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Magnetic Levitation Technology in Trains: a systematic literature review from 2018 to 2023

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SUMMARY- *The purpose of this systematic review is to offer a compilation of information about the technological advances of magnetic levitation applied in trains from the years 2018 to 2023. To collect information, used he seeker Scopus, where we first started with an unfiltered search for the topic to be investigated, thus obtaining a total of 2392documents; After applying a series of filters through the PRISMA selection process, a total of 114 documents that were used for the final development that of the systematic review. Finally, it is concluded that magnetic levitation applied to trains offers a series of advantages in terms of efficiency, speed, and sustainability. However, continued investment and development is still required to overcome challenges and achieve wider implementation in rail transport globally.*

KEYWORDS: *Magnetic Levitation, Superconductors, Trains, Scopus.*

I. INTRODUCTION

Rail transport has advanced rapidly, reducing temporal and spatial distances between people, improving their travel experiences and contributing significantly to economic and social progress. In the constant search for efficient and sustainable changes for modern transportation, magnetic levitation emerges as a revolutionary innovation that redefines the possibilities of railway systems. Magnetic levitation technology, known as maglev, has been the subject of academic interest since the 1960s. Countries such as Germany, Japan, the United States, China, Brazil and South Korea have investigated this technology, but Germany and Japan stand out for its advances, thanks to its early investments in research and development. China has also been actively involved in the development of maglev technology in recent years, using approaches including introduction, absorption, assimilation and reinvention [1].

Magnetic levitation is an engineering principle that uses magnetic fields to suspend and maintain objects in the air without physical contact with any solid surface. It is achieved through the use of superconducting magnets that generate extremely powerful and stable magnetic fields. This technology is used in applications such as magnetic levitation (maglev) trains, in which trains float on a magnetic track and travel at high speeds with very little friction, making them efficient and fast. It is also used in scientific experiments and industrial applications where precise control of the position of objects without physical contact is required.[2].

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Magnetic levitation in superconductors represents a fascinating manifestation of fundamental physical phenomena that defy conventional laws of gravity and magnetic interaction.

Superconductors, materials that exhibit perfect electrical conductivity at extremely low temperatures, have opened the door to revolutionary possibilities in various fields of science and technology. Among these possibilities, magnetic levitation stands out as an impressive and promising phenomenon that has captured the attention of researchers, engineers and science enthusiasts. Magnetic levitation in superconductors is based on the unique ability of these materials to completely expel the magnetic fields from their interior when they reach critical temperatures. This phenomenon, known as the Meissner effect, lays the foundations for the development of levitation systems that defy gravity in an apparently magical way. By eliminating the electrical resistance and energy loss associated with conventional materials, superconductors enable the creation of stable magnetic fields that hold objects in suspension without apparent physical contact.[3].

The application of magnetic levitation to trains represents a significant milestone in the evolution of land transportation, overcoming the traditional limitations of friction and resistance, and opening the door to a new era of speed, energy efficiency and passenger comfort. By eliminating the need for physical contact with rails, this technology eliminates friction and dramatically reduces resistance to movement, enabling exceptional speeds and unprecedented energy efficiency. This cutting-edge approach not only challenges the traditional limitations of rail systems, but also promises a smoother, quieter travel experience, transforming the perception of rail transportation [4].

Magnetic levitation technology continues to be developed and researched, so in recent years research has been presented explaining the failures that Maglev trains could have in different contexts and the possible solutions to these failures based on numerical methods and models. To explain these failures, some study contributions presented are briefly shown:

It is known that the unstable aerodynamic performance of a maglev train is due to the ground conditions, where numerical tests were done analyzing how different ground conditions affect the behavior of the airflow around the maglev train. These changes can influence the stability of the train and simultaneously affect the performance and efficiency, due to which the energy consumption of the train increases and reduces the comfort of users, for these reasons we want to make certain parameters of the train known. Maglev [5] also proposed the method of improving feedback linearization control in suspension systems that counteract the variation of inductance. This method is based on the levitation excitation of the hybrid excitation magnet, the different operating conditions and the sensitivity of the system model to the error of the inductance parameter [6], a speed tracking system based on the algorithm was also proposed APSO-NLADRC control system to solve the instability and uncertainty interference problems in the speed tracking system of maglev trains.[26]

There was also an analysis of traction motor noise and suspension frame vibration. The reasons for the noise were analyzed from the distribution of the high-frequency vibration of the suspension frame in the frequency domain and one of the answers to this problem is that as the train accelerates, the sound pressure increases [7].
It was also sought that by means of a hybrid configuration it allows to strongly increase the levitation force of superconducting magnetic levitation systems, for this it is demonstrated that levitation forces can be obtained more than three times greater than those obtained with a conventional configuration [8].

A fault tolerant control of the magnetic levitation system based on a state observer was also proposed. An investigation was carried out and it reveals that the overall performance is unpleasant, and the electromagnet suffers from severe fevers and it was given as one of the results that the state observer of the fault-tolerant control system is successfully configured and the gap measurement is estimated effectively [9].

Next, three types of typical levitation control methods, namely linear state feedback methods, nonlinear control methods, and intelligent control methods, are reviewed according to their improvements and applications. Finally, we summarize and evaluate the advantages and disadvantages of the three methods, and future developments of levitation control are suggested. The purpose of this systematic review is to offer a study on the use of the advances that superconductors offer us in favor of magnetic levitation applied in trains.

II. METHODOLOGY

To collect and select information for the systematic review, the PRISMA selection process was used, of which the question formulation is: What are the most recent advances in magnetic levitation technology? This selection will be divided into 2 stages, following the strategy of [36], in which each one will offer a reduction in the number of sources initially taken, eventually reaching a defined number of sources that will be used for this systematic review.

To collect the information, used the search engine Scopus.

Stage 1

At this stage, we first started with an unfiltered search for the topic to be investigated, thus obtaining 2,392 results.

Scopus

"Magnetic levitation" AND "train"

Then a filtering was done in the search engine considering the type of document, the age of the documents, region, language, area and type of access. Of which the document type was article, the age was approximately 5 years (2018-2023), the supported regions were all possible, all regions, the main language of articles was English, the area was engineering and finally the type of access was free.

Stage 2

At this stage we started with a total of 114 documents which were analyzed and values (0, 1 and 2) were assigned.

Documents that are not aligned with the objectives of this research received a rating of 0. Documents that are moderately aligned with the objectives were rated 1. Documents that are focused on the objectives were assigned a rating of 2. Only The documents that were assigned a score of 2 remained, those with a score of 1 were reviewed by the rest of the group members to have a consensus decision and the documents with zero points were excluded, leaving 37 relevant documents.

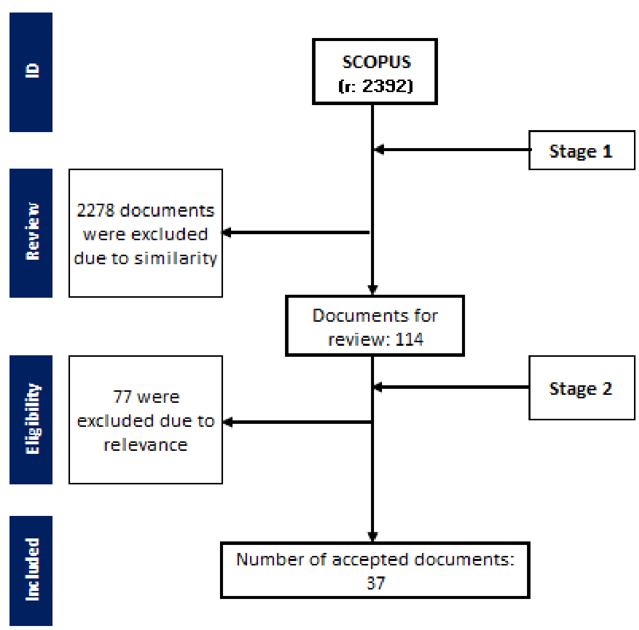

Fig. 1 Selection flowchart

Finally, he carried out an in-depth analysis of the full text of the accepted documents with the purpose of highlighting the most relevant information of each of them.

III. RESULTS

37 documents were obtained for Scopus. There is a growth trend in research focused on magnetic levitation applied to trains, given that 3 documents were obtained in 2018, 4 in 2019, 9 in 2020, 3 in 2021, 9 in 2022 and 9 in 2023.

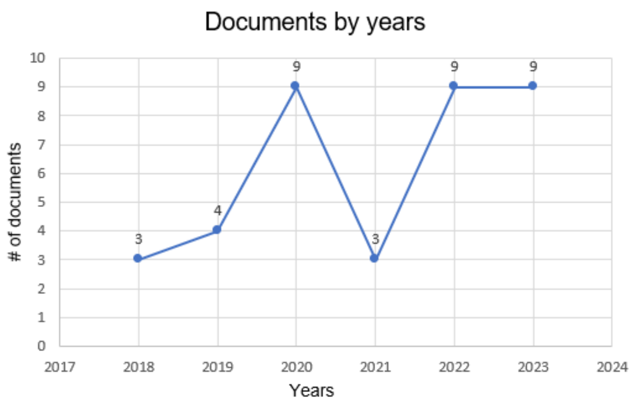

Fig. 2 Documents by years

The documents can also be divided by geographical location of the continents, considering that some documents were collaborations from 7 countries, of which 1 was from Africa, 31 were from Asia, 5 were from Europe. From where we can see that the continent and the year with the most documents are Asia and 2023 respectively.

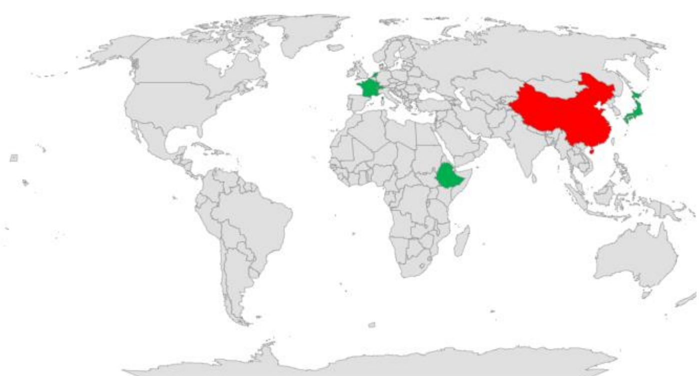

Fig. 3 Documents by country

It can be seen that there is greater emphasis on topics that deal with failures, dynamics, optimization and model. In the topics that talk about failures, the weak points of the system were identified and solutions were created to ensure better service, as well as improving the design to reduce these failures and optimize its operation. In the topics that talk about dynamics, you can understand the behavior of the train in different situations and how parameters such as speed, acceleration and stability in curves vary. In the topics that talk about optimization, they focus on seeking constant improvement, improving efficiency, reducing travel times and in the topics that talk about models, they help simulate the behavior of trains for certain conditions. With these simulations we can analyze the performance of trains and be able to design more effective operation and maintenance strategies.

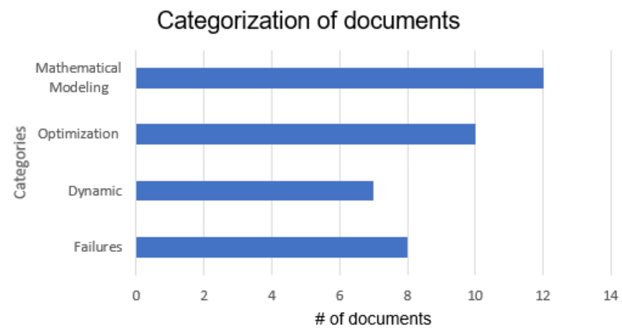

Fig. 4 Categorization of documents

Finally, we can divide the articles by the scope they cover, of which 8 articles were about failures, 7 were about dynamics, 10 were about optimization, and 12 were about mathematical modeling.

IV. DISCUSSIONS

In the present investigation, four categories were obtained in which there were many documents where there is a lot of information on the topic.

Research for **mathematical modeling** found that, the maglev train is the candidate to be the best railway system, since it travels at ultra speed and has self-stability in its movement [10]; models of as reduce the 3 types of resistance that every type of train presents in its movement[eleven]. On the other hand, a model was found for the dynamic state of the train based on the hypothesis that in the levitation suspension there is an electromagnetic hole [12]. Furthermore, it came what is due to provide a force for when the train goes through curves, sometimes there is friction between the track and the guide electromagnet, this affects the operation of this[13].

In [14] a mathematical model was proposed which can detect faults in a timely manner and has a low false alarm rate and could be used in fault diagnosis in this system, also presented a modeling where The use of current feedback and magnetic flux density feedback as control methods is discussed, and the importance of accurate magnetic density measurement is noted.[fifteen]; Another study focused on achieve a stable suspension for non-contact operation of maglev trains, the simulation results indicate that the deflection and deformation direction of the same LM in the front transition curve is opposite to that in the rear transition curve. Furthermore, the deflection and deformation direction of a left LM in the transition curve is opposite to that of the corresponding right LM. It is observed that the deformation amplitudes in the center of the vehicle are small, but the deformation at the ends of the vehicle is considerably large, generating perturbations in the nominal levitation space.[16].

As for the **failures that the Maglev** can suffer, it would be the electromagnet levitation system, since apart from being the smallest, it is also the most important, it can completely reflect the properties of the Electromagnetism Suspension (EMS) system, such as the characteristic of inherent instability and dynamic performance under adjustment from control [17]. In addition, they may also suffer from single-phase disconnection faults of the long stator linear synchronous motor model, which explains that the amplitude of the grid current rises and falls for a short time, indicating that the side, the grid is subject to a shock caused by this, or also short circuit fault between phases of LLSM, indicates that the three-phase current changes, which means that the three phases are not balanced and there are harmonic components in the current [18]. The track beams and other functional parts tend to have irregularities, which is why they must be considered periodic, the deformations of the beams refer to the deflection, caused by the increase in the load when the train passes over them [19]. On the other hand, there is also mechanical fatigue of rubber materials, the reduction of the mechanical properties of rubber with the gradual propagation of cracks under dynamic stress, thanks to studies it was learned that these suffer fatigue damage in areas of high stress, these areas are prone to crack initiation under cyclic loading, rubber failures are mostly due to abnormal cracks, glue failures and surface wrinkles [20].

Maglev vehicles present a peculiar work **dynamic**, since it uses the suspended electromagnet that occurs in two directions, the angle of rotation and the other the vertical vibration, but the dynamic model of the train means that it has three degrees of freedom of the body. , the secondary equivalent model based on the hollow spring and the suspension motion equation, being characteristics of the low or medium speed Maglev train [21], although the body structure of the medium speed maglev train is basically the same as that of the low-speed maglev train. The main difference lies in the mode of levitation and linear traction. , while [22] focuses on between the cars; It also considers the special working conditions of slopes, curves and tunnels, which describe the actual operation of maglev trains more accurately than the single mass point model of maglev trains.[23]. Phase space recurrence analysis is a typical the sensor position, since low-speed Maglev trains (0 – 120 km/h), it is beneficial to reduce the deflection amplitude of the levitation gaps of the low-speed Maglev train. On the other hand, the multi-point kinematic and dynamic model of the maglev train takes into account the electromagnetic resistance and operating resistance of the linear generator of the maglev train, as well as the coupling forces method used to understand nonlinear dynamic systems, such as rotating combustion chambers. In such combustion chambers, physical processes include hydrodynamics, acoustics, and chemical combustion, which are characterized by acoustic pressures, flow velocity and unstable heat release and other variables [24]. Another factor is the cost of construction of the track has been estimated between 60% and 70% of the total initial investment in a Maglev train. To reduce overall construction costs, lighter guideways are used. Recommended due to the high amount of expense. A guide burner is more flexible, which causes serious vibration problems. The cost-effective approach is to reduce the guide rail while maintaining a stability tolerance [25]. Compared with the static ground condition, the drag coefficients of the head and tail gears of the maglev train under moving ground conditions tend to increase, and the increases in the aerodynamic drag coefficients of the head and tail gears are 3.45% and 3.31%, respectively. Compared with the stationary ground condition, the lift coefficients of the head and tail of the maglev train are smaller under moving ground conditions. Compared with the static terrain boundary condition, the lift coefficient of the head and tail car decreases by 157.78% and 5.13% respectively in the moving terrain boundary condition [26].

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For **optimization**, there are many parts and contexts that can be changed, improved or enhanced, for example, proposing a suction method to mitigate the pressure waves of the maglev train and the tunnel. In the article [27], they carried out this research and revealed the ability of the suction technique to alleviate the aerodynamic effect of the tunnel. However, as observed in the evaluation of tunnel surface pressure, the relief effect of multiple suction slots cannot be accumulated. Therefore, further studies on the distribution and dimensions of suction slots will be necessary in the future. It can be said that the topic was left open and that there is much to discover and analyze.

It is also known that the maglev train is easily affected by external interference, which increases the power consumption of the train and reduces the travel comfort of passengers. In [26] focuses on the speed tracking control of the maglev train operation system. Given the complexity and instability of the maglev train operation system, traditional speed tracking control algorithms demonstrate poor tracking precision and large tracking errors, for this reason a speed tracking system based on the algorithm is proposed. APSO-NLADRC control to solve the instability and uncertainty interference problems in the speed monitoring system of maglev trains, showing results that the APSO-NLADRC control algorithm proposed in this article has better control effects and robustness.

To reduce the impact of noise on the environment and reduce wasteful energy dissipation of traction motors, field tests were carried out in [23] to measure the traction noise and vibration of the suspension frame in a maglev train of medium and low speed commercially operational. Tests showed that as the train accelerates, the sound pressure increases overall, but the increase becomes smaller with each test speed. The speed of the maglev train is closely related to the vibrations of the suspension frame in lateral/vertical directions. The dominant frequency of traction motor noise is basically consistent with that of suspension frame vibration acceleration, which demonstrates that suspension frame vibration is the main reason for high-frequency noise in maglev train operation. low to medium speed.

It is known that superconducting magnetic levitation is based on the stable levitation of superconductors on magnets or magnetic guides after cooling them in the field generated by the magnets or guides. This process is known as field cooling. In maglev trains, the magnets are inserted into the guides and the superconductors are located in cryostats located under the carriages, knowing this in [28] a greater magnetic levitation force was evaluated in a stable hybrid superconducting magnetic levitation configuration, where new measurements of levitation and lateral force are reported, carried out with a configuration of this type. The results obtained with an original hybrid configuration that allows the levitation force of superconducting magnetic levitation (SML) systems to be strongly increased are also presented. This article is composed of the experimental section that presents the levitation system that analyzes and details the measurements achieved, the section where the measurements of the levitation and lateral forces carried out with the conventional and proposed configuration are compared, there is also the section where Calculations are made that reproduce the measurements. The conclusion was reached that the measurements reported in this manuscript show that with the proposed configuration levitation forces more than three times greater than those obtained with a conventional configuration can be obtained. These large forces are due to the contribution of the repulsive force between the magnets. One could also say that, contrary to Earnshaw's theorem, superconductors stabilize magnets with opposite magnetizations.

In [29] the authors propose a methodology for the optimal discrete-time control of double integrators with perturbations, providing a closed-form solution with lower computational load that can be easily extended to general second-order systems. The results show fast convergence in finite time, in addition to providing the definitive stable attractor. The proposed algorithm for the optimal discrete-time control of double integrators with perturbations, the perturbations are analyzed, including uncertainty and external perturbations, the main result shows that for the system with perturbations, any point of the initial state can converge to a certain region (region of stable attraction) in a finite time and quickly.

A study was also carried out on the effect of the position of the dimples on reducing the drag of high-speed Maglev train. An improved delayed separated eddy simulation (IDDES) model with good flow field simulation results around the train was used in [30] to numerically simulate a high-speed maglev train with dimples arranged in the aerodynamic area of the caboose. of the train. This study performed the following numerical methods such as geometry models (model used in this study was a TR-08 high-speed maglev train), calculation domain and boundary conditions, mesh strategy, data processing, independence verification of mesh and wind tunnel test verification. The drag reduction mechanism of dimples was revealed and the influence of dimple position on the drag reduction effect of high-speed maglev train was clarified.

There is also talk of optimizing the size of the permanent magnets of the Halbach matrix for the magnetic levitation system for the permanent magnet maglev train. In [31], an investigation was motivated to optimize the size of the permanent magnet Halbach Array by combining finite element analysis with the levitation force model, which avoids the intuitive and empirical design optimization process. Having as results:

- When the width of the Halbach Array permanent magnet stack structure is equal (a=b=c), the optimal thickness and width of a single group of permanent magnets are 20mm and 22mm respectively.
- When the size of the anti-parallel horizontally magnetized permanent magnets is the same and the width of the middle vertical magnetized permanent magnet changes, i.e. (a=c=22mm), the optimal width of the center permanent magnet is 24mm.
- When the width of the permanent magnet is 30mm and the thickness is 13mm, the growth rate of levitation force is the largest; When the thickness of the permanent magnet is

26mm and the width of the permanent magnet is 18mm, the growth rate of the levitation force is the largest, that is, the utilization rate of the permanent magnet is the best.

In [32] an investigation is carried out on how to improve the operational efficiency of a maglev train using a LIM, the relationship between the sliding frequency of the train, the normal force and the propulsion force was analyzed through a mathematical study. Using the analytical results, the sliding frequency with optimal efficiency was deduced based on the operating conditions of the train, while limiting the normal force to the extent that the levitation system of the train did not fail. Subsequently, the slip frequency was modified according to the train operating conditions in real time. Using the ATO driving system, a simulation test was carried out in which the slip frequency was varied depending on the driving conditions of the train while it was running, and an experiment using a real train. Their results confirmed that the efficiency improvement using the proposed method was significant, they also verified that the proposed method is more efficient than the existing method (the proposed method uses LIM features, which are suitable for low and medium speed types).

In other areas It was obtained that the investigation carried out reveals that the general performance is unpleasant, and the electromagnet suffers serious fevers. To solve this problem, they propose to design the state observer as a solution to build the fault-tolerant control system. The designed observer is applied to estimate the failure sensor gap measurement so that the suspension unit does not fail. Therefore, the state observer-based fault-tolerant control system significantly improves the redundancy and fault-tolerant capability of the maglev system in case of sensor failure.

In several documents they aim to create a model that seeks to improve maglev trains, have better energy savings, economic costs, reduce the resistance presented by the trains, examples, running resistance, air resistance, resistance to the coil of the train. suspension frame generator [10]. It also seeks to have better stability in its journey. In all models, the project must be well analyzed, reliability and correctness tests of the system must be carried out with simulations before the production of the prototype [8]. The effectiveness of the models is supported by experimental and simulation results. The models provide a basis for research into improving magnetic levitation technology. They can be used to investigate new techniques and approaches that enable more advanced and efficient systems in the future.

V. Conclusions

Magnetic levitation in maglev trains can be classified as an ambitious project for engineering due to the various mathematical models and designs with which it can be developed, in addition to the social impact it generates by mobilizing many people per day, also mention that would reduce environmental pollution.

Field tests were conducted to measure traction noise and suspension frame vibration on a commercially operational low and medium speed maglev train.

The noise reasons of the traction motor were analyzed from the high-frequency vibration distribution of the suspension frame in the frequency domain. One of the answers to this problem is that as the train accelerates, the sound pressure increases in general, but the increase becomes smaller with each test speed.

Magnetic levitation applied to trains offers a series of advantages in terms of efficiency, speed and sustainability. However, continued investment and development is still required to overcome challenges and achieve wider implementation in rail transport globally.

VI. References

[1] **Feng, Zhao et al.** Dynamic performance of medium speed Maglev train running over girders: Field test and numerical simulation. [Online] June 8, 2022. https://www.worldscientific.com/doi/epdf/10.1142/S0219455423500062

[2] **Liwei Zhang et al.** Research on the improvement of feedback linearization control in suspension system countering inductance variation [Online] July 1, 2019. [Cited on: September 15, 2023.] https://www.hindawi.com/journals/mpe/2019/5747812/

[3] **Bernstein, Xing et al.** Increased levitation force in a stable hybrid superconducting magnetic levitation set-up. [Online] October 31, 2022 [Cited on: October 30, 2023.] https://iopscience.iop.org/article/10.1088/2631-8695/ac9bcf

[4] **Ding, Yang and others.** Three-Dimensional numerical analysis and optimization of electromagnetic suspension system for 200 km/h Maglev train considering Eddy current effect [Online] October 22, 2018. [Cited on: September 15, 2023.] https://ieeexplore.ieee.org/document/8502075

[5] **Shimeng, Chen et al.** Unsteady aerodynamic performance of a Magle train: the effect of the ground condition. [Online] November 9, 2022. [Cited on: September 15, 2023] https://academic.oup.com/tse/article/4/4/tdac023/6815559

[6] **Liwei Zhang et al.** Research on the Improvement of Feedback Linearization Control in Suspension System Countering Inductance Variation. [Online] July 1, 2019.https://www.hindawi.com/journals/mpe/2019/5747812/

[7] **Fengyu Ou, and others.** Field experimental tests and analyzes of suspension frame vibration of low-mediumspeed maglev train. [Online] 2023 https://journals.sagepub.com/doi/epdf/10.1177/14613484221117961?src=getftr

[8] **Liu, Linfeng, and others.** Comprehensive Model Construction and Simulation for Superconducting Electrodynamic Suspension Train. [Online] September 3, 2023https://ieeexplore.ieee.org/document/10206016

[9] **Chunhui Dai, and others.** Research on Decoupling Problem of Suspension Gap and Location of Relative Position Sensor in High Speed Maglev Train. [Online] 2019. https://ieeexplore.ieee.org/ielx7/6287639/8600701/08653822.pdf

[10] **Yi Yu, and others.** Auxiliary Stopping Area Layout Method for High-Speed Maglev Operated Bidirectionally on Single Track. [Online] September 3, 2021 https://downloads.hindawi.com/journals/jat/2021/5571788.pdf

[11] **Wenbai Zhang ,Zbigniew Lukasik and others.** Operation Control Method for High-Speed Maglev Based on Fractional-Order Sliding Mode Adaptive and Diagonal Recurrent Neural Network. [Online] June 7, 2023. https://www.mdpi.com/1996-1073/16/12/4566

[12] **Andriy Chaban, Nicolas, and others.** Mathematical modeling of transient processes in magnetic suspension of Maglev trains. [Online] December 16, 2020. https://www.mdpi.com/1996-1073/13/24/6642

[13] **Chunxia Zhaoand others.** Dynamic modeling analysis and experiment of high-speed Maglev train guidance control system. [Online] November 16, 2020. https://ieeexplore.ieee.org/document/9260237

[14] **Zou, Zheng and Lu.** Modeling and simulation of traction power supply system for High-Speed Maglev train. [Online] July 31, 2020. https://www.mdpi.com/2032-6653/13/5/82

[15] **Ke, Li et al.** Fatigue life prediction of electromagnetic brake connection device in High-Speed Maglevtrain. [Online] May 9, 2022. https://www.iieta.org/journals/jesa/paper/10.18280/jesa.530311

[16] **Junqi Xu, and others.** Dynamic Modeling and Adaptive Sliding Mode Control for a Maglev Train System Based on a Magnetic Flux Observer. [Online] May 15, 2018. https://ieeexplore.ieee.org/document/8359264

[17] **Hu, Ma and others.** Levitation and Hopf bifurcation stability of Maglev trains. [Online] April 7, 2020. https://www.hindawi.com/journals/mpe/2020/2936838/

[18] **Mingda Zhai, Zhiqiang Long and others.** Fault-Tolerant Control of Magnetic Levitation System Based on State Observer in High Speed Maglev Train. [Online] February 7, 2019 [Cited on: October 30, 2023.] https://ieeexplore.ieee.org/document/8636913

[19] **Hu, Feng et al.** Fault detection method for suspension systems of Maglev train based on optimized random matrix theory. [Online] September 18, 2020 [Cited on: September 15, 2023.] https://ieeexplore.ieee.org/document/9199889

[20] **Yu, Li, et al.** Dynamic deformation behaviors of the levitation electromagnets of High-Speed Maglev vehicle negotiating a sharp horizontal curve. [Online] March 3, 2023. https://www.mdpi.com/1424-8220/23/5/2785

[21] **Xu Zhou et al.** Maglev Train Suspension System Fault Detection Based on Historical Health Data.[Online] June 26, 2020. https://ieeexplore.ieee.org/document/9126543

[22] **Kim, Jeongrok and Cho, Il-Hyoung.** Dynamic response analysis of medium-speed Maglev train with track random irregularities [Online] 2021. [Online] November 5, 2021 https://www.hindawi.com/journals/jat/2021/1668496/

[23] **Fengyu Ou, Xiaokang Liao and others.** Field Measurements and Analyzes of Traction Motor Noise of Medium and Low Speed Maglev Train. [Online] November 30, 2022 [Cited on: October 30, 2023.] https://www.mdpi.com/1996-1073/15/23/9061

[24] **Pan, Wang, Yu and Zhao.** Displacement-Constrained neural network control of Maglev trains based on a Multi-Mass-Point model. [Online] April 24, 2022. https://www.mdpi.com/1996-1073/15/9/3110

[25] **Li, Zhou et al.** Dynamic Performance Optimization of Electromagnetic Levitation system considering sensor position. [Online] February 7, 2020 https://ieeexplore.ieee.org/document/8986592

[26] **Lingfeng Hu, Kuangang Fan and others.** Design of Nonlinear Active Disturbance Rejection Controller Based on the Adaptive Particle Swarm Optimization Algorithm for the Maglev Train Traction Control System. [Online] April 14, 2023 [Cited: October 30, 2023.] https://www.hindawi.com/journals/js/2023/6627429/

[27] **Zheng-Wei Chen, Zhan-Hao Guo et al.** A suction method to mitigate pressure waves induced by high-speed maglev trains passing through tunnels. [Online] May 29, 2023 [Cited: November 28, 2023.] https://www.sciencedirect.com/science/article/pii/S2210670723002937

[28] **P Bernstein, Y Xing and JG Noudem.** Increased levitation force in a stable hybrid superconducting magnetic levitation set-up. [Online] October 31, 2022- [Cited November 28, 2023.] https://iopscience.iop.org/article/10.1088/2631-8695/ac9bcf

[29] **Hehong Zhang, Xinghuo Yu, Juan Wang and others.** Discrete-Time Optimal Control of Double Integrators and its Application in Maglev Train. [Online] March 1, 2022 [Cited: November 28, 2023.] https://www.jstage.jst.go.jp/article/ieejjia/11/2/11_21005456/_article

[30] **Dan Zhou, Liliang Wu and others.** Study on the effect of dimple position on drag reduction of high-speed maglev trai. [Online] December 30, 202. [Cited: November 28, 2023.] https://academic.oup.com/tse/article/3/4/tdab027/6490295

[31] **Yang Jiang, Yongfang Deng and others.** Optimization on Size of Halbach Array Permanent Magnets for Magnetic Levitation System for Permanent Magnet Maglev Train. [Online] February 15, 2021. [Cited him: November 28, 2023.] https://ieeexplore.ieee.org/document/9354708

[32] **Sang-Uk Park, Hyung-Soo Mok and others.** Efficiency Improvement by Deriving the Optimal Operating Slip Frequency of a Linear-Induction-Style Maglev Train. [Online] December 11, 2020. [Cited him: November 28, 2023.] https://www.mdpi.com/1996-1073/13/24/6544

[33] **Sun Yuze, Sun Dakun et al.** Characterizing nonlinear dynamic features of self-sustained thermoacoustic oscillations in a premixed swirling combustor. [Online] April 15, 2020[Cited November 30, 2023] https://www.sciencedirect.com/science/article/abs/pii/S0306261920302105?via%3Dihub

[34] **Esaias Abera Teklu and Chala Merga Abdissa**. Genetic Algorithm Tuned Super Twisting Sliding Mode Controller for Suspension of Maglev Train with Flexible Track. [Online] 2016 [Cited 2023-11-30] https://ieeexplore.ieee.org/ielx7/6287639/6514899/10082920.pdf

[35] **Shi Meng, Guang Chen and others.** Unsteady aerodynamic performance of a maglev train: the effect of the ground condition [Online] November 9, 2022 [Cited November 30, 2023] https://academic.oup.com/tse/article/4/4/tdac023/6815559

[36] **D. A. Espejo-Peña, J. Felipe Celis, F. R. De La Cruz Morales, R. E. B. Acuña Rugel y R. A. Torres Lázaro**, Computational Numerical Control (CNC) Machines: A Systematic Review from 2015 to 2022, Proc. LACCEI int. Multi-conf. Eng., Educ. Technol., vol. 2023-July. https://www.scopus.com/record/display.uri?eid=2-s2.0-85172341342&origin=resultslist

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