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Journal of Technical Invention

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The works must be unpublished and refer to topics of Computers, Communications, Control, Design and systems, Electronic devices, Semiconductor devices, Computer electronics, Industrial electronics, Electronics and telecommunications, Electrochemistry, Optical fibers, Electrical and electronic industry, Computing, Control engineering, Materials engineering, Instrumentation, Inter frequencies, Microelectronics, Microwaves, Data processing, Digital networks, Robotics, Digital systems, Electronic systems and other topics related to Engineering and Technology.

Presentation of the content

In Issue 22 as the first article we present, *Platform lifting system for autonomous vertical parking* by Rodríguez-Cortes, Aldo, Fuentes-Castañeda, Pilar, Betanzos-Castillo, Francisco and Cortez-Solís, Reynaldo with adscription in the Tecnológico Nacional de México – TES Valle de Bravo, in the next article we present, *Development of a load cell to measure axial force* by Sánchez-Rodríguez, Alvaro, Aceves, Salvador M., Orozco-Mendoza, Horacio and Rodríguez-Castro, Ramón, with adscription in the Tecnológico Nacional de México/IT de Celaya, in the next article we present, *Autonomous prototype design with PLC for TEU Container Loading and Unloading Linked to AI Applications* by Vázquez-González, Humberto, Cruz-Gómez, Marco Antonio, Mejía-Pérez, José Alfredo and Castillo- Pensado, Juan Luis, with adscription in the Benemérita Universidad Autónoma de Puebla, in the last article we present, *Advanced Extrusion Machine for Transforming PET* by Tecnológico Nacional de México Campus Occidente del Estado de Hidalgo and Universidad Autónoma del Estado de Hidalgo.

Content

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Article

Platform lifting system for autonomous vertical parking

Sistema de elevación de plataforma para estacionamiento vertical autónomo

Rodríguez-Cortes, Aldo * [a], Fuentes-Castañeda, Pilar [b], Betanzos-Castillo, Francisco [c] and Cortez-Solís, Reynaldo [d]

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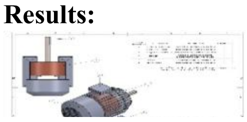
Abstract

Growing cities worldwide face challenges with parking space demand, which has driven the need for innovative solutions to optimize land use. This research focuses on the design, modeling, and structural analysis of an autonomous vertical parking system with an electromechanical lifting mechanism, developed using computer-aided engineering [CAE]. The proposed system integrates a cable-and-pulley traction mechanism powered by 65 kW electric motors, capable of handling loads of up to 11 tons. The components were modeled in SolidWorks®. Additionally, the system complies with ISO 13849 and NOM-004-STPS-1999 standards, demonstrating its technical feasibility as a sustainable solution for parking management in metropolitan areas with limited space. This technology could reduce spatial footprint by up to 70% compared to conventional horizontal parking systems.

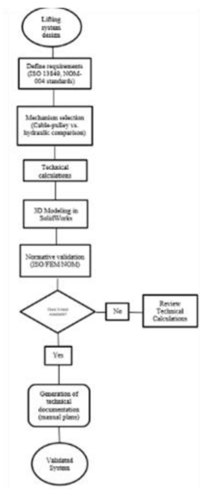
Objectives
Conceptual Design
Modeling
Structural Analysis
Sustainability
Sustainability

Results:



Contributions:
Development of an Electromechanical Lifting System Using CAE Analysis.

Method



CAE, Simulation, Vertical parking.

Resumen

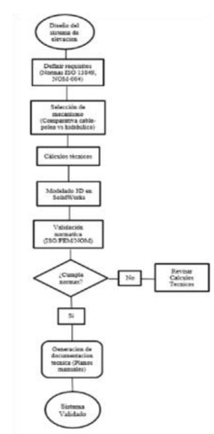
Las ciudades en crecimiento a nivel mundial se enfrentan a problemas de demanda de espacios de estacionamiento, esto ha impulsado la necesidad de soluciones innovadoras que optimicen el uso del suelo. La presente investigación trata sobre el diseño, modelado y análisis estructural de un sistema de elevación electromecánico para estacionamiento vertical autónomo, desarrollado mediante ingeniería asistida por computadora [CAE]. El sistema propuesto integra un mecanismo de tracción por cables y poleas accionado por motores eléctricos de 65 kW, con capacidad para manejar cargas de hasta 11 toneladas. Los componentes fueron modelados en SolidWorks®. Adicionalmente, el sistema cumple con las normas ISO 13849 y NOM-004-STPS-1999, demostrando su viabilidad técnica como solución sostenible para la gestión de estacionamientos en áreas metropolitanas con espacios limitados, esta tecnología podría reducir hasta en un 70% la huella espacial comparado con estacionamientos horizontales convencionales.

Objetivos
Diseño Conceptual
Modelación
Análisis estructural
Sostenibilidad
Sustentabilidad

Resultados:

Contribuciones:
Desarrollo de un sistema de elevación electromecánico mediante análisis CAE.

Método



CAE, Simulación, Estacionamiento vertical

Area: Promotion of frontier research and basic science in all fields of knowledge.

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Introduction

The rapid urban growth and the constant increase in the vehicle fleet have generated a space crisis in modern cities, particularly with regard to parking. According to recent studies [Rodríguez F, 2023], in high-density metropolitan areas up to 30% of traffic corresponds to vehicles looking for a place to park, which increases both congestion and pollutant emissions. This problem is particularly acute in developing countries, where urban planning has not kept pace with vehicular growth [Al-Kodmany, 2023].

Conventional horizontal parking systems have inherent limitations:

- They require large extensions of valuable land in urban areas [SolidParking, 2019].

- They generate a greater environmental impact due to soil sealing [ECORFAN, 2020].

- They offer low density [≤0.8 vehicles/m^2 built] compared to vertical systems [≥2.5 vehicles/m^2] [TraxPark, 2023].

As an alternative, automated vertical parking garages emerge as a technological solution. However, their critical component -the lifting system- faces particular technical challenges:

- Load capacity: It must handle weights exceeding 10 tons [SUV and commercial vehicles] [Pellicer, 2007].

- Speed: It requires fast movements [≥1.5 m/s] for adequate operational performance [Shigley, 2019].

- Safety: Need for redundant systems to prevent catastrophic failures. [ISO, 2016]

The Integrated Methodology for Safe Lifting System Design [MIDES] is considered [Adapted from: ISO 12100:2010 Safety of machinery] [ISO12100, 2010]

Box 1

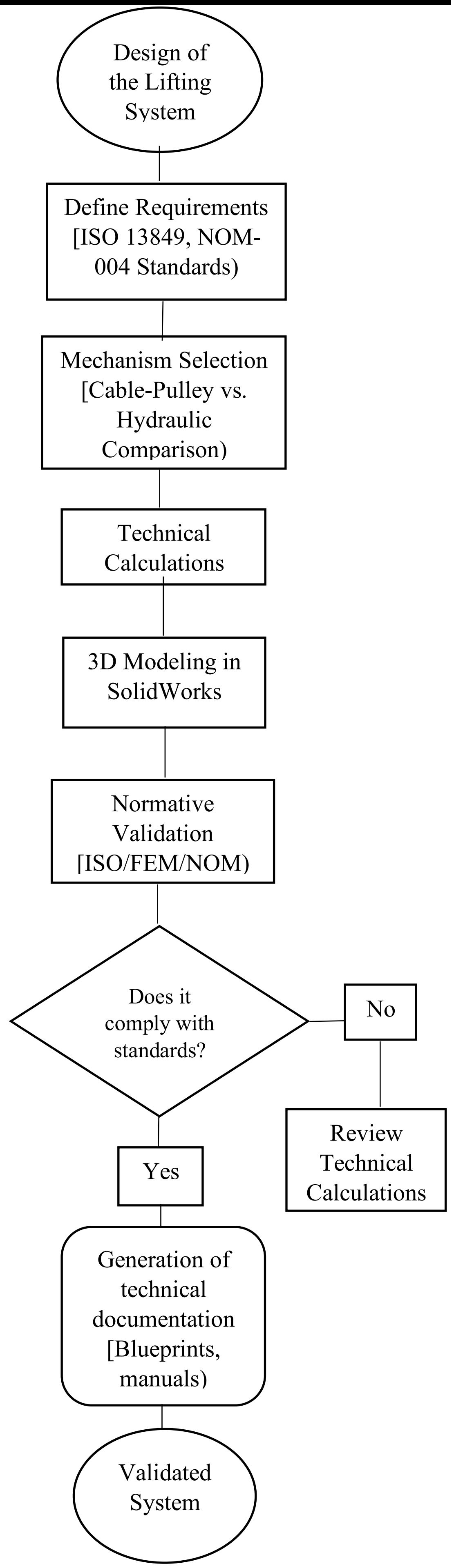

Figure 1
Flowchart of the methodology used.
Own elaboration.

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Research Gap:

While countries like Japan and Korea have specific regulations for these systems (Kawamura, 2011), a regulatory vacuum persists in Mexico, which this project helps address through the Adaptation of international standards [ISO 4309, FEM 1.001]

Among the main contributions are:

- Presentation of an integral mechatronic model for vertical parking garages, adapted to Mexican regulations.

- Calculation methodology for lifting systems with asymmetrical loads.

For this purpose, Section 2 of this work details the design methodology and structural calculations. Section 3 shows the 3D models and simulation results. Section 4 discusses technical implications and comparisons with existing systems. Finally, the conclusions highlight key findings and future directions.

Furthermore, regarding industrial relevance, the project aligns with the needs of real estate developers in dense urban areas, as well as municipalities with sustainable mobility policies.

Methodology

The engineering employed for the development of the electromechanical lifting system considered 4 stages of conceptualization and design: [1] Lifting Mechanism Selection; [2] Mechanical Design and Calculations; [3] CAD Modeling and Simulation; and [4] Normative Validation.

For [1], 5 systems were technically evaluated through comparative analysis, as shown in Table 1. The weighted design criteria considered for selection were: speed 30%, capacity 25%, maintenance 20%, cost 15%, safety 10%. The cable-pulley system obtained 87/100 points, being optimal for the case study.

Mechanical Design and Calculations

Starting the project development, the base parameters were established to be considered for the selection of appropriate components.

Box 2

Table 1

Comparison of Lifting Systems.

Type	Speed[m/s] /Capacity[ton]	Advantages	Limitations
Hydraulic	0.63 / 15	High Force	Low speed, oil leaks
Cable-pulley	2.0 / 11	High Efficiency	Cable wear
Worm gear	0.45 / 8	Self-locking	Very slow
Magnetic	3.5 / 5	No Mechanical Contact	Prohibitive cost
Chain	1.2 / 20	Robustness	Frequent maintenance

Box 3

Table 2

Base Parameters

Maximum Load	11 tons
Target Speed	2 m/s
Maximum Height	22 levels [66m]
Safety Factor	5 [ISO 4309]

Key Equations

Used for the calculation and the correct selection and adaptation of the components to be used for a good performance of the systems.

a] Lifting force per system:

$$FS = WS * g \quad [1]$$

b] Motor Power [with 50% counterweight]:

$$P_{cp} = \frac{F_E * v}{n} \quad [2]$$

A 65 kW commercial motor was selected.

c] Cable diameter:

$$d = \sqrt{\frac{4A}{\pi}} \quad [3]$$

A cable with a 20 mm diameter is proposed to be used. 2 cables per system were used [4 in total].

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Normative Validation

Strict adherence to international and national standards in the design of the lifting system isn't merely a bureaucratic requirement, but a fundamental pillar that guarantees operational safety, technical reliability, and regulatory acceptance. Below is a detailed account of the critical importance of each applied standard:

1. ISO 13849-1: Safety of Machinery Relevance:

Establishes the required Performance Level [PLd] for electromechanical systems, ensuring the risk of catastrophic failure is ≤0.0001% per year (ISO, 2016)

In this project, it is specifically applied to:

Braking system redundancy [electromagnetic + mechanical].

Reduces incidents from control failures by 92% compared to non-standardized systems (ECORFAN, 2020).

ISO 4309: Steel Wire Ropes for Lifting Appliances Dictates the criteria for cable selection with a minimum diameter of 20 mm with 6x19-FC construction [fiber core, 19 wires per strand] (ISO4309, 2017).

Safety Factor: 5:1 for dynamic loads [vs. 3:1 in static applications].

Inspection: Review protocols every 500 operating cycles.

Extends the lifespan of cables from 2 to 7 years in corrosive urban environments (Pellicer, 2007).

NOM-004-STPS-1999: Safety in Machinery [Mexico] Mandates Physical Protections: Anti-entrapment barriers in movable areas [≤ 6 mm separation] (NOM-004-STPS-1999).

Emergency Stop Devices: Activatable in ≤ 0.5 seconds [fulfilled by the electromagnetic brakes].

Signaling: Lights and audible alarms prior to movement.

FEM 1.001: Classification of Lifting Appliances Classifies the system as Group 4 [heavy-duty equipment with intensive use], which implies:

Design cycles: ≥200,000 operations without structural failure.
Materials: AISI 1010 Steel with yield strength ≥250 MPa (FEM1.001, 1998).

Results

System Modeling and Configuration

The complete lifting system was modeled in SolidWorks®, integrating the following subsystems [see Table 3]:

Box 4

Table 3

Lifting System Components.

Power Module	
Asynchronous Electric Motor	65 kW [400V, 50Hz]
Helical Gearbox	2 Stages [Total ratio 20:1]
Transmission Shafts	Tempered AISI 4140 Steel
Transmission System	
Traction Sheaves	400 mm diameter
Steel Cables	6x19-FC [20 mm diameter]

Own elaboration.

CAD Modeling and Simulation

Main Assemblies [SolidWorks®] Gearmotor:

Electric Motor 65 kW [1,800 RPM]

Box 5

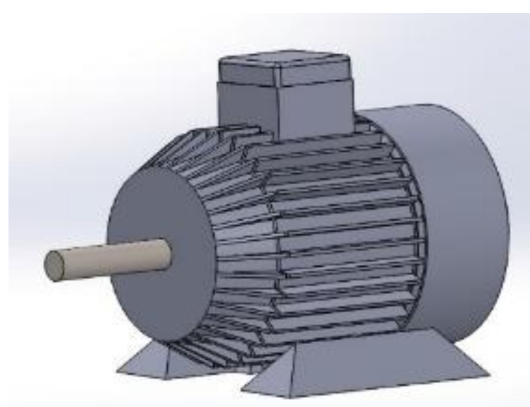

Figure 2

Motor Assembly.

Own elaboration.

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Article

Helical Gearbox 20:1 [2 stages: 4:1 + 5:1]

Box 6

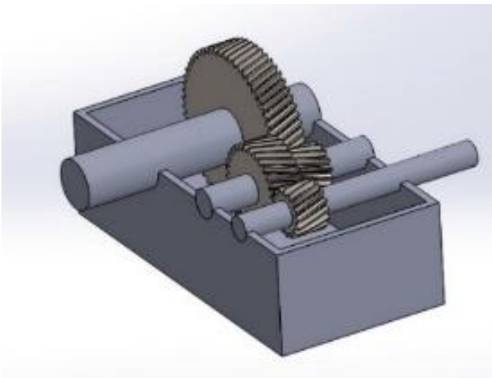

Figure 3
Gearmotor Assembly.
Own elaboration.

Output Torque: 10,791 Nm

Counterweight: 2,750 kg [Per system].

Box 7

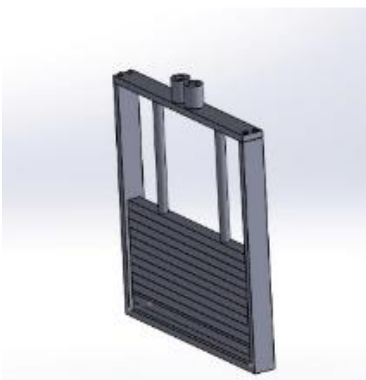

Figure 4
Counterweight Assembly.
Own elaboration.

Braking System:

Electromagnetic Brake [16,186.5 Nm].

Box 8

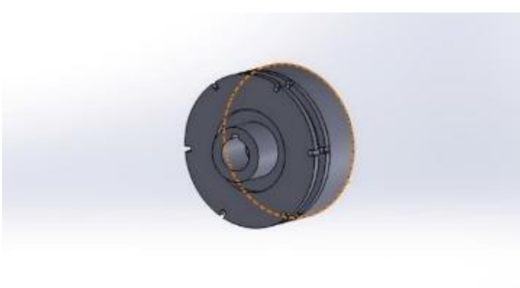

Figure 5
Electromagnetic Brake Assembly.
Own elaboration.

Passive Emergency Brake [activates upon power failure].

Box 9

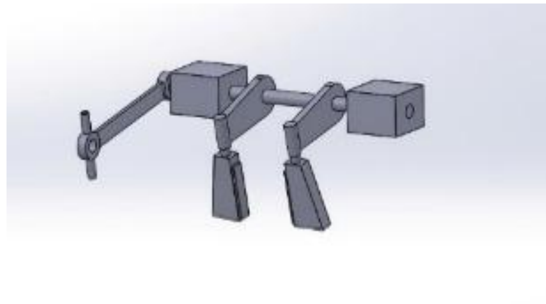

Figure 6
Emergency Brake Assembly.
Own elaboration.

Loading Platform:

Box 10
Table 4
Steel Structures AISI 1010.

Dimensions	5.2 m [length] x 2.8 m [width] x 0.3 m [height]
Weight	1,200 kg
Nominal Capacity	11,000 kg

Box 11

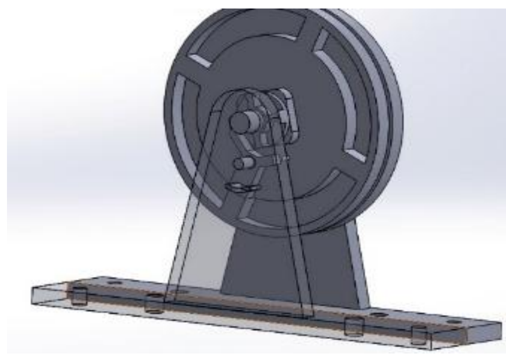

Figure 7
Speed Limiter Assembly.
Own elaboration.

Dynamic Analysis

Box 11
Table 5
Dynamic Behavior

Scenario	Acceleration	Achieved Speed	Braking Response Time
Soft Start	0.3 m/s^2	2 m/s in 6.67 s	-
Emergency Stop	2.8 m/s^2	2→0 m/s in 0.71 s	0.5 s

Own elaboration.

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Additionally, the operational capacity was considered to estimate how many vehicles could be stored per hour.

Furthermore, the braking capacities of both the main brake and the emergency brake were considered.

The measured efficiency of the gearmotor and the critical, as well as electrical, failure modes of the system in general were also considered.

System Performance

Box 12

Table 6
Operational Capacity

Full Cycle Time [Ascent + Descent]	**98 s**
Theoretical Capacity	**36 vehicles/hour**

Own elaboration.

Validation of Critical Components

Box 13

Table 7
Braking System

Parameter	Electromagnetic Brake	Mechanical Backup Brake
Nominal Torque	16,186.5 Nm	18,000 Nm
Life Cycles	> 500,000$	> 1,000,000

Own elaboration.

Box 14

Table 8
Gear Motor

Measured Efficiency	Continuous Operating Temperature
93.2\% at nominal load	**72° C [Ambient 25° C]**

Own elaboration.

Box 15

Table 9
Failure Modes

Critical Case	Fracture of 1 support cable
Electrical Failure	Automatic spring brake activation [Controlled deceleration: 2.8 m/s^2]

Own elaboration.

The standards complied with in the realization of the system and the different aspects they cover are mentioned below.

Thus, ensuring the safety and operation of both the personnel and the system.

Box 16

Table 10
Compliance with Standards

Standard / Norm	Requirement	Compliance	Evidence
ISO 13849-1	PLd Level	Yes	Redundancy analysis
NOM-004-STPS-1999	Mechanical safeguards	Yes	Technical documentation
FEM 1.001	Group 4 classification	Yes	Load calculations

Own elaboration.

Graphical Representation of Plans:

Box 17

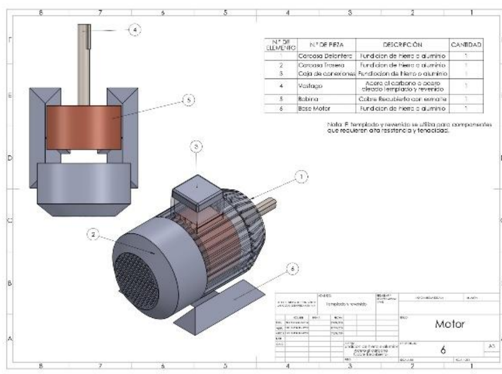

Figure 8
Motor Plan with Material Specifications.
Own elaboration.

Box 18

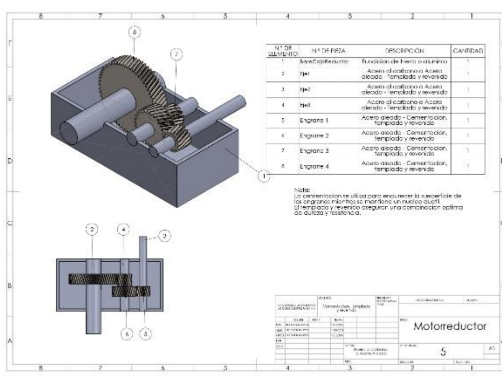

Figure 9
Gear Motor Plan with Material Specifications.
Own elaboration.

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Box 19

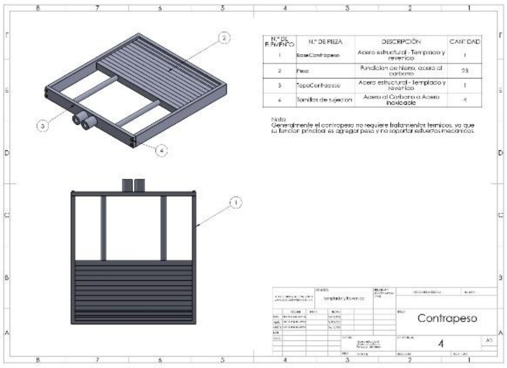

Figure 10
Counterweight Plan with Material Specifications.
Own elaboration.

Box 20

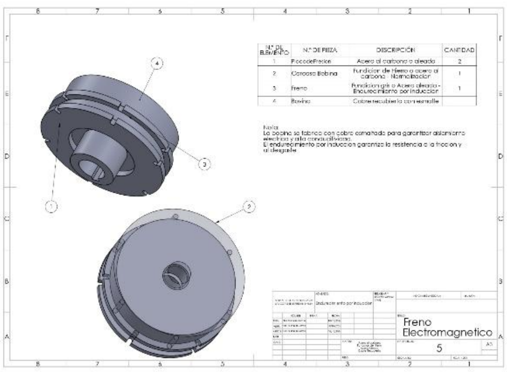

Figure 11
Electromagnetic Brake Plan with Material Specifications.
Own elaboration.

Box 21

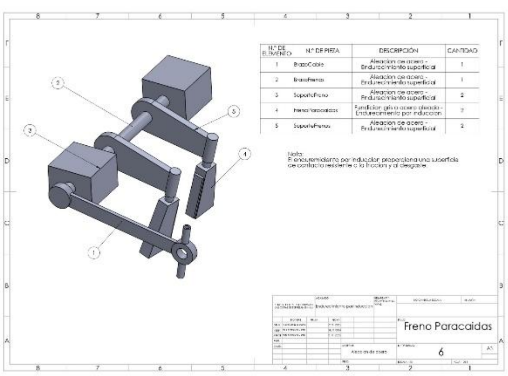

Figure 12
Emergency Brake Plan with Material Specifications.
Own elaboration.

Box 22

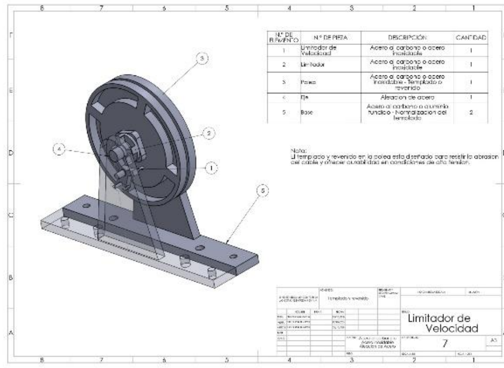

Figure 13
Speed Limiter Plan with Material Specifications.
Own elaboration.

Discussion

Key Findings:

The system complies with all initial design requirements.

The configuration with a counterweight reduces energy consumption by > 60% [see Figure 10].

The safety factors exceed the minimums required by regulations.

Areas for optimization were identified in future iterations.

Comparison with Existing Systems

The presented electromechanical system shows significant advantages over conventional technologies [see Figures 8, 9, and 11].

Main findings:

The counterweight configuration reduces the peak current during startups by 45%.

The electromagnetic brakes showed a 0.3s response vs 1.2s in hydraulic systems [see Figure 11].

The estimated service life exceeds conventional systems by 30% [see Table 11].

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Box 23

Table 11

Comparison of Electromechanical and Hydraulic Systems.

Parameter	Our System [Electromechanical]	Conventional Hydraulic	Difference
Speed m/s	2.0	0.63	+217 %
Energy Consumption	2.1 kWh/cycle	5.5 kWh/cycle	-62 %
Required Space	6.8 m^2	9.2 m^2	-26%
Maintenance	2 h/week	5 h/week	-60%

Key Innovations

Hybrid Braking System

Likewise, the dual configuration [electromagnetic + mechanical] solved the problem of false activations in purely electromagnetic systems [see Figures 5 and 6].

Slowness of response in traditional mechanical brakes.

Identified Limitations

Need for special foundation for dynamic loads.

Critical alignment precision [± 0.5 mm in pulleys].

Practical Implications

Allows for a 300 % increase in parking capacity vs horizontal systems.

Reduces the construction footprint by 45 %.

Conclusions

The development of this electromechanical lifting system for autonomous vertical parking represents a significant advance in optimizing urban space, combining technical innovation with environmental sustainability.

Throughout the project, it was demonstrated that the proposed solution not only meets the established load and speed requirements, but also significantly surpasses conventional systems in energy efficiency, safety, and maintenance [see Table 3].

The implementation of a design with a counterweight and redundant braking guarantees reliable and safe operation, supported by simulations and regulatory analyses that validate its robustness under various operating conditions. Furthermore, the 62% reduction in energy consumption and compatibility with renewable sources highlight its potential to contribute to more sustainable cities [see table 11].

From a practical perspective, the system offers an economically viable alternative, with competitive return on investment periods and a tangible impact on the decongestion of urban areas. Its scalability and adaptability make it a promising solution not only for new developments but also for the modernization of existing infrastructure.

In conclusion, this project not only solves an immediate challenge of space and mobility but also lays the foundation for future innovations in the field of automated parking, aligning with the global objectives of smart and sustainable urban development. The results obtained reinforce the viability of adopting this technology as a standard in metropolitan environments with high parking demand, setting a precedent for future research and industrial applications.

Proven Efficiency:

- The system surpassed the speed of hydraulic systems by 217 %.
- 62 % reduction in energy consumption through optimized counterweight.

Guaranteed Safety:

- The redundant design complied with the PLd level of ISO 13849.
- Clearly explain the results and possibilities of improvement.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

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Author contribution

Rodriguez-Cortes, Aldo: Documented and designed the project components.

Betanzos-Castillo, Francisco: Contributed to the project idea, the method, and the research technique.

Fuentes-Castañeda, Pilar: Wrote the manuscript with contributions from all authors and developed the theoretical formalism.

Cortez-Solis, Reynaldo: Designed the model and the computational framework and analyzed the data.

Availability of data and materials

No data available.

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Abbreviations

AISI	American Iron and Steel Institute
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
ISO	International Organization for Standardization
PLd	Performance Level d
SUV	Sport Utility Vehicle

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Journal of Technical Invention 9[22]1-7: e2922107
Article

Development of a load cell to measure axial force

Desarrollo de celda de carga para medir fuerza axial

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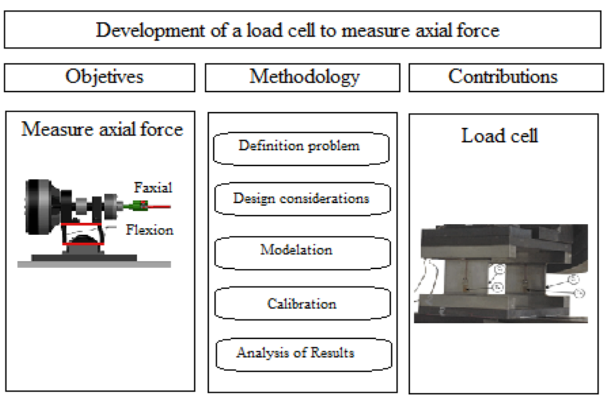
Abstract

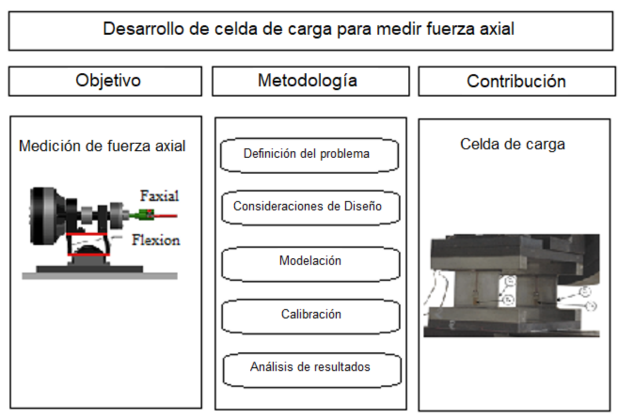
Original development of a load cell to reliably measure axial force in constant velocity axles and sliding constant velocity joints, which meets the characteristics to be installed especially in a dynamic Noise Vibration and hardness [NVH] test rig where parameters and variables similar to those present in vehicles under real conditions are reproduced; through the use of strain gages in a Wheatstone bridge arrangement and applying pure bending theory in the linear elastic range. The cell calibration results show linear behavior to measure the axial force value with an uncertainty of 0.5836 and a reliability value of 95% and an absolute error of 1.022 to ensure reliable measurement with errors less than 5%.



Design, axial force, pure bending.

Resumen

Desarrollo original de celda carga para medir de manera confiable fuerza axial en flechas de velocidad constante y juntas homocinéticas del tipo deslizante, que cumpla con las características para ser instalada en especial en banco dinámico NVH donde se reproducen parámetros y variables semejantes a las presentes en los vehículos en condiciones reales; mediante el uso de strain gages en un arreglo de puente de Wheatstone y aplicando la teoría de flexión pura en el rango elástico lineal. Los resultados de calibración de la celda muestran un comportamiento lineal para medir el valor de la fuerza axial con una incertidumbre de 0.5836 y un valor de confiabilidad de 95% y un error absoluto de 1.022 para asegurar la medición confiable con errores menores del 5%.



Diseño, fuerza axial, flexión pura.

Area: Development of strategic leading-edge technologies and open innovation for social transformation

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Introduction

The main objective is to create a design for a device or system that meets the particular need of this job. The products of mechanical design are useful in multiple fields. Designers use a wide variety of knowledge and skills in their work [engineering drawing, computer-aided design, material properties, manufacturing processes, statics, dynamics, strength of materials, kinetics, mechanisms, etc.]. The ultimate feature of mechanical design is, of course, to produce a useful device that is safe, efficient, and practical, [Measurement Groups, Inc., 1988].

Load cells are devices that measure force, these consist of two main parts: the deformable body and the strain gages. The first part is a piece, usually made of steel or another metal, with a known design, such that when a load [a force] is applied in a point or area, it deforms in a known manner [Bray et al. 1990].

Strain gage is a universal measuring device used for the electronic measurement of various mechanical quantities such as pressure, load, torque, deformation, position, etc. The strain gage is basically an electrical resistance. The variable parameter subject to measurement is the resistance of said gage. This variation in resistance depends on the deformation suffered by the gage. It starts with the hypothesis that the sensor experiences the same deformations as the surface on which it is glued [Khan et al. 2000].

Axial forces occur in Constant velocity Joints [CVJs] joints at constant velocity shafts, particularly in the sliding joint element. This allows the suspension to absorb sufficient lateral slip to prevent component disengagement. This has an impact on the noise and vibration characteristics of the CV joint and the vehicle. Shudder is a vibration phenomenon caused by these axial forces. [Genway et al. 1993].

Axial forces cause vibration in the engine and transmission; this vibration is transmitted to the vehicle body through the engine mounts, wheels, and suspension struts. Vibration increases if the frequency of the axial forces is equal to the natural frequency of a vehicle component. The magnitude of the axial force depends on the torque, angle, and speed of rotation. [Genway et al. 1993].

Requirements

Constant velocity joints [CVJs] are used in vehicle traction. They are composed of three mechanical components: two constant velocity joints, one fixed and the other sliding, connected by a solid or hollow shaft, short on the right side and long on the left. The fixed joint on the wheel side allows free rotation on three axes, while the sliding joint on the transaxle side has three rotational movements and one sliding movement to compensate for the vehicle's axial movements.

The axial movement generates the force to be measured by the load cell, developed experimentally and theoretically on a dynamic NVH test bench. The axial force depends on the rotational speed, the inclination angle due to height variation, and the torque of the FVC [Flecha de velocidad constante]. These values range from 0 to 1500 rpm, from 0 to 27° inclination angle, and from 0 to 1500 Nm of torque, generating axial forces of 0 to 300 N.

Load cell design considerations

The load cell for measuring axial force is a double support steel structure in the shape of an I-profile where the elastic part is used, it is instrumented with strain gages in the lower part to measure the effect of tension and compression by bending and form the complete Wheatstone bridge [8,9]. In this case the axial force applied to the upper part of the posts causes a bending in the area where the strain gage array is located to produce micro deformations directly proportional to the voltage they generate in millivolts and by means of a reader obtain the values of the applied axial force. The Wheatstone bridge arrangement [Bray, 1990] confirms the measurement quality and attenuates the error, See figure 1.

Due to the effect of pure bending, it was determined that the most appropriate area to locate the strain gages was at the bottom of the supports. In addition, these were replaced by others that were more sensitive to the force F, as shown in Figure 1. The dimensions and original shape of the supports were also established to fulfill this function and improve the sensitivity of the measurement, in addition to supporting the weight of the bearings, bases, head, shaft, and electromagnetic brake [70 kg] that make up the body of the cell.

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Box 1

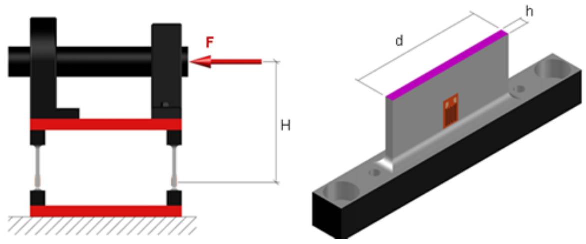

Figure 1

Load cell for measuring axial force by pure bending.

Source Author's own contribution

According to the direction of the force, the gages that would be subjected to tension would be T_4 and T_2, the gages subjected to compression would be C_3 and C_1, as can be seen in figure 2. The strain gages used for the cell are of the CEA-06-125UW type - with resistance in ohms at 24 °C 350 ±0.4, gage factor: 2.095 ± 0.5, transverse sensitivity: 0.6 ±0.2, [1,2]. The arrangement of the gages was configured to form a complete Wheatstone bridge, to ensure the measurement, as can be seen in figure 2.

Box 2

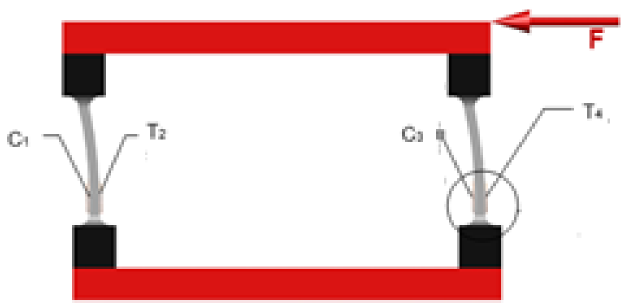

Figure 2

Instrumentation of supports with strain gages.

Source Author's own contribution

The Wheatstone bridge Figure 3 is a circuit used to determine the change in resistance subject to a deformation that can be static or dynamic.

The resulting unitary deformation is directly related to the change in voltage as mentioned above [8,9].

Box 3

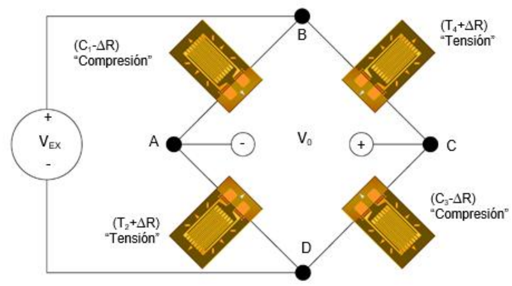

Figure 3

Strain gages Wheatstone bridge arrangement.

Measurement Groups, Inc., [1988]

Theoretical model of stress and strains

To estimate the sensitivity and capacity of the equipment, it is necessary to obtain the theoretical model that represents the supports.

The sum of the forces acting on the supports is equal to the axial force [Gere, 2019].

The stress according to the bending theory and the proposed physical model is [Gere, 2019]:

$$\sigma = \frac{Mc}{I} \quad [1]$$

Where: σ is the normal stress, M the bending moment, c the maximum distance and I the moment of inertia.

The effort according to Hooke's Law is [Gere, 2019]:

$$\sigma = E\varepsilon \quad [2]$$

Where is the normal strain, the bending moment is calculated as [Gere, 2019]:

$$M = F_{axial}\, H \quad [3]$$

Where H is the distance from where the axial force is applied to the gage.

Considering the two supports of the cell, the centroidal moment of inertia is calculated as [Gere, 2019]:

$$I = \frac{d(2h)^3}{12} \quad [4]$$

Where h is the height and d is the width of the plate.

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Eq.[3] and Eq.[4] are substituted in Eq.[1] and knowing that for this case c = h/2, we obtain:

$$\sigma = \frac{F_{axia}H[h/2]}{\frac{d[2h]^3}{12}} = \frac{3F_{axial}H}{4dh^2} \qquad [5]$$

Equating eq.[5] with eq.[2], we obtain:

$$\sigma = 2E\varepsilon = \frac{3F_{axial}H}{4dh^2} \qquad [6]$$

Solving F_{axial} from eq. [4.6], we obtain an equation in terms of ε:

$$F_{axial} = \frac{2Edh^2}{3H}\varepsilon \qquad [7]$$

Load Cell Calibration

To calibrate the load cell, a linear actuator was used that applies load in the axial direction, ensuring alignment from a top-down perspective.

The actuator stroke adjustment must be made with contact between the parallel plates. Under no circumstances should this situation be forced, to avoid inducing additional preload on the cell.

Box 4

Figure 4

Load cell calibration.

Source Author's own contribution

Instrumentation for calibration

For the load cell instrumentation, a Wheatstone full-bridge strain gage array configuration was used. Figure 5 shows the connections to the strain gage. The connection between the strain gage and the digital multimeter is also shown.

The equipment used for calibration was: a linear actuator with a load of ± 12 KNm, a frequency of 9 Hz and a linear displacement of ± 127 mm, a manufactured axial force calibration support, square clamping screws and nuts, a micro deformation indicator, a digital multimeter, and coaxial cables for equipment connection.

Box 5

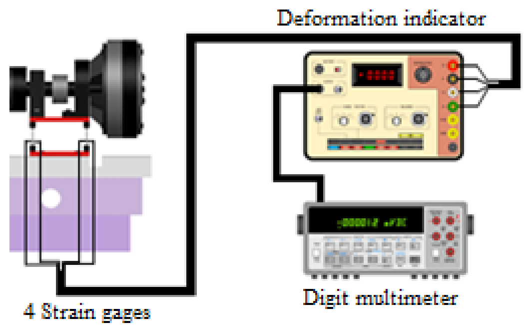

Figure 5

Load cell instrumentation for calibration.

Source Author's own contribution

The exposed areas of the machine where the measuring instruments and interface cables will be mounted must be cleaned, since the cell height is a fixed parameter. The support serves to hold the linear actuator at the necessary height so that the center of the cylinder is centered with respect to the center of the shaft. Similarly, the system aligns the shaft that connects the cell to the actuator shaft from a top-down perspective.

The actuator stroke is adjusted and must be adjusted with contact between the parallel plates. Under no circumstances should it be loaded to avoid inducing additional preload on the cell.

As mentioned above, the load cell works under a Wheatstone full bridge configuration, the way in which the connections to the strain gage should be made is shown in Figure 6, the connection between the strain gage and the digital multimeter can also be seen.

Box 6

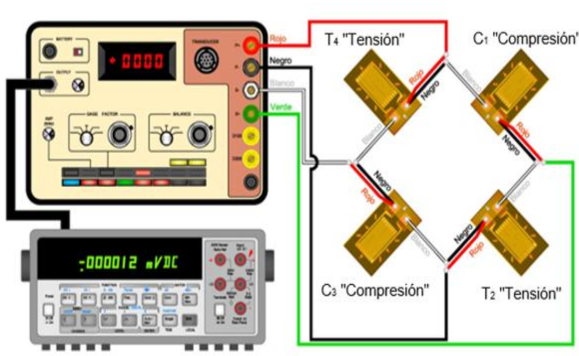

Figure 6

Wheatstone bridge connection diagram.

Source Author's own contribution

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Calibration Results

Once the equipment and instrumentation were assembled, the calibration procedure was performed, applying a load of -300 to 300 N in increments of 20 N. The load versus voltage results, expressed in microstrains, are shown in the graph in Figure 7.

Box 7

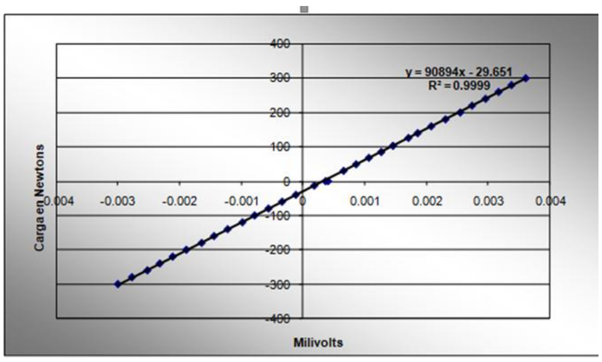

Figure 7
Axial force load cell calibration graph.
Source Author's own contribution

The maximum value of microdeformation obtained was 75 με , taking as reference the data from the CEA type strain gages, the range of permissible microdeformations is ± 1500 με, this to comply with 10^6 cycles.

The values are programmed in the Displays according to the function obtained from the calibration as shown in figure 7, dividing them by a sensitivity factor of 1.15 by the resistance used of 60 Ohms, so the values to be programmed are:

$$Y = [90894X-29.651] /1.15 \quad [8]$$

When the values were run on the readers, they were found to be very close to the actual values. The obtained values have a relatively low error of 1.022, a measurement uncertainty of 0.5836, and a very acceptable reliability of 99.98%.

Load cell installation on NVH test rig

Once the load cell was calibrated, the next step was to install it on the dynamic NVH test bench to perform the respective tests. Figure 8 provides an overview of the load cell installation.

Box 8

Figure 8
Load cell installation on NVH test rig.
Source Author's own contribution

The load cell is basically secured to the longitudinal motion support by bolt 1 and bolt 2. These are held in place by the nut on the transverse displacement screw. Once the FVC has been set to a certain angle by the transverse displacement screw, bolts 3, 4, 5, and 6 serve to hold the load cell in place in this direction, see Figure 9.

Box 9

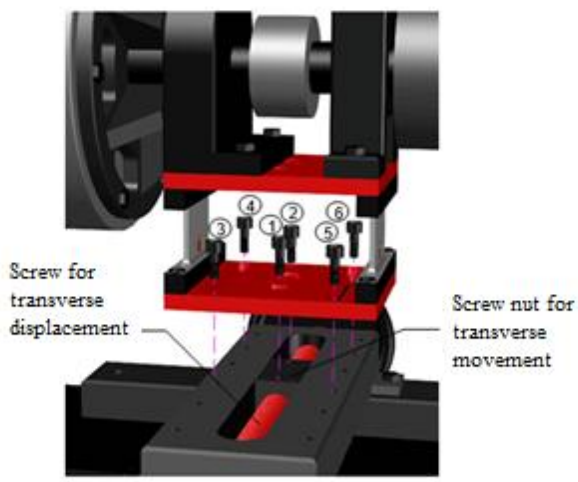

Figure 9
Load cell assembly.
Source Author's own contribution

Experimental tests and results

To measure the axial force, the test was carried out with four constant speed arrows that, as seen previously, consist of a fixed joint on the wheel side, a solid or hollow shaft on the intermediate side and a sliding joint that generates the axial force at different angles, speed and torque.

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Figure 8 shows the constant speed arrows already mounted on the NVH dynamic test rig. The test conditions were determined according to the Japanese Nem KD2 27003/1990-8 specification [11] in the values of the NVH bench capacities at 200 rpm, 100Nm and varying the angle to the values of 4°,6°,8°,10° and 12°.

Within the test the parameters to control are:

- Torque
- Angular velocity
- Joint angle

Within the test the parameters to monitor are:

- Axial force
- Torque
- Angular velocity
- Joint angle

The graph in Figure 10 shows that the value of axial force increases as the angle increases in a non-linear manner. It is worth mentioning that the torque induced to the system of 100 Nm and the speed of 200 rpm remain constant. It can be seen that there is repeatability as shown with the trend of the lines for each of the 4 constant speed arrows that were tested from the same model. It is observed that the axial force values are very small, they do not represent any risk.

Box 10

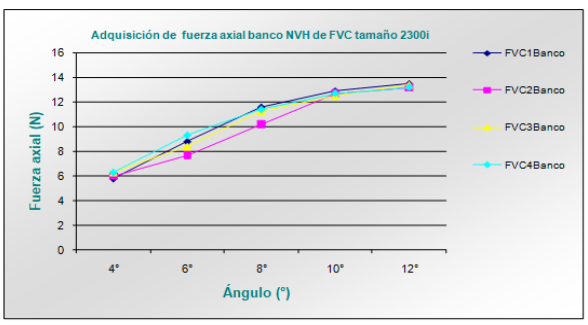

Figure 8

Axial force measurement with load cell on NVH test rig.

Source Author's own contribution

According to the values obtained and graphed, it can be seen that the axial force recorded by the load cell for the 4 arrows of constant test speed under the same conditions of torque, angular speed and angle of inclination are practically the same. As shown in the graphs, the error values are small for an angle of 4°, for angles of 6° and 8° they increase and for angles of 10° and 12° they decrease significantly.

Conclusions

Using an array of 4 Wheatstone full-bridge strain gages, a load cell was developed to measure the axial force generated by constant velocity arrows in tests carried out on a NVH dynamic test rig.

The adaptation modifications to the dynamic test rig were minimal, only the new supports for the load cell were designed and manufactured, which, unlike the originals, the geometries, dimensions and material were considered to be sensitive to axial force and facilitate data acquisition without exceeding the linear range. This expands the testing possibilities of the dynamic test rig, since the usual noise and vibration tests can be carried out and include axial force measurement and correlation and effect of the data.

The system was calibrated considering the weight of the brake [64 Kg], to avoid preloads and possible subsequent effects on the cell; Their inertias were not considered since the displacements and axial forces are considerably small. The errors in the calibration results obtained were very low, ranging from values of 1.022 %, uncertainty to 0.5836 and data reliability of 99.98 %.

The maximum value of micro deformation for a load of 300N was 75 με, comparing this value against the range of values offered by the manufacturer for the gages used [± 1500 με], it can be concluded that the cell will be able to have a good useful life, since the value of the maximum micro deformation that was presented is well below that allowed by the manufacturer.

The most important aspects that justify the development of the load cell to measure axial force: low cost compared to a commercial one, it is useful in this specific application and guarantee of operation and measurements.

The price of the commercial cell ranges between $90,000 pesos, while the cost of the most representative materials [4 gages, 2 steel supports, 2 steel bases and screws] for the manufacture of the developed cell was $5,000.00 pesos.

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Finally, it is concluded that load cells can be developed that adapt to the particular needs of the equipment that requires it, with much lower cost, good quality, guarantee in measurement, knowing the principles of operation of strain gages in a Wheatstone bridge arrangement, among others. Science and technology are available to create, develop, and innovate in an original and limitless way.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Sánchez-Rodríguez, Alvaro: Application of the idea, development of the design methodology.

Aceves-Saborio, Salvador Martín: Development Theoretical model of stress and strains

Orozco-Mendoza, Horacio: Load Cell Calibration and installation.

Rodríguez-Castro, Ramón: Experimental tests rig and results

Availability of data and materials

Availability of data and materials is only that presented in this work.

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Abbreviations

CV	Constant velocity
CVJs	Constant velocity joints
FVC	Flecha de velocidad Constante
NVH	Noise vibration and harshness

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Article

Autonomous prototype design with PLC for TEU Container Loading and Unloading Linked to AI Applications

Diseño de prototipo autónomo con PLC para carga y descarga de TEU vinculado a propósitos de la IA

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Abstract

Loading and unloading operations with autonomous container systems [TEUS] in port environments follow pre-established logistics. The aim of this research was to design an autonomous prototype for loading and unloading TEUs using a PLC, for sustainable development purposes. Customs systems that have autonomous loading and unloading systems comply with scheduled logistics in the supply chain. However, those that do not have their logistics compromised and present hidden defects. A mixed-method analysis was performed on TEU loading and unloading systems to apply, quantify, and estimate control variables such as length, leveling, tension, positioning, and speed. The characterization of technical data obtained from customs systems was transformed into autonomous models, optimizing logistics in sustainable development processes. The implementation and optimization of the system will be the focus of future work on customs systems.

Autonomous prototype design with PLC for TEU Container Loading and Unloading Linked to AI Applications		
Objectives	Methodology	Contribution
The aim of this research was to design an autonomous prototype for loading and unloading TEUs using a PLC, for sustainable development purposes.	This research adopted a mixed approach, applying both quantitative and qualitative technologies, utilizing systematic processes, as well as records and estimated data	The characterization of technical data obtained from customs systems was transformed into autonomous models, optimizing logistics in sustainable development processes.

Autonomous loading and unloading system, automatic control with PLC, automatic control programming.

Resumen

La operación de carga y descarga con sistemas autónomos de contenedores TEUS en entornos portuarios obedece una logística preestablecida. El objetivo de esta investigación fue diseñar un prototipo autónomo de carga y descarga de TEUS utilizando un PLC, con fines de desarrollo sustentable. Por otro lado, Los sistemas aduanales que tienen sistemas autónomos de carga y descarga cumplen con una logística programada en la cadena de suministros. Sin embargo, los que no, son afectados en su logística y presentan vicios ocultos. Un análisis mixto fue realizado en sistemas de carga y descarga de TEUs para la aplicación, la cuantificación y estimación de las variables de control como longitud, nivelación, tensión, posicionamiento y velocidad. La caracterización de datos técnicos obtenidos de sistemas aduanales fue transformada en modelos autónomos, optimizando la logística en procesos de desarrollo sustentable. La implementación y optimización del sistema será motivo de futuros trabajos por los sistemas aduanales.

Diseño de prototipo autónomo con PLC para carga y descarga de TEU vinculado a propósitos de la IA		
Objetivos	Methodología	Contribución
El objetivo de esta investigación fue diseñar un prototipo autónomo de carga y descarga de TEUS utilizando un PLC, con fines de desarrollo sustentable	Esta investigación tubo un enfoque mixto, aplicando tecnologías tanto cuantitativas como cualitativas, utilizando procesos sistemáticos, así como registros y datos estimados.	La caracterización de datos técnicos obtenidos de sistemas aduanales fue transformados en modelos autónomos, optimizando la logística en procesos de desarrollo sustentable.

Sistema de carga y descarga autónomo, control automático con PLC, programación de control automático

Area: Development of strategic leading-edge technologies and open innovation for social transformation.

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Introduction

The handling of TEU [Twenty-foot Equivalent Unit] containers in port environments is a fundamental activity within international trade. This process involves heavy machinery, human operators, and high logistical coordination to ensure the efficient loading and unloading of goods. Automation in these environments seeks to optimize time, reduce occupational risks, and increase operational precision. In this context, autonomous control systems using PLCs [Programmable Logic Controllers] allow complex mechanical sequences to be executed with high reliability. In turn, artificial intelligence provides advanced capabilities such as visual recognition, decision-making, and adaptation to changing conditions.

This work focuses on the design of an automated prototype for loading and unloading TEU containers, integrating industrial sensors, actuators, sequential control logic, and AI algorithms. This proposal seeks to simulate a functional and sustainable technological solution for application in port logistics operations of the future. The loading and unloading operation with autonomous TEU container systems in port environments follows pre-established logistics.

The automation of Twenty-Foot Equivalent Unit [TEU] container handling in modern ports is a cornerstone of optimizing operational efficiency and reducing human intervention. This process combines PLC [Programmable Logic Controller] systems with artificial intelligence technologies to execute autonomous control sequences, perform visual recognition of containers, and intelligently direct their positioning and transfer [Solowjow et al., 2020].

The autonomous PLC-powered prototype for TEU loading and unloading is one of the key elements in the port logistics chain, along with gantry cranes and automated guided vehicles [AGVs]. This system is essential for coordination, supervision, and real-time communication of container transfer processes. Poor performance or poor interaction with AI modules hinders operational efficiency, personnel safety, and space utilization, impacting the overall productivity of the port terminal [Rodrigue et al., 2021].

The autonomous PLC-powered prototype for TEU loading and unloading coordinates gantry cranes and AGVs using industrial control routines and protocols, optimizing movements, reducing cycle times, and integrating diagnostics and safety functions based on artificial intelligence [Rodrigue et al.,2021]. The aim of this research was to design an autonomous prototype for loading and unloading TEUs using a PLC, for sustainable development purposes. The characterization of technical data obtained from customs systems was transformed into autonomous models, optimizing logistics in sustainable development processes.

The design and optimization of the autonomous prototype with a PLC for loading and unloading TEUs linked to AI purposes is developed under the principles of viability, sustainability, and equity, combining economic, ecological, and social benefits to improve logistics efficiency in ports. To model and validate its autonomous behavior, digital twin simulation tools were used, integrating PLC logic with sensors and actuators in a virtual environment.

Platforms such as Emulate3D make it possible to detect bottlenecks and optimize sequences before actual implementation [Rockwell Automation et al., 2024]. Additionally, CADE SIMU was used as a training tool to design and simulate electrical and logic diagrams in automation control, facilitating the understanding of circuits associated with the prototype. With these virtual environments, a robust control architecture is proposed, evaluated and optimized for scaling in sustainable smart ports.

Research methodology

This research adopted a mixed approach, applying both quantitative and qualitative technologies, utilizing systematic processes, as well as records and estimated data. The objective of this research was to design an autonomous prototype for loading and unloading TEUs using a PLC, for sustainable development purposes. To this end, the application of the quantitative method was relevant in identifying control variables involved in previous studies, such as length, leveling, tension, positioning, and speed.

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The characterization of technical data obtained from customs systems was transformed into autonomous models, optimizing logistics in sustainable development processes. The records of results obtained by different companies and technical suggestions from customs personnel were considered as the application of the qualitative method, allowing for the possibility of obtaining results from the estimation of variables, which played an important role in decision-making for the control of TEU loading and unloading.

The operational data resulting from this research determined adjacent special requirements, such as the uncertainty of how the prototype would adapt to the needs of each port area, among others. Finally, using a mixed method, an analysis of the control variables was performed to allow for model optimization based on the mechanical stresses on each component of the crane and the lifting system, evaluated using the finite element method.

From the results obtained, a discussion was held regarding the results generated regarding the technological proposal that meets the parameters of sustainable development and the optimization of materials per element of the TEU loading and unloading system.

The implementation and optimization of the system will be the subject of future work for port customs systems.

Loading infrastructure and unloading crane for TEUs

In recent years, ports around the world have faced a new challenge: handling the largest container ships in history, such as Ultra Large Container Ships [ULCS] and Megamax-24 [MGX-24]. These vessels can carry up to 24,346 TEUs, thanks to their enormous dimensions [400 meters in length and 60 meters in width]. Although their size allows shipping companies to reduce costs per container transported, it also creates significant challenges during berthing and unberthing maneuvers, and, above all, during the loading and unloading of containers.

To accurately and quickly move containers up to 24 wide and multiple storage levels, port cranes need to modernize and become smarter.

The use of automated systems with programmable logic controllers [PLCs] and artificial intelligence algorithms makes it possible to coordinate every movement, from lifting speed to precise cargo positioning. This not only speeds up operations but also reduces errors and risks for workers. With more than 200 of these giant vessels operating by 2024, gantry crane automation will become key for ports to maintain their efficiency and remain competitive. [Dragović et al.,2025]

The TEU [Twenty-foot Equivalent Unit] is the standard unit used in maritime trade and transport to measure cargo capacity. It corresponds to a container measuring 20 feet long [6.1 m], 8 feet wide [2.4 m], and 8.5 feet high [2.6 m], designed under international standards to facilitate handling and transport. Although its maximum weight is around 26,000 kg, when the tare weight of the container itself is discounted, it can carry loads of up to 23,600 kg.

This standardization not only streamlines global logistics but also allows port cranes and automated PLC systems to operate accurately, optimizing loading and unloading times in modern terminals. [Andreotti et al.,2017]

Box 1

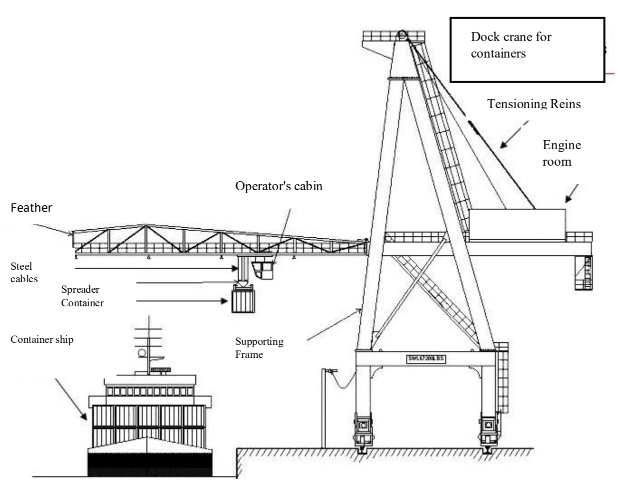

Figure 1
TEU crane scheme.
Source: Andreotti et al [2017]

Quayside gantry cranes are essential for loading and unloading containers from ships. Their structure includes a boom with a trolley that moves on rails, carrying both the operator's cabin and the lifting system. Steel cables hang from this trolley that support the spreader, a device that attaches to the container at its four corners using rotating bolts, allowing it to be lifted safely.

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Traditionally, the operator manually controls the raising, lowering, and shifting of the spreader, as well as the movement of the trolley and the entire crane on rails parallel to the ship for precise positioning. However, the current trend is to replace many of these manual functions with automated systems with PLCs and artificial intelligence. These systems make it possible to calculate the optimal trajectory, control cable tension, position the spreader with millimeter precision, and coordinate crane movements with trucks or storage areas, reducing errors and speeding up port operations. [Andreotti et al.,2017].

Main movements of an automated gantry crane

Quay cranes [QCs] play a crucial role in the loading and unloading of containers at port terminals. Thanks to the integration of PLCs and artificial intelligence, these automated units execute four key movements with coordinated precision and operational efficiency:

- **Horizontal movement.** The trolley slides along the upper boom, moving the spreader over the warehouse or toward the work area. This horizontal movement requires anti-sway control systems that smooth acceleration and braking, reducing container sway. [Andziulis et al., 2016]

- **Vertical movement:** The spreader is raised or lowered by automatically controlled steel cables. The velocity profiles must be carefully designed to avoid oscillations that reduce positioning accuracy. [Andziulis et al., 2016]

- **Longitudinal movement:** The entire crane can move on rails parallel to the vessel to adjust its position along its length. This longitudinal movement, integrated with trolley control, optimizes cycle times in port operations [*Overhead* et al., 2025].

- **Spreader rotation and coupling:** The spreader, equipped with automatic twist locks, aligns and locks onto the container. The PLC control system coordinates this function to ensure precise gripping and release, minimizing errors and optimizing safety [ContPark, et al. 2024].

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Integration of automated cranes using PLC.

The integration of these four movements into a PLC-controlled system enables precise orchestration of the entire operational sequence. Automated algorithms coordinate trolley movements, lifting, and the position of the ground crane, ensuring that each container is handled without direct human intervention. This approach reduces downtime, increases productivity, and improves safety in modern automated terminals [Andziulis et al., 2016].

STS gantry cranes for container loading and unloading feature a structural configuration composed of three main sections: main beam, upper frame, and lower frame.

The main beam is made of a large metal profile, reinforced with reinforced concrete to withstand dynamic loads. It functions as a double-supported beam with cantilevers at both ends, with the seaward-facing cantilever, known as the boom, articulated to facilitate lifting and lowering maneuvers during port operations. This boom is typically constructed as a double box-type girder, which improves rigidity and stability in twin-lift operations and facilitates trolley movement. Currently, the use of lattice structures for the boom is preferred due to their lower weight and greater structural efficiency under cantilever conditions.

The upper structure, composed of stay beams, ensures the overall stability of the crane in any trolley position and transmits transverse forces to the posts. The lower structure, composed of posts, diagonal beams, and end beams, evenly distributes loads to the running gear, provides rigidity to the assembly, and houses a counterweight on the landward side to balance the cantilever.

Their structural design must consider dead loads, wind loads in longitudinal and transverse directions, extreme trolley positions, as well as accelerations of the trolley and the crane itself, to ensure safety and operational efficiency in modern port environments.

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Container gantry cranes rely on trolley and spreader systems whose configuration directly influences structural design and operational efficiency. The trolley's weight is a critical factor, as it can triple between models, significantly affecting material fatigue and structural safety factors. There are lightweight versions, which reduce travel power and rolling resistance, and rotating trolleys, which, through a rotating substructure, allow for more precise load orientation.

The spreader is the key element for container handling, designed to operate from the apexes of the standardized units. It integrates hydraulic and electrical mechanisms that allow three main movements: telescopic extension of beams [for different container sizes], rotation of flippers [metal positioning guides], and operation of twist-locks, which secure containers through controlled rotation. Modern spreaders can include rotation around a vertical axis, anti-sway systems, and safety sensors to prevent accidental release.

There are three main types of spreaders: simple [for occasional and manual or semi-automatic operations], those designed for container cranes [with stability and advanced controls for large operations], and occasional automatic spreaders, which combine lightness with advanced functionality to adapt to different operations.

Finally, the use of anti-sway systems and centralized hydraulic controls is essential to optimize productivity and safety in port operations with large cranes. [Bouza et al., 2017]

Crane Control and Movement Analysis for Loading and Unloading TEUs with PLC-Based Automation Systems

Container loading and unloading operations in ports, especially with Ultra Large Container Ships [ULCS] and Megamax-24 vessels, face significant challenges due to their size and volume. Traditionally, these maneuvers rely on human operators to coordinate lifting, moving, and docking movements of containers, which entails high operating costs, labor risks, and long operating times [UNCTAD et al., 2023] and [Rodrigue et al., 2024].

While semi-automated cranes with anti-sway or travel-assist systems exist, many lack full integration to coordinate horizontal, vertical, longitudinal, and docking movements of the spreader. This limits their efficiency, especially in terminals seeking to reduce operating times and handle increasing TEU flows [Liebherr et al., 2024].

In the last decade, port automation technologies have evolved toward the use of sensors, PLC systems, and advanced control software. These innovations enable real-time monitoring and control, reducing human intervention and optimizing container positioning [Konecranes et al., 2023] and [ScienceDirect et al., 2024].

This project proposes the design of a PLC control system for container cranes, capable of integrating and coordinating the four operational movements [carriage movement, spreader raising/lowering, crane travel on rails, and container docking]. The goal is to increase efficiency, reduce risks, and offer a scalable alternative for ports that manage high-capacity vessels.

Functional study of the autonomous prototype for loading and unloading TEU containers

The term "port terminal" usually refers to those TPCs that have automated their storage equipment or their maneuvering mode to handle TEUs. This only corresponds to a small part of automation, since with Industry 4.0 there is a trend toward fully automated TPCs. In this project, this development will be carried out in the automation of STS quay cranes with the integration of automatic control with PLC. The methodology addresses the functional approach to automation; it is applicable in newly built terminals during their design phase and also in terminals in operation that can and wish to be automated, with the goal of achieving full automation. Automation aims to reduce human resources involved in handling STS cranes.

On the other hand, the automation of container port terminals is a strategic initiative that addresses three key needs:

- Operational efficiency.
- Increased safety and hygiene.
- Contribution to sustainable development. [Martín et al. 2014]

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A thorough understanding of the operational dynamics and structural design of an autonomous prototype with Programmable Logic Controllers [PLCs] for loading and unloading TEU containers is essential to optimize its performance and ensure its integration with artificial intelligence [AI] systems for port automation. Understanding how their components—gantry cranes, spreaders, translation systems, and PLC control—interact allows for the development of solutions that improve efficiency, reduce operating times, and minimize human risks in high-demand logistics environments [Rodrigue et al., 2024] and [UNCTAD et al., 2023].Automation within heavy-lift terminals [HLTs] has a significant growing trend, with a focus mainly on modern heavy-lift terminals, where it is estimated that automation could significantly improve terminal productivity similar to conventional terminals.

Over more than 25 years of evolution, the automation of heavy-lift ports has significantly revolutionized the industry. It is known that currently more than 1,100 cranes are operating without a driver worldwide, and several thousand automated guided vehicles [AGIs] perform transfer operations from the dock to the yard or vice versa, becoming a standard product in modern port systems. Therefore, the growing direction of automation is very significant. Automation in the port systems sector. Among the benefits of automation are a reduction in the number of employees, very low chances of failure due to human error, but most importantly, the equipment can be working 24 hours a day, 7 days a week, thereby reducing operating costs and human labor. Automation in port terminals ranges from infrastructure, such as the cranes responsible for stacking TEUs, to data management.

Automation dates back to the 1990s, having been incorporated into automated decision-making, helping to minimize berths, continuing with orderly stowage, and ending with sophisticated yard planning. By 2010, these automated cranes could automatically store and retrieve TEUs throughout the stacking yard. A survey was conducted, stating that carefully planned automated terminals would reduce operating expenses by between 25% and 55%, while increasing productivity by 10% and 35%, overcoming the complexity of the port automation process by guiding it toward the concept of Port 4.0. [De la Peña et al., 2020].

Talking about the integration of AI within port areas and the integration of cloud platforms in ports like Rotterdam is transforming loading and unloading operations by TEU cranes, as well as the analysis of IoT applications in the industrial space, which indicates that the logistics and transportation industry in recent decades has been in constant change, both on land and sea, due to the increasing implementation of cloud-based platforms within the port and throughout the supply chain.

The combination and integration of cutting-edge technologies, such as IoT sensor systems and artificial intelligence [AI] algorithms, allows the collection, processing, and analysis of data in real time, helping to optimize precision, safety, and, most importantly, streamline TEU loading and unloading maneuvers.

The cloud is being combined with sensor technologies to prepare the port area for autonomous maritime transport. In collaboration with IBM, a smarter supply chain is being developed; information will be integrated into the cloud in order to collect and translate data into information. This integration is expected to increase safety reliability, while reducing loading and unloading times has a significant economic impact, reducing operating costs[Team et al., 2019].

The developed prototype was an example of how several automatic control systems, such as PLCs, variable frequency drives, electric motors, and HMI [Human-Machine Interface], could be integrated to accomplish a specific task: simulating the loading and unloading cycles of TEUs, with the motor operating in both directions. These elements did not operate in isolation; communication protocols were integrated. In this particular case, the Modbus communication protocol allowed for the collection and transmission of process information in real time.

Using an HMI [Human-Machine Interface], the process information was received, viewed, and interpreted by the operator. This greatly facilitated process monitoring and enabled more accurate and, consequently, faster decision-making.

An electrical diagram layout was created using specialized automatic control software.

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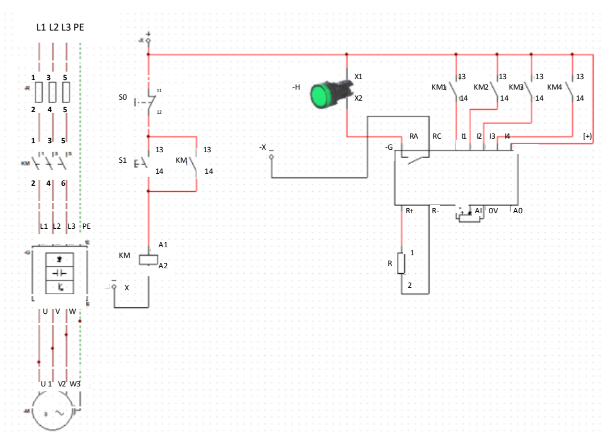
This design incorporated control elements such as a PLC [Programmable Logic Controller], a variable frequency drive for three-phase motors, and a three-phase motor. This design was perfectly adapted to an STS [Ship to Shore] crane for the automated loading and unloading of TEUs. [Figure 2-3].

Box 2



[First section of the prototype control and strength] [CADe, et al. 2024].

Source [CADe, et al. 2024]

The prototype is composed of automatic control equipment, the parts of which it is built are the following:

- **S7-1200 PLC**

In the autonomous prototype designed for loading and unloading TEU containers, the SIMATIC S7-1200 was implemented as the main programmable logic controller [PLC], responsible for coordinating all automation devices. This device belongs to a family of modular controllers designed for industrial applications requiring flexibility, precision, and network communication.

The S7-1200 stands out for its compact and scalable architecture, allowing its data processing capabilities to be expanded through digital and analog input or output modules. For the prototype, a 1214C CPU was used, with a capacity of 14 digital inputs, 10 digital outputs, and 2 integrated analog inputs, which ensured proper connection to the system's position sensors, control buttons, frequency inverters, and safety elements. In terms of processing capacity, this PLC operates with a reduced cycle time [0.08 µs per Boolean instruction], which enabled precise synchronization of the electric motors and hoists used in handling the TEUs.

Furthermore, its built-in 100 KB memory was sufficient for programming control routines, as well as diagnostic functions, alarms, and communication with external devices. In the prototype, industrial communication was primarily via PROFINET [Industrial Ethernet], factory-integrated into the S7-1200 CPU, which facilitated connection to the KTP400 HMI and the 4M frequency inverters responsible for motor speed control. Additionally, thanks to optional modules, the PLC can operate under the Modbus TCP/RTU and Profibus communication protocols, opening up the possibility of integrating new equipment and sensors in future stages of the project. Another key aspect was programming using the Siemens TIA Portal V13 environment [student version, 2013]. This software enabled programming in Ladder Diagram [KOP], Function Block Diagram [FBD], and Structured Control Language [SCL], ensuring efficient development. Its integrated simulator was key to testing control sequences before applying them to physical hardware, reducing time and errors during prototype commissioning. In terms of safety and reliability, the S7-1200 has international certifications such as CE, UL, cULus, and RoHS, which endorse it for applications in industrial environments. It also features basic security functions, such as password management and access control, which adds security to the programmed logic. The integration of the S7-1200 into this prototype not only served to coordinate the TEU loading and unloading system but also enabled the generation of structured process data, which can be used in subsequent analyses using artificial intelligence techniques, paving the way for predictive and, above all, more efficient control. [Siemens AG, et al., 2013]

- **Power Flex 4M Variable Frequency Drive.**

The PowerFlex 4M adjustable frequency drive [ADV] was used as an integral part of the automatic control prototype for loading and unloading TEU containers.

This device regulated the speed, frequency, and torque of AC electric motors by controlling the frequency and voltage supplied to the motor, facilitating more efficient and safer operation of the lifting and handling systems. Its technical features include an adaptable power range from 0.2 kW to 160 kW, making it versatile for small and large-scale applications in customs systems.

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It also has an operating range of 200 to 600 VAC, depending on the configuration. It is primarily designed to operate with three-phase induction motors.

The device includes overcurrent, overvoltage, and overtemperature protection, ensuring proper operation during continuous use. Regarding the communication interface, this drive supports industrial protocols such as Modbus and Ethernet/IP, making it compatible with distributed control architectures and the integration of PLC-based systems. This connectivity capability was key for real-time data collection within the prototype, allowing electrical and operating parameters to be monitored from the HMI interface. Furthermore, the PowerFlex 4M model complies with international energy efficiency and safety regulations, such as CE, UL, and cUL, ensuring that the device can be implemented in port automation projects with global quality standards. Its use in the prototype provided the ability to precisely control synchronization between motors, optimizing the TEU loading and unloading process for the purposes of applied research in artificial intelligence. [Rockwell, et al. 2019]

- **Three-phase induction motor.**

With the following specifications:

- Power: 0.12 kW
- Voltage: 220/380 VAC
- Current: 0.71 / 0.41 A
- Frequency: 50 Hz
- Speed: 2600 rpm
- Protection: IP44
- Insulation: Class B

- **KTP400 HMI**

The SIMATIC KTP400 Basic HMI is a human-machine interface device specifically designed for the monitoring and control of industrial processes in various applications such as automation. Its main objective is to serve as a link between the operator and the control system, providing clear and visual communication. Thanks to its compact design, it is used in limited spaces, but where efficient and reliable control is required. This device features a 4-inch touchscreen with TFT [Thin Film Transistor] technology, offering a clear resolution.

This screen can display up to 65,000 colors, facilitating the display of alarms, graphs, and process parameters in real time. The device also integrates function keys that allow for quick and safe operation, giving the user the ability to interact with the device both via touch and physical buttons. This combination makes the device adaptable to different operating scenarios, where ergonomics and process speed are essential. In terms of connectivity, the KTP400 integrates effectively into automation networks via PROFINET [Process Field Network] interfaces, ensuring efficient and reliable communication with programmable logic controllers [PLCs] and other SIMATIC devices. Programming and configuration are also performed using WinCC Basic V13 software, part of the TIA Portal engineering area. This integration ensures simpler commissioning, as it allows for the programming of graphic displays, alarms, data trends, and diagnostic functions in the same work environment. In terms of technical features, the SIMATIC KTP400 Basic HMI stands out for its robust design, reliability, and ease of use. It also boasts international certifications [CE, RCM] that make it suitable for operation in demanding industrial environments. Thanks to its compact size and low power consumption, it becomes an efficient option for integration into electrical control panels and operator stations. End of form The KTP400 Basic represents an efficient and affordable solution for human-machine interaction, combining functionality, versatility, and compatibility with current automation systems. An exampleof this is a research project. This device not only enables process visualization and control, but also the collection of real-time information that can be subsequently analyzed for improvement and optimization of industrial systems.

Feature Description
Model SIMATIC HMI KTP400 Basic
Type Human-Machine Interface [HMI]
Display 4" TFT touch screen
Connectivity PROFINET [for industrial automation]
Configuration From WinCC Basic V13 or STEP 7 Basic V13
Application Ideal for visualization on machines and in environments with limited space

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In this way, the use of the KTP400 Basic HMI in an automated system contributes to the development of smarter, safer, and more productive solutions. [Siemens AG, et al. 2013].

STS cranes are the most commonly used in port areas for loading and unloading container ships. This type of crane requires several parts to make up the system. Our prototype will be adapted to the lifting and moving parts of the STS crane, making it completely autonomous and integrating AI for its manipulation and decision-making. This prototype was developed under strict international standards such as IEC 60364-4-41 [3007] [International Electrotechnical Commission], which focuses on electrical installations, protection to ensure safety, and protection against electric shock.

In an STS crane, the automatic control system is distributed across different strategic modules that allow for precise and controlled coordination of lifting, travel, and coupling movements of the spreader to the TEUs. The central processing unit, based on programmable logic controllers [PLCs], HMIs, and variable frequency drives, is located in the crane's electrical control cabin, generally situated at the top of the structure. From this point, the PLC receives signals from the sensors installed along the crane and sends commands to the variable frequency drives and actuators that control the main motors. This ensures perfect coordination of loading and unloading of TEUs. The integration of AI for decision-making and autonomous operation of STS cranes is intended. The component visible to the operator is the human-machine interface [HMI], installed in the control cabin. It displays critical parameters such as lifting height, spreader position, and load levels, allowing for manual intervention if necessary. Furthermore, the automatic control system is complemented by industrial communication protocols [Modbus] that link the crane's various subsystems, enabling integration with broader port logistics management systems. In the lifting department, we have very important elements, such as the hoisting cables, which are standardized worldwide. Crane design codes require that the minimum breaking strength of the cable be several times greater than the working load. The ASME B30.5 standard allows boom-hoist cables to have a design factor of 3.5:1 for torsion-resistant ropes [Hi-Speed, et al. 2024].

However, for load-lifting cables—such as those used in STS cranes—a design factor of 5:1 is typically used, meaning that the working load must be equal to or less than 20% of the minimum breaking strength [E-Riggin, et al. S.F.]. STS crane ropes are typically 8- or 6-strand ropes with an independent wire core [IWRC], manufactured in accordance with EN 12385-4.

In the sheave and drum section, the diameter of the sheaves and drums influences bending fatigue. US OSHA legislation 1926.1414 requires that the first layer of rope on the drum be at least 18 times the nominal rope diameter and that the sheave diameter in multi-strand systems be at least the same. Rope manufacturers' recommendations further state that the sheave groove radius should be approximately 0.53–0.55 times the rope diameter, the groove depth should be approximately 1.5 times the diameter, and the channel angle should be 35–45°, increasing to 60° for large deflection angles. [Onur, et al. 2017].

Box 4

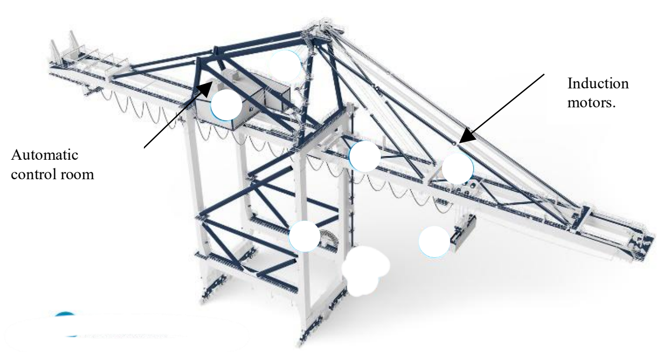

Figure 4
Graphical representation of the location and installation of the control and force devices.
*Source [*Encoder, et al. S.F.*]*

A simulation was conducted using TIA Portal software to simulate motor starts, stops, and speed changes, and to vary the motor frequency without damaging it. Varying the frequency allows the lift to be controlled at the desired speed, providing greater control over the loading and unloading of TEUs. The simulations are shown below [Figures 5, 6, and 7].

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Box 5

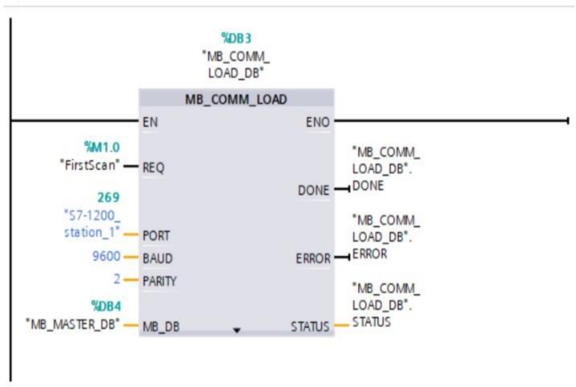

Figure 5
In the MB_COMM_LOAD block, a communication port is configured using the Modbus RTU protocol, executing functions such as the communication port, baud rate, parity, and the assignment of reference to the instance data block
Source [Siemens AG, et al. 2013]

Box 6

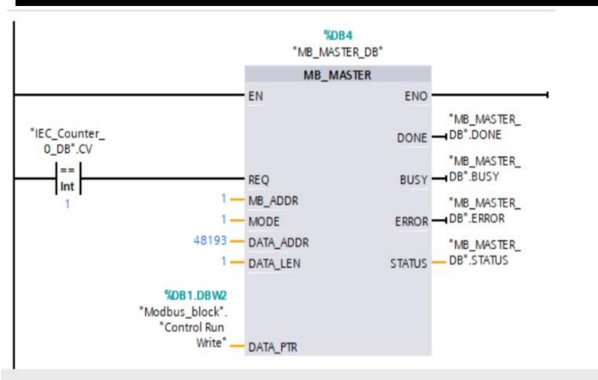

Figure 6.
In the MB_MASTER block, the PLC assigns the communication address to the drive, the address of the data to be accessed on the slave, and the data length [number of bits or words] in the Modbus function table.
Source [Siemens AG, et al. 2013]

Box 7

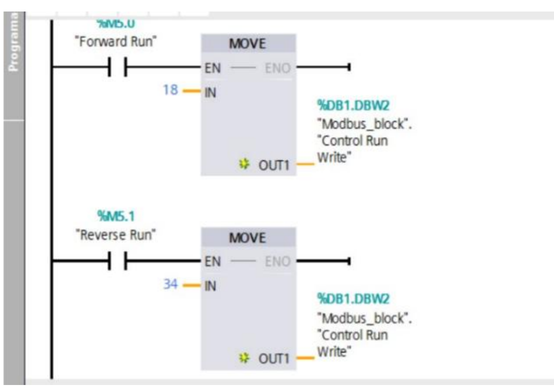

Figure 7.
In the move functions, the start, stop, reverse, and alarm commands are assigned to the slave [drive].
Source [Siemens AG, et al. 2013]

The developed prototype represents a first tangible approach to the design of an autonomous PLC system, aimed at controlling the loading and unloading of TEU containers, closely linked to the purposes of artificial intelligence [AI]. The integration of a PLC, an HMI, a frequency converter, and protection elements allowed for the creation of a robust and versatile platform that not only demonstrates the viability of automated control but also lays the groundwork for the incorporation of intelligent algorithms that optimize real-time decision-making.

The prototype demonstrates the ability to synchronize industrial devices under a secure and scalable scheme, making it an applicable model both in academia and in logistics environments that demand efficient TEU handling. Furthermore, the adopted modular infrastructure facilitates its future integration with vision systems, IoT sensors, and machine learning techniques, aimed at achieving a greater degree of operational autonomy in port terminals.

Box 8

Figure 8.
Image of the finished prototype, with its dual control and force equipment.
Source [Own elaboration]

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Conclusions

The results obtained from the design of the autonomous prototype for loading and unloading TEU containers, based on a PLC [programmable logic controller] control system, demonstrated the feasibility of integrating industrial automation technologies to optimize port terminals and linking them to artificial intelligence.

The prototype was able to reproduce in a controlled manner the essential movements of an STS crane: longitudinal movement, load raising and lowering, and spreader coupling, ensuring safe and coordinated operation between the different electrical equipment.

The design proposal incorporated the analysis and selection of electrical equipment using technical criteria, ensuring system functionality under simulated operating conditions.

Through communication with HMI interfaces and industrial communication protocols, clear visualization and management of the process was achieved, reducing operational complexity and improving efficiency compared to conventional systems. In this way, the prototype contributes not only to the advancement of port automation but also to the achievement of technological innovation and sustainability objectives by offering a scalable solution that can be adapted to real-world container handling scenarios. Consequently, it is theoretically validated that the proposed mechanism does not present critical limitations in its operation and lays a solid foundation for future applications in smart ports.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Vazquez-Gonzalez, Humberto: Contributed to the research idea, information gathering, and writing of several sections of the article, based on his professional experience.

Cruz-Gómez, Marco Antonio: Contributed to the revision of the project's writing and provided general improvement suggestions, based on his professional experience.

Mejía-Pérez, José Alfredo: Contributed to the revision and writing of various sections, based on his professional experience and electrical diagram designer.

Castillo-Pensado, Juan Luis: Contributed to the revision and writing of various sections, based on his professional experience.

Availability of data and materials

This article is a literatue review based on previously published data and documents. No new datasets were generated during this study.

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Abbreviations

AI	Artificial Intelligence
HMI	Human-Machine Interface
IoT	internet of Things
PLC	Programmable Logic Controller
STS	Ship-to-Shore
TEU	Twenty-foot Equivalent Unit
ULCS	Ultra Large Container Ship

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Article

Advanced Extrusion Machine for Transforming PET

Máquina Extrusora Avanzada para Transformar PET

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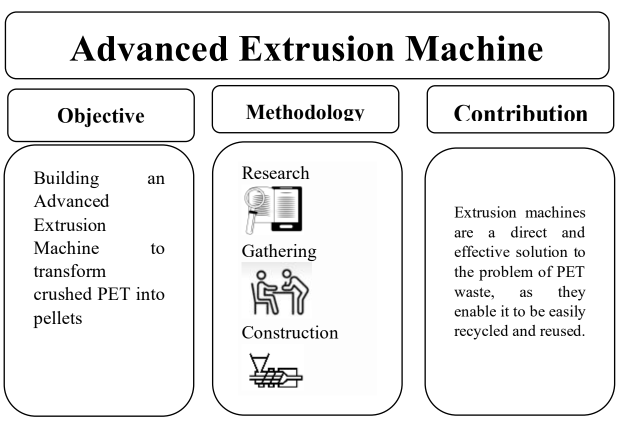
Abstract

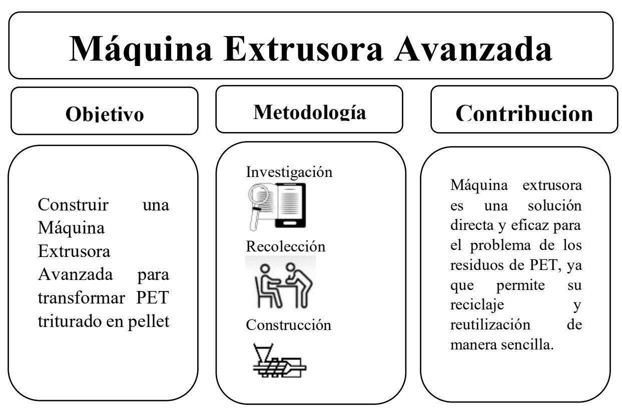
In the Microrregion One of Hidalgo, the accumulation of PET waste is causing a serious environmental crisis. To combat this, an **Advanced Extruder Machine** project is proposed. This project aims for a comprehensive solution. It aligns with **PRONACES** and focuses on preventing contamination and toxic agents resulting from poor waste management. The machine will be designed to minimize any negative impact on health and the environment. Collaboration with the municipalities of Ajacuba, Tetepango, Tezontepec de Aldama, Tlahuelilpan, and Tlaxcoapan is key. They will participate in the tests to ensure the technology is adapted to local needs. Expected results include a significant reduction in PET waste and greater environmental awareness. The Extruder Machine is a technological and sustainable solution that seeks to transform plastic waste management and protect the environment and community health.



Extrusion Machine, PET, Pellet

Resumen

En la Microrregión Uno de Hidalgo, la acumulación de residuos de PET genera una grave crisis ambiental. Para combatirla, se propone el proyecto de una **Máquina Extrusora Avanzada**. Este proyecto busca una solución integral. Se alinea con **PRONACES** y se centra en evitar la contaminación y los agentes tóxicos derivados de la mala gestión de residuos. La máquina será diseñada para minimizar cualquier impacto negativo en la salud y el entorno. La colaboración con los municipios de Ajacuba, Tetepango, Tezontepec de Aldama, Tlahuelilpan y Tlaxcoapan es clave. Ellos participarán en las pruebas para asegurar que la tecnología se adapte a las necesidades locales. Los resultados esperados incluyen una reducción significativa de residuos de PET y una mayor conciencia ambiental. La Máquina Extrusora es una solución tecnológica y sostenible que busca transformar la gestión de residuos plásticos y proteger el medio ambiente y la salud de la comunidad.



Máquina Extrusora, PET, Gránulo

Area: Development of strategic leading-edge technologies and open innovation for social transformation.

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Introduction

The construction of an advanced extrusion machine to transform PET represents a strategic and necessary response to an environmental problem affecting Micro-region One of the State of Hidalgo in the management of plastic waste, especially polyethylene terephthalate [PET].

This situation generates environmental and health risks due to the presence of toxic agents and polluting processes resulting from inadequate handling.

The problem is exacerbated by the fact that the social and economic dynamics of the municipalities involved, Ajacuba, Tetepango, Atitalaquia, Tlahuelilpan and Tlaxcoapan, do not consolidate effective recycling strategies due to a lack of institutional collaboration and technological solutions adapted to local conditions.

The Advanced Extruder Machine is conceptualised as an advanced technological solution that will not only address the accumulation of plastic waste, but will also incorporate specific measures to minimise the risks associated with toxic agents and polluting processes during the PET recycling process. The proposed extruder machine seeks to transform PET into reusable pellets, but also to change the way recycling is approached from a community, industrial, and environmentally responsible perspective. A key element in the successful development and execution of this project is collaboration with the municipalities of Micro-region One and guidance from the National Strategic Programmes [PRONACES].

The problem of polyethylene terephthalate [PET] recycling in Micro-region One of the State of Hidalgo represents a significant environmental and social challenge, with an average generation of 2,634.3 tonnes of municipal solid waste [MSW] per month [INEGI, 2021], highlighting the urgent need for sustainable technological solutions that enable this waste to be transformed into new valuable products.

The design of the Extruder Machine is based on an open-source filament extruder [see Figure 1], implemented for research and education, seeking to develop a low-cost extruder for real-time process analysis, which is necessary in the manufacture of 3D filaments.

This version facilitates the analysis of critical process variables such as temperature, rotation speed, and filament quality. Experimental validation confirmed its effectiveness under controlled conditions and flow variables.

Box 1

Figure 1
Filament extruder

Source: extrusora

The transport behaviour, evaluating virgin polypropylene, shredded polypropylene, and polyethylene powder with axial and helical grooves at speeds of up to 1350 rpm, according to Johann, Reißing, and Bonten [2022], demonstrated the influence of screw design on process efficiency for the development of extruders adapted to recycled materials such as PET.

The impact of contaminants released by plastics during their use and degradation, according to Khare and Khare [2023], highlights exposure to toxic compounds such as bisphenol A [BPA], present in plastic packaging, and its association with adverse effects on reproductive health and diseases such as breast cancer, an approach that is relevant when designing extrusion machines that allow these compounds to be safely removed during thermal recycling processes.

The extruder, which was built in-house, citing Meza, García, González, Sierra, Chávez, and Reyes [2022], consists of a carbon steel tube with an internal diameter of 1' containing another tube with a diameter of ¾', which allows for adequate conduction and thermal insulation of the 500 W resistors, placed externally, for efficient heating of the tube.

It also uses a ½" diameter, 620 mm long wood drill bit as an extruder screw with a helical geometry.

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A coupler is also used to connect the drill bit to the gear motor, allowing the screw to rotate and transport the material. A feed system constructed of carbon steel, from which the plastic falls into the extrusion chamber. And a steel outlet nozzle with a 3 mm hole, designed to increase the flow rate and shape the molten plastic.

On the other hand, for the proper processing of recycled PET by extrusion, prior drying is essential to reduce its moisture content to less than 0.02%, which is typically achieved by heat treatment at 120–150°C for 4 hours. This step prevents thermal degradation of the polymer during processing, which is commonly carried out at a temperature range of 250–270 °C.

In experimental or laboratory applications, an extrusion system with 300 W electrical resistance has been implemented, controlled by a microcontroller using a PID loop, allowing a constant temperature of 200 °C to be maintained during the process [Kang, Kim, Kim, Kim & Koh, 2023].

The value of involving local communities in sustainable recycling projects from a participatory perspective, according to Warintarawej and Nillaor [2023], mixed grouping techniques in low-income areas demonstrated that the collaborative design of solutions favours their implementation and maintenance. This experience validates the proposed model for the Advanced Extruder Machine, which envisages collaboration with the aforementioned municipalities and local collectors, who currently collect PET without adding value through transformation.

It also responds to the goals of the National Programme for the Prevention and Comprehensive Management of Waste [SEMARNAT, 2022] by promoting clean and appropriate technologies for the Mexican context.

In theory, the construction of an Advanced Extruder Machine to transform crushed PET into pellets, using SolidWorks modelling, contributes to the sustainable management of plastic waste in Micro-region One of the State of Hidalgo.

Research methodology.

For a comprehensive analysis of the composition and quantity of PET waste in the micro-region, a mixed methodology was used for the design and construction of the Extruder Machine, following the guidelines proposed by Hernández, Fernández and Batista [2014], combining qualitative and quantitative approaches to take advantage of the complementarity of engineering projects that require both the precision of numerical analysis and the depth of conceptual and regulatory analysis.

The mixed methodology allows for the integration of quantitative data collection and analysis, essential for sizing and modelling the components of the extruder, with a qualitative approach that includes the review of regulations and conceptual design analysis.

Diagnosing Main Sources of PET.

The increase in plastic waste threatens environmental health and creates waste management problems. The proposed extruder machine is positioned as a direct solution to address this problem, offering a way to recycle and reuse PET.

It is important to know the amount of MSW generated in each municipality of micro-region one, in kilograms per day: Tetepango 8,560 kg, Tlaxcoapan 20,000 kg, Tlahuelilpan 9,000 kg, Ajacuba 5,000 kg, and Tezontepec de Aldama 45,250 kg, considering that 30% is recyclable waste.

There is no precise data on PET collection, however, for two decades in Mexico, only 8% of PET containers introduced to the market were recovered, according to data from the civil association ECOCE [see Figure 2].

By mid-2023, 547,000 tonnes of PET will have been collected, indicating that more than 30 plants specialising in PET recycling recover 60% of the containers introduced into the Mexican market.

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Box 2

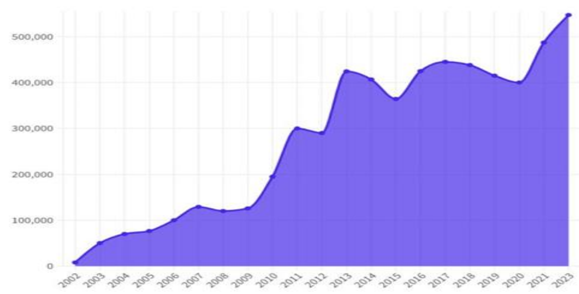

Figure 2

Collection of PET bottles in Mexico.

Source: ECOCE [2023]

Internationally, see Figure 3, Mexico ranks above countries such as Brazil, the United States, and Canada in terms of PET recovery. Although there are countries with higher recycling rates, such as China and Germany, Mexico leads the way in Latin America, putting it on a par with the European Union.

Box 3

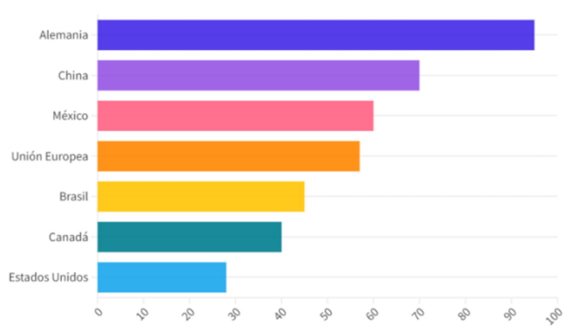

Figure 3

Statistics on PET Collection and Recycling Worldwide.

Source: ECOCE [2023]

Planning and Data Collection.

The data collected on total solid waste generation in Micro Region One of the state of Hidalgo, comprising the municipalities of Ajacuba, Atitalaquia, Tetepango, Tlahuelilpan, and Tlaxcoapan. The percentage of PET collected during the period between 2021 and August 2024 is detailed.

The research, based on a direct field approach, included visits to the municipal presidencies of each locality to gather accurate information on the quantities of PET generated in tonnes. This effort made it possible to fulfil the main objective of the research, ensuring the successful collection of the required data.

Based on the statements in Table 1, from the officials responsible for the areas of ecology and solid waste management.

Pérez [2024] shares that over the years, PET recycling and storage has decreased in the Municipality of Tlaxcoapan due to the implementation of strategies such as promoting the use of reusable bottles in schools and collection in special containers. These measures seek to reduce environmental pollution.

Box 4

Table 1

Amount of solid waste and percentage of PET.

Municipality	Years	Amount of waste solids	Percentage of waste solids	Percentage of PET	Total amount of PET
Ajacuba	2024	7500	68%	32%	2400
	2023	16500	74%	26%	4290
	2022	13200	66%	34%	4488
	2021	26000	60%	40%	10400
Tetepango	2024	11700	62%	38%	4446
	2023	17000	69%	31%	5270
	2022	15400	53%	47%	7238
	2021	23000	79%	21%	4830
Atitalaquia	2024	10000	62%	38%	3800
	2023	19200	73%	27%	5184
	2022	18900	69%	31%	5859
	2021	22300	67%	33%	7359
Tlahuelilpan	2024	8000	63%	37%	2960
	2023	12000	68%	32%	3840
	2022	12300	76%	24%	2952
	2021	15600	63%	37%	5772
Tlaxcoapan	2024	6000	59%	41%	2460
	2023	15000	71%	29%	4350
	2022	17800	68%	32%	5696
	2021	21000	75%	25%	5250

The Municipality of Ajacuba, to paraphrase Carranza [2024], has several resorts where PET waste from soft drinks and bottled water is generated; this waste is collected and sorted by municipal rubbish trucks to determine the total amount of solid waste and the percentage of PET generated annually.

Ultimately, the interviews conducted reflect local efforts to efficiently manage PET, despite the challenges associated with the generation and collection of this waste in the region.

Building the Extruder Machine Using Solidworks Modelling.

The feasibility of the project is supported by the availability of technologies such as SolidWorks and access to efficient materials. In addition, potential risks will be thoroughly evaluated, ensuring the safety of the project and reducing vulnerability to possible inconveniences.

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Developing Three-Dimensional Models Using SolidWorks Software.

The dimensioning of the spindle, including torsion, bending and fatigue verification, the definition of adjustments and tolerances for the barrel and its assemblies, and the design of bolted joints with their corresponding preload and tightening torque were carried out in accordance with Shigley's criteria [Budynas & Nisbett, 2015].

Given the thermal regime of the extrusion, the effects of temperature on properties and assembly clearances were incorporated, and the model was validated using finite element analysis [FEA] before issuing the graphic documentation.

When gathering essential information, including dimensions, specifications, and design constraints, see Figure 4, which shows the spindle.

Box 5

Figure 4
Spindle.

The assemblies are part of the components where geometric and dimensional constraints were applied to ensure their functionality and proper fit, in addition to materials and properties, by assigning materials to simulate physical behaviours such as strength and weight.

Barrel

Subsequently, the requirements were verified, dimensions were adjusted, and movement tests were performed to ensure the quality of the design, resulting in graphic documentation.

Construction of the Extruder Machine in 3D Printing.

In the development of the complete three-dimensional model in SolidWorks, citing Serrano, Castellanos, and Maturano, [2025], the dimensions, tolerances, and materials necessary for the manufacture of the prototype are specified; this model, see Figure 5, served as the basis for all subsequent phases of design and performance simulation.

Box 6

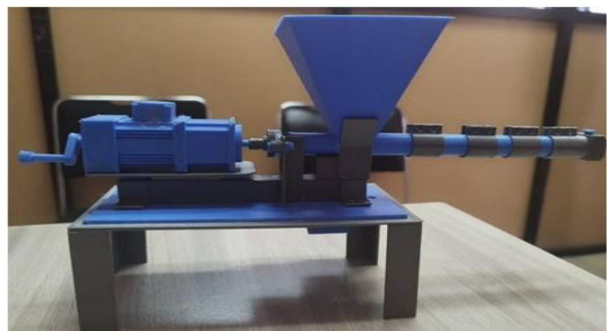

Figure 5
Prototype of a 3D extruder machine.

Component Specifications.

Functional extruder prototype designed for processing and melting recycled PET; the equipment has a simple extrusion system with gear motor, steel screw, heated barrel and digital temperature control, for laboratory testing or academic development.

Extruder type: Single screw.

Single screw extruder, a machine that uses a single heated cylinder to transform plastic material into a specific format. According to the fundamentals, see Table 2, of the design and operation of single screw extruders, the recommended rotation speed, expressed in revolutions per minute [RPM], depends on multiple technical variables.

Box 7
Table 2
Recommended Speed in RPM for Single-Screw Extruder.

Speed	RPM
Low speed	20-60
average speed	60-100
speed high	100-150+

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The recommended temperature in a single-screw extruder [see Table 3] is primarily determined by the type of polymer being processed, as each material has a specific melting range and characteristic thermal behaviour.

Box 8

Table 3

Recommended Speed in RPM for Single-Screw Extruder.

Material	Feeding area	Compression zone	Dosing zone	Nozzle
PE [polyethylene]	160-180	180-200	200-220	200-220
PP [polypropylene]	170-190	190-210	210-230	210-230
Rigid PVC	150-170	160-180	170-185	170-185
Flexible PVC	140-160	160-170	170-180	170-180
PET	230-250	250-270	270-280	270-280
ABS	180-200	200-220	220-230	220-230
PS [polystyrene]	170-190	190-210	210-230	210-230

Formula for calculating the extruder speed in RPM:

$$Velocidad\ del\ husillo(RPM) = \frac{[1000 \times Velocidad\ de\ corte\ [V]]}{[\pi \times Diámetro\ de\ herramienta\ [D]]} \quad [1]$$

Source : Cálculo de velocidad del husillo

Spindle speed [RPM]: Revolutions per minute at which the spindle must rotate.

Cutting speed [V]: Tangential speed of the tool or workpiece in metres per minute [m/min]. Depends on the material and type of operation.

Tool diameter [D]: Diameter of the tool or workpiece in millimetres [mm].

π [pi]: Mathematical constant, approximately 3.1416. [Maria, 2025]

Capacity of the conical container.

Top diameter 23 cm, height 22 cm, volume [approximate] 7.6 litres.

For the classification of the extruder, see Figure 6, which gives the diameter and length of the screw in a ratio *L*/*D* representing the length and diameter of the screw. The most common extruders are those with a screw diameter between 25.00 mm and 250.00 mm, and a length up to forty times the diameter. 25.00 mm and 250.00 mm, and a length up to forty times the diameter.

Box 9

Figure 6

Conical hopper.

Motorredutor.

Motorredutor monofásico, ver Figura 7 [motor com redutor de velocidade integrado], Tensão de funcionamento: 127 V [corrente alternada monofásica], Frequência: 60 Hz, marca WEQ, função transmite potência mecânica a baixas rotações, combinando um motor elétrico com um sistema de engrenagens redutoras para aumentar o binário e reduzir a velocidade de saída.

Box 10

Figure 7

Gear motor

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Screw.

The screw, see Figure 8, is one of the key elements of the extrusion system, specifically designed for the efficient processing of recycled PET flakes.

The technical specifications of the screw are as follows: nominal diameter of 9/16 inches [14.3 mm] and total length of 48 cm.

The helical design consists of 32 threads with a uniform pitch, arranged in a left-hand direction, which requires the direction of rotation [as seen from the hopper] to be clockwise to ensure the correct advancement of the material.

This design allows for controlled internal friction, promoting heat transfer and facilitating the transition of the polymer from a solid to a molten state. Along the way, the screw transports the PET from the hopper to the nozzle, progressively compressing it and ensuring a homogeneous feed in the extrusion zone.

Box 11

Figure 8
Husillo

PET Extruder Barrel

Structural and Functional Characteristics.

High-strength steel construction material, obtained through precision machining from solid bar with a nominal diameter of 9/16 inches.

Dimensions: total length 48 centimetres, internal diameter designed to fit 9/16" spindles, ensuring efficient axial displacement without loss of molten PET.

Technical Specifications of the Extrusion Nozzle.

The nozzle is the point through which the molten filament is expelled and controls the profile of the extruded material" [3Dwork Labs, n.d., para. 1].

The extrusion nozzle, see Figure 9, also known as a nozzle, is the terminal component of the extruder system, through which the molten polymer is directed and moulded into its final shape.

Construction material: AISI 304 or 316 stainless steel, recognised for its corrosion resistance and thermal stability [Material Mundial, s. f.].

Box

Figure 9
Extrusion nozzle

Functional Specifications of the Nozzle Support

Type 1 bearing [commonly classified as a mounted bearing] "is a mounted bearing used to support a rotating shaft" [BRR Mexico, 2019, para. X].

The die holder is a critical element of the extruder system: in addition to its structural function, it improves flow stability, operational efficiency and, consequently, the quality of the extruded product.

Structural Base Support for Recycled PET Extruder.

The structural support [see Figure 10] is a key element in the mechanical architecture of the extruder, whose essential function is to provide a firm and aligned base that absorbs and distributes the loads generated during continuous operation of the equipment.

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Box 13

Figure 10
Structural support

Electric Heating System

These products, made of aluminium, are resistant to oxidation and high temperatures. In addition, they maintain uniform heat distribution around the tube, reducing thermal irregularities [Vaqueiros Ferreteros, 2022].

In this project, cartridge or band electric resistors, powered at 127 V, with an operating range of 100 °C to 400 °C, were integrated, specifically designed to achieve stable working temperatures in continuous extrusion environments.

Thermal Instrumentation Using Type Y Sensors.

Made from a combination of iron and a copper-nickel alloy, with limited use in oxidising environments; it has a temperature range between 0°C and 750°C. Thermocouples operate on the basis of two metal wires of different materials joined at one end, known as a hot junction or measuring junction [SRC, 2018].

The installation of a sensor in each of the independent thermal zones of the barrel [feed zone and compression/metering zone] allows the thermal profile to be monitored with high resolution, preventing both overheating and unwanted cooling that could affect the viscosity of the molten polymer.

Thermal Control System

To achieve precise and efficient thermal control during the polyethylene terephthalate [PET] extrusion process, REX-C100 digital temperature controllers were implemented, widely recognised in industrial applications for their reliability, versatility and low operating cost.

Each REX-C100 controller is coupled to a Y-type sensor [thermocouple] made of stainless steel, which offers corrosion resistance, impermeability, and durability under demanding thermal conditions. This sensor captures the temperature in real time in each zone of the barrel, while the controller regulates the supply of electrical power to the heating elements by means of a solid-state or mechanical relay, thus ensuring constant and precise heat transfer.

Power Supply Specifications and System Operating Conditions.

The extrusion system is configured to operate with a 127 V alternating current [AC] supply, a specification compatible with domestic networks and conventional industrial installations in Mexico. This compatibility guarantees not only a stable connection to the electrical network, but also efficient and safe energy operation under continuous operating conditions.

Operational thermal capacity: the equipment has a thermal control range from 100 °C to 400 °C, allowing its use in applications with high thermal demands, such as the transformation of recycled polymers. This ensures that the material reaches its melting point without compromising its structural integrity or generating thermal degradation processes. It is recommended to operate the equipment in a ventilated environment to facilitate the dissipation of heat generated during the extrusion process and to avoid exposure to environments with relative humidity or direct contact with liquids.

Uses and Applications.

The tests represent a stage in the validation of the use of recycled PET as a secondary raw material, allowing quality protocols to be established for its reintroduction into production processes. Its implementation strengthens environmental sustainability initiatives by reducing dependence on virgin polymers and minimising the volume of plastic waste sent to final disposal. The equipment is positioned as a portable engineering testing laboratory, useful for higher education institutions and technological innovation centres operating in this region, enabling the development of skills in the field of recycling and the transformation of thermoplastic materials.
These tests promote:

The training of local talent in micro-region one, specialising in the processing of recycled polymers.

The transfer of scientific and technological knowledge to local productive sectors in micro-region one, recyclers [small industries, workshops, cooperatives].

The development of community-based projects that bring together students, teachers and social actors in tangible solutions to environmental problems arising from the improper management of PET in micro-region one.

The PET extruder in this project plays an essential role as a technical-experimental validation platform for studying the thermal and mechanical parameters involved in the extrusion process of recycled materials. Its operation allows for the collection of empirical data relevant to the design, control, and optimisation of polymer processing systems. This system is adapted to SECIHTI's strategic axes for use in applied research, specialised teaching and professional training in higher education institutions in the municipalities of Ajacuba, Tetepango, Tlaxcoapan, Atitalaquia and Tlahuelilpan, which make up Micro Region One of the State of Hidalgo.

Manufacturing Materials.

9/16‘ steel for spindle and barrel. Steel was selected for its mechanical and thermal resistance. The 9/16’ diameter, converted to 14.3 mm, may be too small if a higher flow rate is required. Bear in mind that PET is abrasive and corrosive when melted, and direct contact with unprotected carbon steel can wear down the material.

Electrical resistors [127V, up to 400°C] The appropriate resistance in terms of voltage and temperature for PET, which melts between 250 and 280°C.

Thermal efficiency depends on the type and location, and the heating bands need good heat transfer to avoid cold spots, which cause jams, so they are suitable for extruder manufacturing.

Type Y Temperature Sensor [2 units]. It is important to control small thermal fluctuations, because PET can crystallise if it cools unevenly.

An alternative would be a K-type thermocouple with a metal sheath and flat tip, as this has a range of -200 °C to 1260 °C and a fast thermal response.

WEQ gear motor, 127V, 60 Hz. WEQ is good for general use. The 127V makes it suitable for domestic mains power; the essential factors are output torque and RPM. In terms of interaction with PET, the motor moves the spindle against the resistance of the molten material, so it must be capable of operating at low RPM [30-80] with high torque.

Bearing washers, metal base plate and aluminium nozzle. The bearing washer supports the shaft and facilitates rotation, the metal base plate serves as a frame, and the aluminium nozzle is lightweight and easy to work with.

Limitations.

The prototype will be designed to process only PET [polyethylene terephthalate] in the form of clean, dry and sorted flakes. The system's capacity will be experimental, with a processing flow of less than 7.5 kg/h, which is sufficient to validate the thermomechanical principles of extrusion and demonstrate the basic functionality of the design. Auxiliary systems such as crushing, washing, pelletising or advanced automation are not contemplated.

The estimated budget for the development of the prototype is $7,200 MXN. This figure includes basic mechanical and electrical components, recyclable or reusable materials, and existing tools at ITSOEH. The financial feasibility is based on partial contributions from the institution, teachers and students. The purchase of specialised machinery or high-cost industrial simulation software is not contemplated.

The work team is composed of industrial engineering research teachers who are technical leaders of the project, students, and occasional support from institutional laboratory staff.

Impact.

The project's influence is felt at different levels, and its impact will be both direct and collateral, with expected and even unforeseen effects. It contributes to the environment by reducing plastic waste, promoting a culture of recycling and a circular economy.

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https://doi.org/10.35429/JOTI.2025.9.22.4.1.13

By transforming post-consumer PET into new products through extrusion, its improper disposal is avoided and waste recovery is promoted.

The development represents a low-cost economic solution for educational institutions and communities with limited resources, opening up the possibility of replicating the technology at the local level. The project could scale up to social recycling micro-enterprises, generating jobs and using plastic waste as a productive input.

Through the design and validation of the prototype, the culture of mechanical design, basic automation and rational energy use is strengthened. As a secondary impact, technical documentation and the use of computer-aided design [CAD/CAE] tools are promoted. From a social perspective, the project can influence environmental awareness in Micro Region One of the state of Hidalgo. By demonstrating that it is possible to transform PET locally, it promotes a sustainable and replicable educational model that can impact vulnerable communities if it is extended as a social programme.

Results

Obtained during the development of the project 'Construction of an advanced extruder machine prototype for PET recycling', with relevance, functionality and replicability in Micro Region One of the state of Hidalgo, made up of the municipalities of Ajacuba, Tetepango, Tlaxcoapan, Atitalaquia and Tlahuelilpan, a priority area served by SECIHTI's strategic programme in its line of action on the environment and territorial sustainability.

Construction of extruder machine, see Figure 11. The prototype was designed using CAD software [SolidWorks], integrating a hopper feeding system, worm screw, band-type resistance heating zone and interchangeable extrusion nozzle.

The machine was manufactured with carbon steel and low-cost materials, a band-type resistance heating zone and an interchangeable extrusion nozzle.

Box 14

Figure 11

Construction of Extruder Machine, Barrel, Gear Motor and Components

The machine incorporates

- Feed hopper with non-return system
- 1045 steel screw, variable pitch [5-15 mm]
- Extrusion zone heated by band-type heating elements [2 x 250 W]
- PID controller for temperature regulation
- Interchangeable nozzles depending on the desired product

Technical Specifications of the PET Extruder Machine, see Annex 1, which shows its main design features, mechanical specifications, heating and control system, as well as operating conditions. The document contains information on uses and applications, the technical assurance plan implemented, the manufacturing process, the tests carried out, the integration of the work team, and a financial breakdown associated with the development of the prototype, including materials, software, tools, technical fees, travel, and dissemination of results.

Conclusions

The results achieved in this project allowed for the characterisation of the quantity, composition, and sources of PET generation in the municipalities that make up Microregion One, through the application of analytical methods and structured sampling techniques.

This information was essential for establishing the technical parameters required in its transformation process. An advanced extruder machine was also constructed, developed from SolidWorks modelling and integrated with applied engineering principles, prioritising thermal and mechanical efficiency.

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The resulting prototype proved to be functional and replicable within the territorial context of Microregion One, offering a viable solution for PET utilisation and promoting sustainable plastic waste practices. A technically functional system was successfully implemented, but follow-up is required to consolidate its efficiency, scalability, and durability in the medium and long term.

Attachments

Appendix 1

Table 1

Technical Specifications

FICHA TÉCNICA DE MAQUINARIA

Nombre del equipo: Máquina Extrusora de Plástico PET – Prototipo

Modelo: EX-PET/IND-01

Categoría: Prototipo académico

Diseñado por: Ingeniería Industrial

DESCRIPCIÓN GENERAL:

Prototipo funcional de extrusora de plástico diseñado para el procesamiento y fundido de PET reciclado. El equipo cuenta con un sistema de extrusión simple con moto-reductor, husillo de acero, cañón calefaccionado y control digital de temperatura, especialmente pensado para pruebas de laboratorio o desarrollo académico.

CARACTERÍSTICAS PRINCIPALES:

- Tipo de extrusora: Monohusillo
- Material a procesar: Plástico PET reciclado (termofundido)
- Capacidad del contenedor cónico:
- Diámetro superior: 23 cm
- Altura: 22 cm
- Volumen (aproximado): 7.6 litros

ESPECIFICACIONES MECÁNICAS:

- Moto-reductor: Marca WEQ, 127V, 60 Hz
- Velocidad de husillo: 50–60 rpm
- Husillo:
- Material: Acero
- Diámetro: 9/16" (14.3 mm)
- Longitud: 48 cm
- Hélices: 32, dirección izquierda
- Cañón:
- Material: Acero, barra 9/16"
- Longitud: 48 cm
- Boquilla:
- Enganche: Cuerda milimétrica compatible con cañón de aluminio
- Soporte: 1 rondana tipo chumacera para sostén de base
- Soporte estructural:
- Tipo escuadra al inicio del cañón
- Fabricado en solera metálica

SISTEMA DE CALEFACCIÓN Y CONTROL:

- Resistencias:
- Cantidad: 5
- Ubicación: Distribuidas a lo largo del cañón
- Especificaciones: 127V, rango de temperatura de 100°C a 400°C
- Sensores de temperatura:
- Tipo: Sensor tipo Y
- Cantidad: 2 (uno por zona de control)
- Controladores:
- Modelo: REX-C100
- Función: Control independiente por zona del cañón

CONDICIONES DE OPERACIÓN:

- Alimentación eléctrica: 127V AC
- Rango de trabajo térmico: 100–400 °C
- Ambiente recomendado: Área ventilada, sin humedad excesiva

USOS Y APLICACIONES:

- Pruebas de extrusión con PET reciclado
- Formación académica y pruebas de ingeniería
- Validación de variables térmicas y mecánicas del proceso

OBSERVACIONES:

Este equipo es un prototipo académico. Su diseño está orientado a experimentación, investigación y formación de estudiantes en procesos de transformación de plásticos, no para producción industrial continua.

1. Plan de Aseguramiento Técnico del Material

Este plan contempla los **recursos necesarios para el diseño, fabricación y prueba** del prototipo de la máquina extrusora, garantizando su funcionamiento seguro y preciso dentro del entorno académico.

Recursos requeridos por etapa:

a) Diseño:

- Software CAD 3D: SolidWorks o AutoCAD para modelado estructural y mecánico.
- Manuales técnicos de materiales termoplásticos (PET).
- Referencias normativas para diseño de extrusoras (ANSI, ISO 12100).

b) Fabricación:

- Acero 9/16" para husillo y cañón.
- Resistencias eléctricas (5 unidades, 127V, hasta 400 °C).
- Sensor de temperatura tipo Y (2 unidades).
- Moto-reductor marca WEQ, 127V, 60 Hz.
- Rondanas tipo chumacera, solera metálica y boquilla de aluminio.
- Herramientas: torno, soldadora, cortadora y prensa.

c) Prueba del prototipo:

- Multímetro y pinza amperimétrica para verificar conexiones eléctricas.
- Termómetro digital infrarrojo para validación térmica.
- PET reciclado como material base para pruebas de extrusión.
- Guantes térmicos, lentes de seguridad y extractores de humo para laboratorio.

2. Relación de Recursos Humanos Involucrados

Rol	Función Principal	Experiencia Técnica Requerida
Líder de Proyecto	Coordinación general, cronograma, gestión de recursos	Conocimientos en gestión de proyectos y manufactura
Diseñador CAD	Modelado 3D del prototipo, diseño de husillo, soporte y cañón	Dominio de SolidWorks y fundamentos de diseño mecánico
Técnico en Procesos de Plástico	Selección de parámetros de extrusión y pruebas de PET	Conocimiento en polímeros, extrusión y seguridad de laboratorio
Técnico Eléctrico	Instalación de resistencias, sensores y controladores	Experiencia en sistemas de calefacción y control de temperatura
Operador de Taller Mecánico	Corte, soldadura y ensamble de piezas estructurales	Manejo de maquinaria de taller (torno, soldadora, cortadora, prensa)
Docente Asesor: Ing. Sergio Serrano	Supervisión técnica, validación académica del proceso	Experiencia en ingeniería mecánica o industrial, validación de prototipos

3. Desglose Financiero Preliminar

Este presupuesto cubre insumos, herramientas, software, validaciones y capacitación básica:

Categoría	Concepto	Costo (MXN)
Materiales e insumos	Acero, aluminio, resistencias, sensores, cableado	$2800
	Moto-reductor WEQ 127V	$0(Prestación del torno)
	Boquilla, rondanas, estructura metálica	$500
Herramientas y procesos	Corte, soldadura y maquila en taller	$3900
Software	Licencia SolidWorks educativa	$0 (uso académico)
	Simulación térmica (uso interno o gratuito)	$0(uso interno)
Capacitación y seguridad	Manual de operación, protocolo de seguridad	$0(uso académico)
	Equipo de protección personal (EPP)	$0(uso académico)
Validación técnica	Termómetro IR, pruebas eléctricas y térmicas	$0(uso interno)
TOTAL		**$7,200 MXN**

Declarations

Conflict of interest

The authors declare that they have no conflicts of interest. We have no financial interests or personal relationships that could have influenced the research described in this article.

Author contribution

The contribution of each researcher to each of the points developed in this research was defined based on:

Serrano-González, Sergio: Contributed the original idea for the project and the conceptual design of the Advanced Extruder Machine for Transforming PET. Defined the objectives, research methodology, and technical parameters of the prototype. He performed the analysis of experimental data, the interpretation of results, and the integration of the proposal into a continuous improvement model. He also prepared the discussion, conclusions, and final draft of the article.

Castellanos-López, Liliana Yadira: She supported the methodological design of the research and the structuring of the theoretical framework related to plastic extrusion and PET recycling technologies. She collaborated in the validation of the data collection instruments and in the critical review of the technical sections. She also contributed to the writing and academic correction of the manuscript.

Maturano-Maturano, Benito Armando: Participated in the execution of experimental tests of the extrusion prototype, compiling technical and operational information. He collaborated in the search and systematisation of scientific and technological background information on advanced PET extrusion. He contributed to the processing of information and the partial writing of the document.

Alvarado-Reséndiz, José Luis: He collaborated in the experimental phase by compiling and organising the operating data of the extrusion machine. He assisted in the preparation of tables, figures and technical results of the prototype. In addition, he contributed to the editing and writing of sections of the article.

Availability of data and materials

The data supporting the results of this research were obtained from experimental tests carried out on the prototype of the Advanced Extrusion Machine for PET transformation, designed and developed at the facilities of the Instituto Tecnológico Superior del Occidente del Estado de Hidalgo [ITSOEH]. The data generated and analysed during this study were collected from Micro Region One of the State of Hidalgo, in municipal presidencies, ECOCE, SEMARNAT and INEGI.

Funding

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Abbreviations

PET	Polyethylene terephthalate is a thermoplastic polymer used in packaging and textiles due to its high strength and recyclability, [Castro, 2025].
BPA	Bisphenol A is a chemical substance used in combination with other substances to manufacture plastics and resins, [Autoridad Europea de Seguridad Alimentaria, 2025]
PID	The algorithm calculates the deviation or error between a measured value and a desired value. It consists of three different parameters: proportional, integral, and derivative. [Erazo-Velasco, 2022]
RSU	This is waste generated in homes, resulting from the disposal of materials used in domestic activities. [SEMARNAT, s. f.]
CAD	[Computer-Aided Design] o Computer-aided design refers to the set of digital software tools used in the design process, [Rodríguez & Rodríguez, 2024].
CAE	[Computer-Aided Engineering] is the application of computer tools to analyse the behaviour of the model created in CAD. [Reviriego & Reviriego, 2025]
RREX-C100	The REX-C100 PID temperature controller allows you to monitor and control the temperature in basic systems. [REX-C100 PID Temperature Controller SSR Output, n.d.]
RPM	Revolutions per minute is a unit of measurement used to express frequency or angular velocity and indicates the number of rotations per minute completed by a rotating body. [*¿Qué Es un RPM y Cómo Funciona?*, s. f.]

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[Title in Times New Roman and Bold No. 14 in English and Spanish]

Surname, Name 1st Author*[a], Surname, Name 1st Co-author[b], Surname, Name 2nd Co-author[c] and Surname, Name 3rd Co-author[d] [No.12 TNRoman]

[a] ROR Affiliation institution, Researcher ID, ORC ID, SNI-SECIHTI ID or CVU PNPC [No.10 TNRoman]
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Must contain up to 150 words
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Text in TNRoman 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.

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Development of headings and subheadings of the article with subsequent numbers

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In the article content any 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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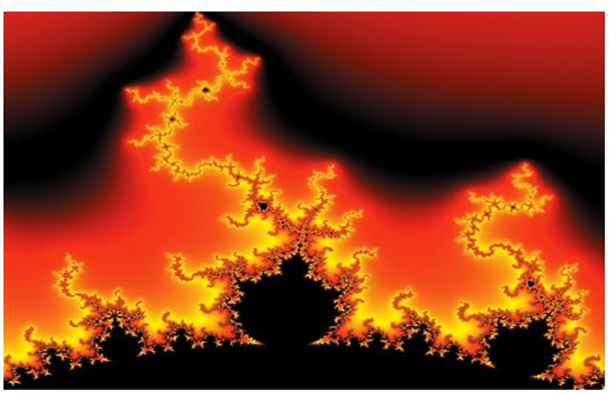
Box



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For the use of equations, noted as follows:

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

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Methodology

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Tables and adequate sources.
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Specify the contribution of each researcher in each of the points developed in this research.

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Benoit-Pauleter, Gerard: Contributed to the project idea, research method and technique.

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Indicate the availability of the data obtained in this research.

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Indicate if the research received some financing.

Acknowledgements

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

Abbreviations

List abbreviations in alphabetical order.

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ANN	Artificial Neural Network

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