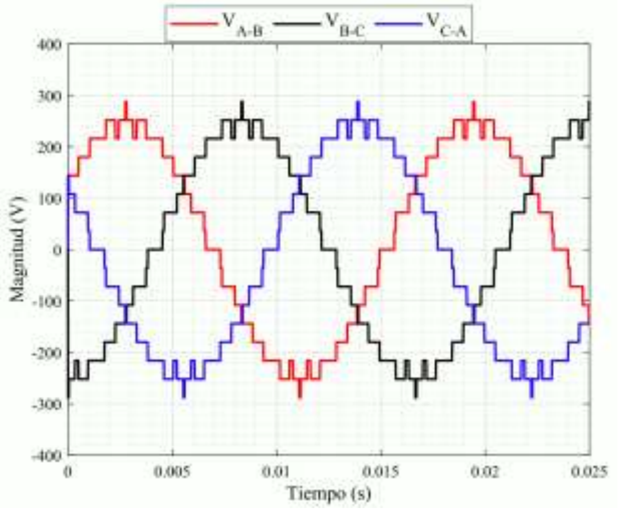

Figure 13 Line voltage for modulation index 0.8

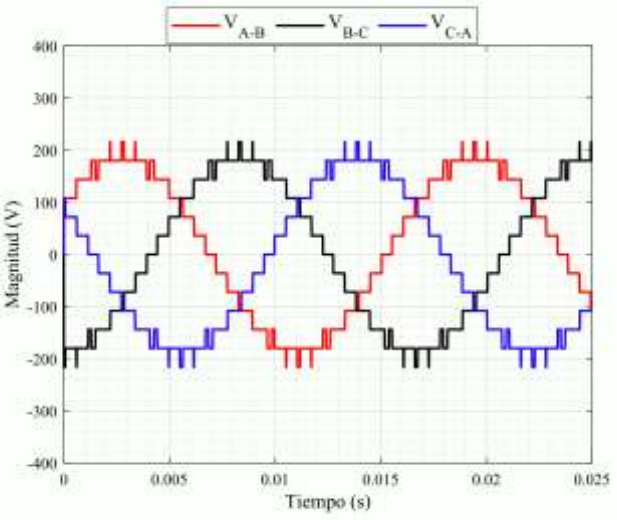

Figure 14 Line voltage at a modulation index of 0.6

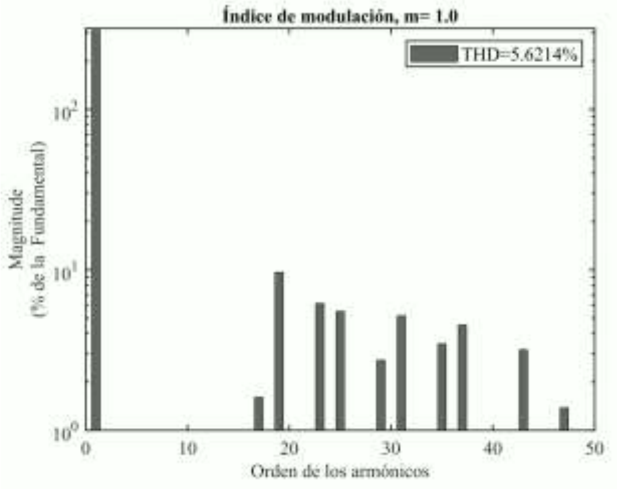

Figure 15 Harmonic content of the phase voltage for a modulation index of 1.0.

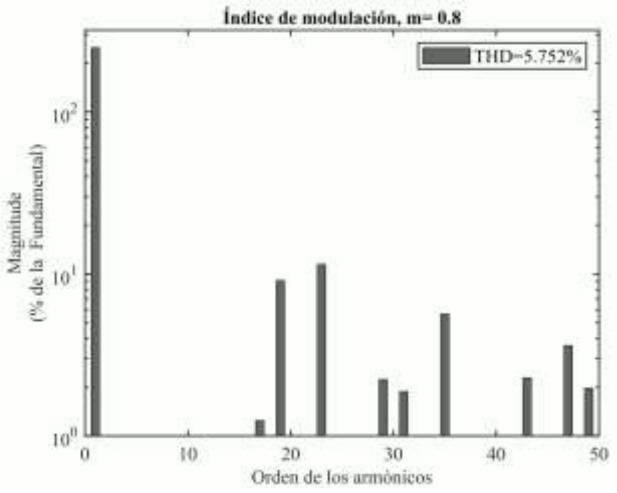

Figure 16 Harmonic content of the phase voltage for a modulation index of 0.8.

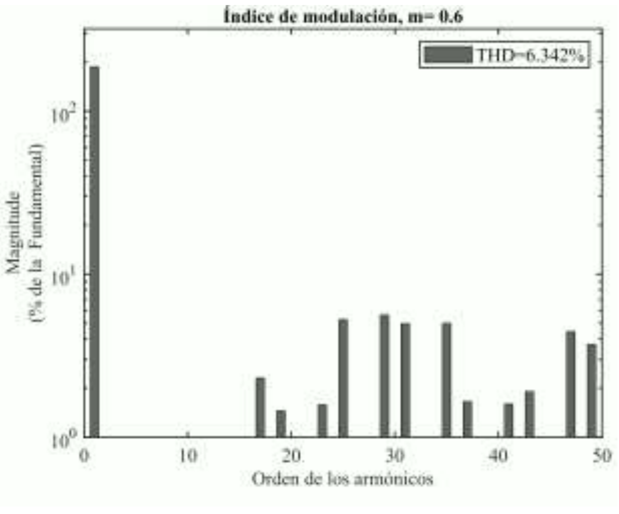

Figure 17 Harmonic content of the phase voltage for a modulation index of 0.6

Conclusions

In this paper, a simulation of an 11-level multilevel inverter is presented. This proved that in terms of the inverter output voltages the typical staircase signal is obtained for both line and phase voltages. Additionally the simulation platform proved to be sensitive to variations in the modulation index and how this manifests itself in the output voltages.

On the other hand, it was also considered from the voltage waves generated in the simulation, the calculation of the harmonic component of these, as well as its total harmonic distortion, obtaining satisfactory results by demonstrating graphically the elimination of the fifth, seventh, eleventh and thirteenth harmonics.

Financing

This research work has been financed by the Universidad Tecnológica de Altamira.

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June 2023, Vol.7 No.17 24-26

Meteorological parameters monitoring system using free hardware and software with data storage and display on Nextion screen

Sistema de monitoreo de parámetros meteorológicos utilizando hardware y software libre con almacenamiento de datos y visualización en pantalla Nextion

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Abstract

A portable station was designed and built to measure weather conditions using open-source hardware and software, aiming for versatility and low cost. Data acquisition and storage from climate variable measurements are carried out, allowing for interaction through a graphical interface built on an open-source software display. Additionally, there is access and control of the data using an Internet of Things platform that, like the HMI itself, enables real-time monitoring of variable measurements and storage of the monitored data. The designed station, being portable and having internet access, can serve as a support tool for monitoring weather conditions in a photovoltaic systems station, for example. This is highly useful because such conditions interfere with system performance, impacting the energy conversion process. This data collection and storage, for instance, allows for generating forecasts to determine the suitable energy generation type based on the installation location's conditions and foreseeing the potential impact of weather conditions.

Environmental conditions, Internet of the things, Photovoltaic energy

Resumen

Se diseñó y construyó una estación portátil para medir condiciones climáticas, utilizando hardware y software libre, para hacerla versátil y de bajo costo. Se realiza la adquisición y almacenamiento de los datos, provenientes de la medición de variables climáticas, con la versatilidad de permitir la interacción por medio de una interfaz gráfica construida en una pantalla de software libre. Adicionalmente se cuenta con un acceso y control de los datos utilizando una plataforma de Internet de las cosas que, tal como la misma HMI, permite el monitoreo de las mediciones de las variables en tiempo real, así como el almacenamiento de los datos monitoreados. La estación diseñada, al ser portátil y tener acceso a Internet, puede funcionar como herramienta de apoyo para el monitoreo de las condiciones climáticas, en una estación de sistemas fotovoltaicos, por ejemplo; esto es muy útil debido a que tales condiciones interfieren en el desempeño de los sistemas, impactando en el proceso de conversión de energía. Esta recolección y almacenamiento de datos, permite, por ejemplo, generar pronósticos para conocer qué tipo de generación de energía se adecua a las condiciones del lugar a instalar, así como prever el impacto que se pueden generar las condiciones climáticas.

Condiciones climáticas, Internet de las cosas, Energía fotovoltaica

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Introduction

In times of climate change, or the increase of the planet's temperature, it is important and relevant to monitor weather conditions, not only as a hobby, but as a matter of social responsibility. The increase in the amount of work done in the field of the Internet of Things is due to the availability of the tools to do so; however, this does not mean that it is simple, but it is viable and feasible because it allows or motivates the socialization of knowledge. The use of renewable or "clean" energies is therefore necessary to replace the use of fossil fuels, which employ processes that contribute to high greenhouse gas emissions, contributing to the increase in global temperature. Climatic conditions are important, both for selecting the type of renewable energy to use, as well as for monitoring the conditions, because they impact the performance of power generation.

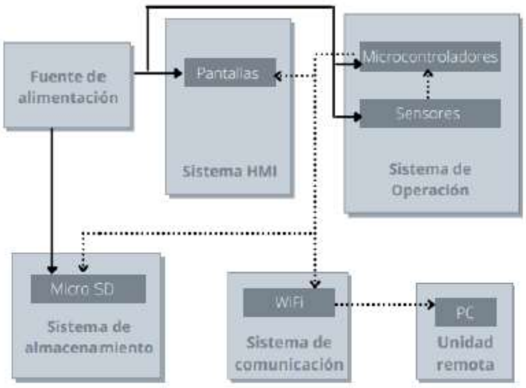


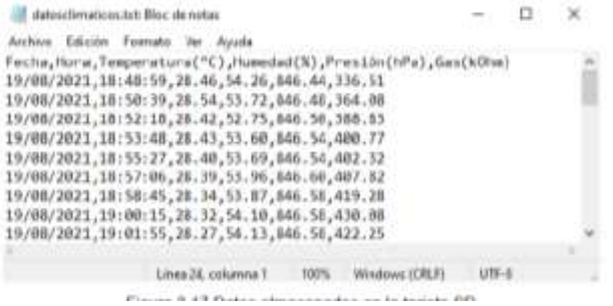
Figure 1 Proposed system architecture.

Temperatura:27.94 *C
Presion:856.71 hPa
Humedad:62.10 %
Gas:64.81 KOhms
Altitud aprox:1393.35 m

Figure 2 Parameters displayed on OLED screen

Figure 3 Parameters displayed on NEXTION screen.

Figure 4 Working whiteboard in ubidots



```
Fecha,Hora,Temperatura(°C),Humedad(%),Presión(hPa),Gas(kOhm)
19/08/2021,18:48:59,28.46,54.26,846.44,336.51
19/08/2021,18:50:39,28.54,53.72,846.48,364.08
19/08/2021,18:52:18,28.42,52.75,846.50,388.85
19/08/2021,18:53:48,28.43,53.60,846.54,400.77
19/08/2021,18:55:27,28.40,53.69,846.54,402.32
19/08/2021,18:57:06,28.39,53.96,846.60,407.82
19/08/2021,18:58:45,28.34,53.87,846.58,419.28
19/08/2021,19:00:15,28.32,54.10,846.58,430.08
19/08/2021,19:01:55,28.27,54.13,846.58,422.25
```

Figure 5 Data stored on micro SD

Se ha subido a la SD
Espacio Total: 7380 MB
Espacio Usado: 2 MB

Figure 6 Message on OLED display.

Results

The portable station was completely built, with connection to the Internet through the use of a low-cost electronic card called ESP32, Figure 5.

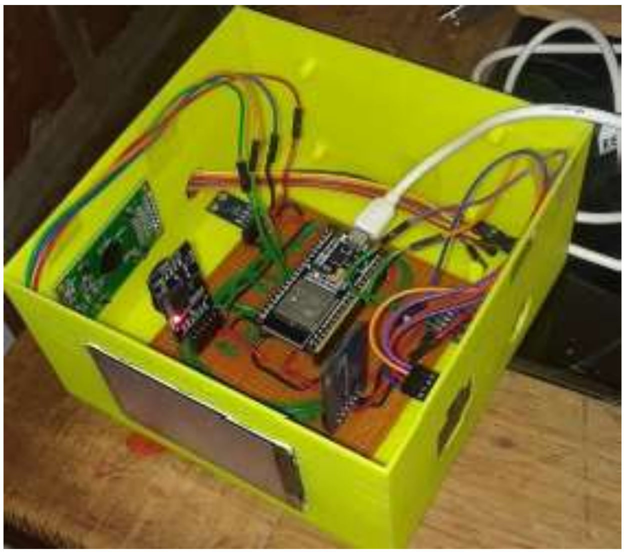


Figure 5 Low-cost portable station.

Acknowledgments

The authors are grateful for the great effort and work of the student Sebastián Flores Velazco, without whom the project would have taken longer to complete.

Conclusions

The performance of the weather data acquisition station was successfully tested.

It is feasible to build low-cost monitoring tools with open source hardware and software.

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(Report Submission Date: Month, Day, and Year); Accepted (Insert date of Acceptance: Use Only ECORFAN)

Abstract (In English, 150-200 words)

Objectives
Methodology
Contribution

Keywords (In English)

Indicate 3 keywords in Times New Roman and Bold No. 10

Abstract (In Spanish, 150-200 words)

Objectives
Methodology
Contribution

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* Correspondence to Author (example@example.org)
† Researcher contributing as first author.

Introduction

Text in Times New Roman No.12, single space.

General explanation of the subject and explain why it is important.

What is your added value with respect to other techniques?

Clearly focus each of its features

Clearly explain the problem to be solved and the central hypothesis.

Explanation of sections Article.

Development of headings and subheadings of the article with subsequent numbers

[Title No.12 in Times New Roman, single spaced and bold]

Products in development No.12 Times New Roman, single spaced.

Including graphs, figures and tables-Editable

In the article content any graphic, table and figure should be editable formats that can change size, type and number of letter, for the purposes of edition, these must be high quality, not pixelated and should be noticeable even reducing image scale.

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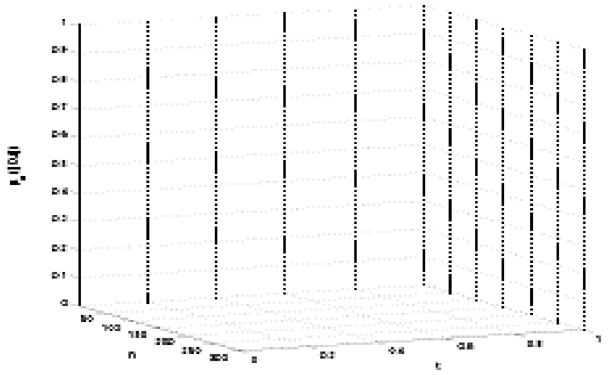

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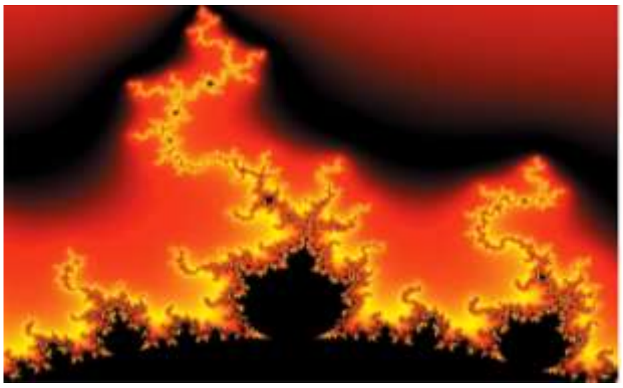

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Each article shall present separately in **3 folders**: a) Figures, b) Charts and c) Tables in .JPG format, indicating the number and sequential Bold Title.

For the use of equations, noted as follows:

$$Y_{ij} = \alpha + \sum_{h=1}^{r} \beta_h X_{hij} + u_j + e_{ij} \qquad (1)$$

Must be editable and number aligned on the right side.

Methodology

Develop give the meaning of the variables in linear writing and important is the comparison of the used criteria.

Results

The results shall be by section of the article.

Annexes

Tables and adequate sources

Thanks

Indicate if they were financed by any institution, University or company.

Conclusions

Explain clearly the results and possibilities of improvement.

References

Use APA system. Should not be numbered, nor with bullets, however if necessary numbering will be because reference or mention is made somewhere in the Article.

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Each article must submit your dates into a Word document (.docx):

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Article title
Abstract
Keywords
Article sections, for example:

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2. Description of the method
3. Analysis from the regression demand curve
4. Results
5. Thanks
6. Conclusions
7. References

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