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Use of Magnetic Levitation Systems in Measuring Technological Parameters

Abstract

Magnetic levitation systems (MLS) are a modern technology that provides a stable hold of a physical object in the air without contact under the influence of magnetic forces. These systems minimize friction due to the absence of mechanical contact between moving parts, reduce wear and energy loss and thus increase the accuracy and durability of measurement processes. MLS is widely used in industrial and scientific research fields that require high accuracy and stability, especially in areas such as semiconductor manufacturing, aerospace systems, medical diagnostic devices, and automated production lines, where technological parameters (such as position, speed, vibration, temperature, and pressure) are measured and controlled. This article analyzes in detail the physical and technological foundations of magnetic levitation, its application areas and its advantages over traditional measurement methods. In addition, the ability of MLS to perform non-contact control and high-precision measurements in real time strengthens its role as a promising application area in modern technologies. In light of current technological developments, the focus of attention is not only on measurement technology, but also on the potential for integration with automation and artificial intelligence of MLS systems.

Keywords: *magnetic levitation systems, automation, measurement process, aerospace systems, mechanical contact*

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Texnoloji parametrlərin ölçülməsində maqnit levitasiya sistemlərinin istifadəsi

Xülasə

Maqnit levitasiya sistemləri (MLS) fiziki obyektin maqnit qüvvələrinin təsiri altında təmas etmədən havada sabit tutulmasını təmin edən müasir texnologiyadır. Bu sistemlər hərəkət edən hissələr arasında mexaniki təmasın olmaması səbəbindən sürtünməni minimuma endirir, aşınma və enerji itkisini azaldır və beləliklə, ölçmə proseslərinin dəqiqliyini və davamlılığını artırır. MLS yüksək dəqiqlik və sabitlik tələb edən sənaye və elmi tədqiqat sahələrində, xüsusən də texnoloji parametrlərin (vəzifə, sürət, vibrasiya, temperatur və təzyiq kimi) ölçüldüyü və idarə olunduğu yarımkeçiricilərin istehsalı, aerokosmik sistemlər, tibbi diaqnostika cihazları və avtomatlaşdırılmış istehsal xətləri kimi sahələrdə geniş istifadə olunur. Bu məqalədə maqnit levitasiyasının fiziki və texnoloji əsasları, tətbiq sahələri və ənənəvi ölçmə üsulları ilə müqayisədə üstünlükləri ətraflı təhlil edilir. Bundan əlavə, MLS-in real vaxt rejimində təmassız nəzarət və yüksək dəqiqlikli ölçmələr aparmaq qabiliyyəti müasir texnologiyalarda perspektivli tətbiq sahəsi kimi onun rolunu gücləndirir. Mövcud texnoloji inkişaflar fonunda diqqətin mərkəzində təkcə ölçmə texnologiyası deyil, həm də MLS sistemlərinin avtomatlaşdırılması və süni intellektlə inteqrasiya potensialı var.

Açar sözlər: *maqnit levitasiya sistemləri, avtomatlaşdırma, ölçmə prosesi, aerokosmik sistemlər, mexaniki kontakt*

Introduction

In modern industry, the demand for high-precision measurement and real-time control systems has significantly increased, driven by the need for optimizing complex technological processes and ensuring consistent product quality. Precision in measurement not only contributes to improved efficiency but also plays a critical role in maintaining system stability, especially in high-performance environments. According to Farkas and Molnár (Farkas, Molnar, 2017), one of the essential prerequisites for enhancing productivity and operational reliability is the implementation of robust and accurate measurement systems that can withstand varying environmental conditions and operational stress.

However, traditional mechanical measurement systems often face significant limitations due to physical contact components, which are susceptible to friction, wear, temperature fluctuations, and mechanical fatigue (Black, Campbell, 2015). These limitations can degrade measurement accuracy over time, reduce system lifespan, and increase maintenance costs. Consequently, the scientific and industrial communities have increasingly turned their attention to non-contact measurement technologies as a viable alternative to overcome the drawbacks of conventional systems.

In this context, magnetic levitation systems (MLS) have emerged as a promising solution, offering high durability, accuracy, and operational efficiency. As demonstrated by Zhang and Lin (Zhang, Lin, 2020), MLS-based systems outperform traditional mechanical systems in several aspects, including reduced sensitivity to vibrations, frictionless operation, and extended service life. By utilizing electromagnetic forces to suspend and control objects without any physical contact, MLS eliminates mechanical wear and minimizes disturbances that typically affect measurement fidelity.

Experimental research carried out by Ma and Ko (Ma, Ko, 2018) further supports these advantages, showing that MLS can achieve sub-micron-level precision in position and vibration measurements. Furthermore, the integration of MLS with optical and laser-based sensors, as highlighted by Torres and Silva (Torres, Silva, 2022), opens new opportunities for its use in sensitive environments such as cleanrooms, laboratories, and medical facilities. The contactless nature of MLS not only ensures higher measurement stability but also provides significant benefits in terms of hygiene, maintenance, and compatibility with modern digital systems.

Additionally, a growing body of research (Humbataliyev, 2014; Mirzoyev, Humbataliyev, 2011; Humbataliyev, 2008; Humbataliyev, 2009; Gumbataliyev, 2007; Humbataliyev, 2021; Ahmadov, Humbataliyev, 2021; Afandiyev, Allahverdıyeva, Aliyeva, Afandiyeva, 2023; Allahverdiyeva, 2021) focuses on the development of mathematical models to describe material behavior, such as corrosion under mechanical stress in aggressive environments, which further emphasizes the importance of advanced measurement technologies in structural health monitoring and predictive maintenance.

In this study, we explore the capabilities and applications of magnetic levitation systems for non-contact measurement of various technological parameters including position, velocity, vibration, temperature, and pressure. Our objective is to design and evaluate high-precision, long-lasting measurement solutions that address the limitations of conventional methods and offer

We also examine the potential for integrating MLS with artificial intelligence and automation systems to create smart, adaptive measurement platforms for use in industries such as manufacturing, aerospace, medicine, and robotics. Such integration is expected to further enhance the versatility, accuracy, and autonomy of modern measurement systems.

In conclusion, magnetic levitation systems represent a transformative approach to measurement technology, particularly in scenarios that demand exceptional precision, reliability, and environmental resistance. This paper aims to provide a comprehensive overview of the technological principles behind MLS, evaluate its industrial applications, and compare its performance with existing measurement methodologies.

Research

Basic Principles of Magnetic Levitation Systems. A magnetic levitation system (MLS) works on the principle of keeping physical objects suspended in the air or in a contactless state by the action of magnetic forces. The basic physical law underlying this technology is the effect of the attractive and repulsive forces of magnetic fields on the object. MLS keeps the position of the object stable by controlling these forces synchronously and precisely, thus eliminating traditional problems such as friction and mechanical contact.

Magnetic levitation systems are mainly divided into two categories: active and passive systems.

Active Magnetic Levitation Systems. In active MLS, the position of the object is regulated in real time by electromagnetic fields. In these systems, the position of the object is continuously measured by sensors and the currents applied to the electromagnets are regulated by a feedback mechanism. As a result, magnetic forces allow the object to be held stable and in any desired position.

Let's look at a simple model to describe the operation of active systems. The magnetic force F_m , gravitational force F_g and other external forces acting on the object are taken into account. For the stability of the system, the following equation must be satisfied:

$$F_m = F_g + F_{ext}$$

where F_m is the magnetic force, $F_g = m \cdot g$ is the weight of the object (m – mass, g – free fall velocity), and F_{ext} are the other acting forces. The control system keeps these forces in balance.

The intensity of the electromagnetic field is regulated by changing the current, and thus the position of the object is precisely controlled. This type of MLS is widely used in high-speed transportation systems (e.g., maglev trains) that require dynamic control, and in micro- and nano-positioning systems.

Passive Magnetic Levitation Systems. Passive MLS mainly uses permanent magnets and superconducting materials. Here, the object is held in a fixed position in a magnetic field and the system does not require control unless there is an external intervention. Passive levitation is based on physical phenomena such as diamagnetism or the Meissner effect.

Stability in passive systems is limited by physical laws such as the Larmor theorem and the Earnshaw theorem. For example, the Earnshaw theorem shows that it is impossible to achieve static stability with static magnetic fields. Therefore, passive systems overcome this limitation by creating unusual magnetic fields using superconducting or diamagnetic materials.

bThe stability of levitation in these systems depends on the topological structure of the magnetic field and the magnetic properties of the object. Passive MLS has low power consumption and simple mechanical structure, but additional methods may be required to maintain a stable position under dynamic loads and pressures. Applications of passive levitation include magnetic bearings for high-speed maglev trains, isolated sensitive devices, and medical applications.

General Advantages and Limitations of MLS Technology.

Advantages	Restrictions
Lack of mechanical friction	Complexity of management systems (especially in active MLS)
Low wear and long-lasting use	High energy consumption (for active systems)
High accuracy and response speed	Low adaptability and dynamic stability difficulties of passive systems
Suitable for clean environments due to lack of contact	The effect of electromagnetic fields on other equipment
Possibility of position control at micro and nano levels	Physical constraints (Earnshaw's theorem)

Thus, magnetic levitation systems have significant advantages over traditional methods in measuring and controlling technological parameters. This technology eliminates mechanical limitations such as friction and wear, ensuring high accuracy and durability**.**

Application of Magnetic Levitation Systems in Measuring Technological Parameters. Reliable and accurate control of technological processes is of crucial importance for both industrial production and scientific research. In this regard, magnetic levitation systems (MLS) stand out as an alternative to traditional contact measurement methods with their unique technical advantages. Through MLS, technological parameters - position, speed, vibration, temperature and other physical variables - can be monitored without contact and with high accuracy.

One of the main factors that makes the application of MLS possible in this field is the frictionless and non-mechanical contact environment it provides. Friction and wear caused by the contact of moving parts with each other in classical measurement systems both reduce measurement accuracy over time and cause instability in the calibration of the system. MLS eliminates these problems and enables longer and more stable measurement processes.

Another important advantage is the ability to monitor process parameters in real time. Sensor systems equipped with MLS, due to their fast response capability, can immediately detect dynamic changes in any technological process and provide important feedback signals for process optimization. This feature makes the application of MLS especially necessary in agile production systems and automation.

MLS technology also provides high sensitivity. Modern systems allow for position measurements at the nanometer level and time measurements in the microsecond range, which makes them indispensable in areas requiring the highest accuracy - for example, aerospace technologies and nanoelectronics.

Application Areas. The advantages of MLS technology have led to its wide application in various fields:

• In the field of high-precision metrology, MLS is used to perform nano-level measurements. This technology ensures repeatability and long-term stability of measurements.

• In the field of medical devices, the non-contact structure of MLS is of great importance, especially in sterile environments (for example, in operating rooms or laboratory analyses). The absence of any mechanical contact prevents both contamination of devices and risks that may arise from contact with patients.

• MLS systems operating in ultra-clean environments for the semiconductor industry provide both measurement and micron-level motion control by minimizing the spread of particles.

• For vibration-sensitive technologies, MLS is important in terms of eliminating external vibrations and mechanical effects. In such conditions, the measurement errors that may occur in classical systems are significantly reduced in MLS.

Current Limitations and Technical Challenges. However, there are certain technical and economic limitations that prevent the widespread application of MLS technology. High-precision control and electronic control modules are required to make these systems operational. The design and calibration of such complex systems is challenging from an engineering perspective and sometimes requires high costs.

In addition, the electromagnetic fields used in MLS systems can in some cases cause electromagnetic interference with other electronic equipment in the environment. This raises the issue of compliance with electromagnetic compatibility (EMC) standards in some application areas.

Conclusion

Magnetic levitation systems offer significant advances in technological measurement methods. Their advantages such as non-contact operation, high accuracy, durability and real-time measurement make this technology an ideal choice for a number of critical areas. All these features indicate that MLS will be one of the key components not only for the current but also for future technological development stages.

The integration of MLS with artificial intelligence systems will further increase the potential of this technology, especially in terms of adaptive control, autonomous decision-making and process optimization. Research conducted in this direction shows that by expanding the functionality of MLS, it is possible to move to a new qualitative stage in both measurement technologies and automation and production processes.

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