Article

Platform lifting system for autonomous vertical parking

Sistema de elevación de plataforma para estacionamiento vertical autónomo

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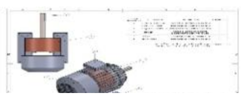
Abstract

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.

Objective

- 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

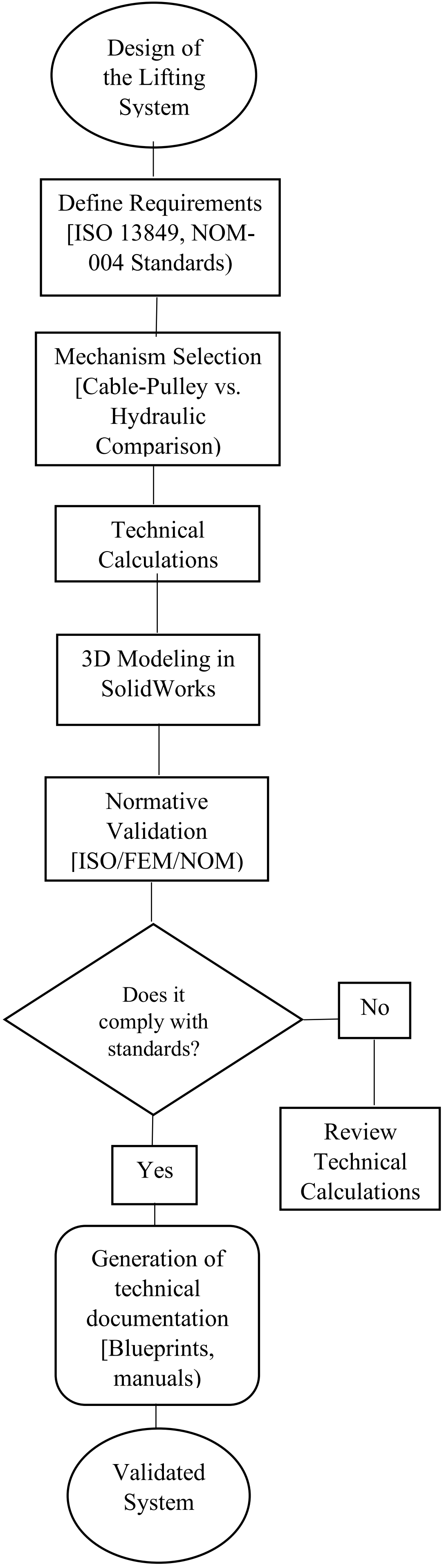

Figure 1

Flowchart of the methodology used.

Own elaboration.

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:

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

b] Motor Power [with 50% counterweight]:

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

A 65 kW commercial motor was selected.

c] Cable diameter:

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

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

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

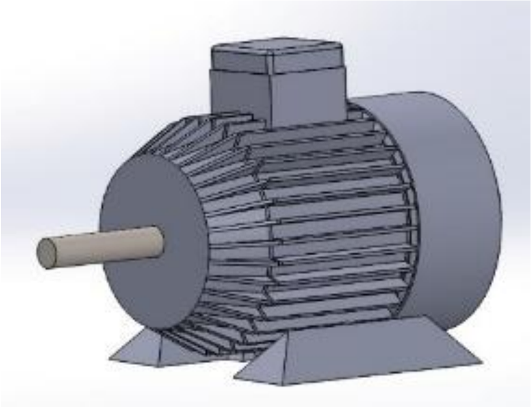

Figure 2
Motor Assembly.

Own elaboration.

Rodríguez-Cortes, Aldo, Fuentes-Castañeda, Pilar, Betanzos-Castillo, Francisco and Cortez-Solís, Reynaldo. [2025]. Platform lifting system for autonomous vertical parking. Journal of Technical Invention. 9[22]1-9: e1922109.
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Helical Gearbox 20:1 [2 stages: 4:1 + 5:1]

Box 6

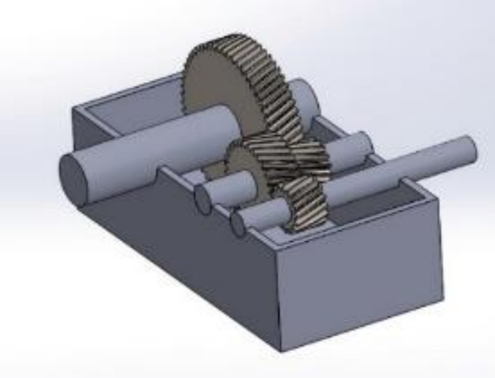


Figure 3
Gearmotor Assembly.

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

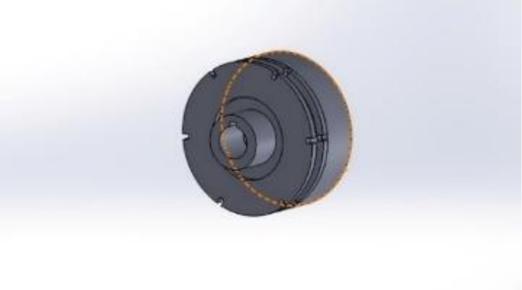


Figure 5
Electromagnetic Brake Assembly.

Own elaboration.

Passive Emergency Brake [activates upon power failure].

Box 9

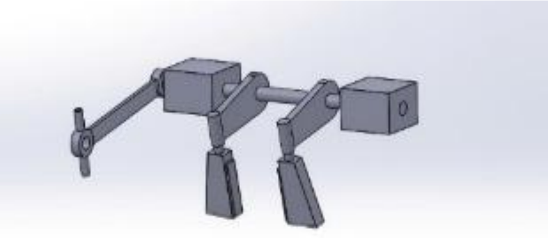


Figure 6
Emergency Brake Assembly.

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

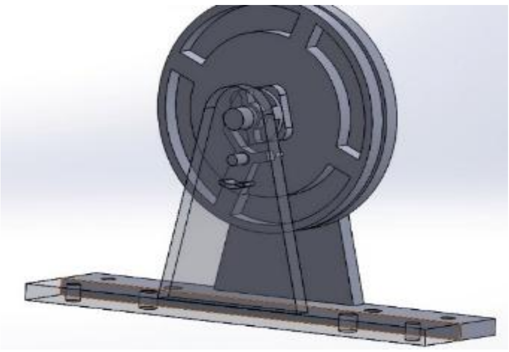


Figure 7
Speed Limiter Assembly.

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.

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

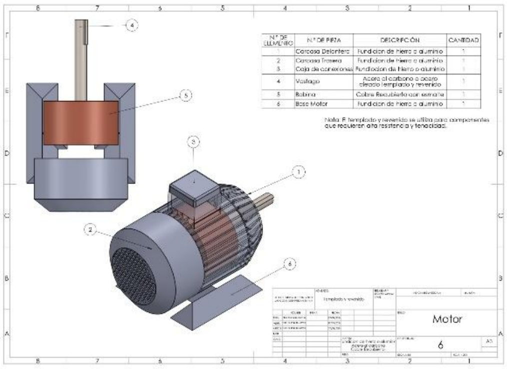
Compliance with Standards

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



N.º DE ELEMENTO	N.º DE PIEZA	DESCRIPCIÓN	CANTIDAD
1	Carcasa Delantera	Fundicion de hierro o aluminio	1
2	Carcasa Trasera	Fundicion de hierro o aluminio	1
3	Caja de conexiones	Fundicion de hierro o aluminio	1
4	Vastago	Acero al carbono o acero aleado templado y revenido	1
5	Bobina	Cobre Recubierto con esmalte	1
6	Base Motor	Fundicion de hierro o aluminio	1

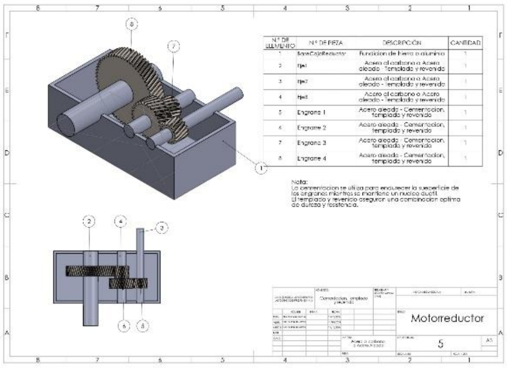
Nota: El templado y revenido se utiliza para componentes que requieren alta resistencia y tenacidad.

Figure 8

Motor Plan with Material Specifications.

Own elaboration.

Box 18



N.º DE ELEMENTO	N.º DE PIEZA	DESCRIPCIÓN	CANTIDAD
1	BaseCajaReductor	Fundicion de hierro o aluminio	1
2	Eje1	Acero al carbono o Acero aleado - Templado y revenido	1
3	Eje2	Acero al carbono o Acero aleado - Templado y revenido	1
4	Eje3	Acero al carbono o Acero aleado - Templado y revenido	1
5	Engrane 1	Acero aleado - Cementacion, templado y revenido	1
6	Engrane 2	Acero aleado - Cementacion, templado y revenido	1
7	Engrane 3	Acero aleado - Cementacion, templado y revenido	1
8	Engrane 4	Acero aleado - Cementacion, templado y revenido	1

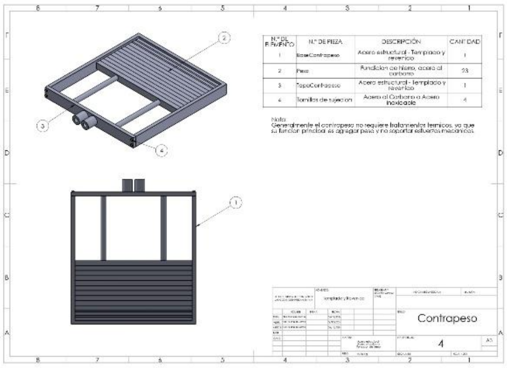
Nota:
La cementacion se utiliza para endurecer la superficie de los engranes mientras se mantiene un nucleo ductil.
El templado y revenido aseguran una combinacion optima de dureza y resistencia.

Figure 9

Gear Motor Plan with Material Specifications.

Own elaboration.

Box 19

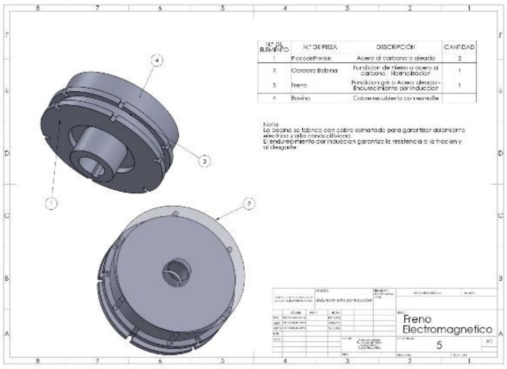


N.º DE ELEMENTO	N.º DE PIEZA	DESCRIPCIÓN	CANTIDAD
1	BaseContrapeso	Acero estructural - Templado y revenido	1
2	Peso	Fundicion de hierro, acero al carbono	23
3	TopeContrapeso	Acero estructural - Templado y revenido	1
4	Tornillos de sujecion	Acero al Carbono o Acero Inoxidable	4

Nota:
Generalmente el contrapeso no requiere tratamientos termicos, ya que su funcion principal es agregar peso y no soportar esfuerzos mecanicos.

Figure 10
Counterweight Plan with Material Specifications.
Own elaboration.

Box 20

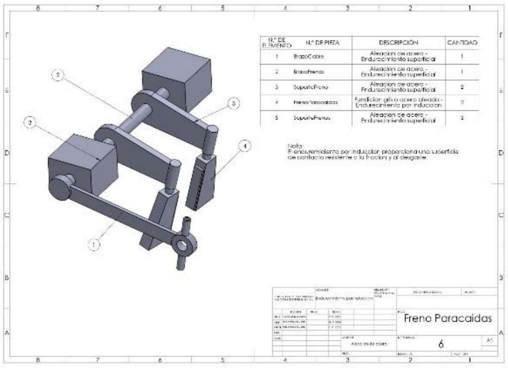


N.º DE ELEMENTO	N.º DE PIEZA	DESCRIPCIÓN	CANTIDAD
1	PlacadePresion	Acero al carbono o aleado	2
2	Carcasa Bobina	Fundicion de Hierro o acero al carbono - Normalizacion	1
3	Freno	Fundicion gris o Acero aleado - Endurecimiento por induccion	1
4	Bovina	Cobre recubierto con esmalte	

Nota:
La bobina se fabrica con cobre esmaltado para garantizar aislamiento electrico y alta conductividad.
El endurecimiento por induccion garantiza la resistencia a la friccion y al desgaste.

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

Box 21

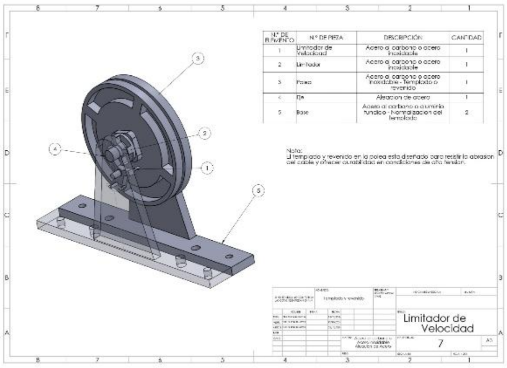


N.º DE ELEMENTO	N.º DE PIEZA	DESCRIPCIÓN	CANTIDAD
1	BrazoCable	Aleacion de acero - Endurecimiento superficial	1
2	BrazoFrenos	Aleacion de acero - Endurecimiento superficial	1
3	SoporteFreno	Aleacion de acero - Endurecimiento superficial	2
4	FrenoParacaidas	Fundicion gris o acero aleado - Endurecimiento por induccion	2
5	SoporteFrenos	Aleacion de acero - Endurecimiento superficial	2

Nota:
El endurecimiento por induccion proporciona una superficie de contacto resistente a la friccion y al desgaste.

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

Box 22



N.º DE ELEMENTO	N.º DE PIEZA	DESCRIPCIÓN	CANTIDAD
1	Limitador de Velocidad	Acero al carbono o acero inoxidable	1
2	Limitador	Acero al carbono o acero inoxidable	1
3	Polea	Acero al carbono o acero inoxidable - Templado o revenido	1
4	Eje	Aleacion de acero	1
5	Base	Acero al carbono o aluminio fundido - Normalizacion del templado	2

Nota:
El templado y revenido en la polea esta diseñado para resistir la abrasion del cable y ofrecer durabilidad en condiciones de alta tension.

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].

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.

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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