

Online Monitoring System for Short Stator Maglev Train

YANG LU, SEMEI WANG, QI ZHU, SHENGYUAN LIU
and YIQING NI

ABSTRACT

Maglev train is a new kind of transportation mode that uses magnetic force to levitate and propel the train along a track. It is becoming more popular especially in China, where several maglev lines are in operation or under construction. Unlike the traditional wheel-based train, maglev train is suspended above the track, with a desired gap of about 8 mm. Due to the small gap, any disturbance of the suspension system may cause failure of suspension. The sources of disturbance include irregularity of track, variation in load, variation in parameters of the train structure (such as stiffness and damping of air spring), unexpected coupling vibration of the train-track-bridge system, and large displacement of the track and bridge. An online monitoring system was designed and installed on a maglev train and the corresponding line to collect the necessary data for analyzing the condition of the train and line and the mechanism of dynamic interaction of the train-track-bridge system. The monitoring items for the maglev train include the acceleration of the maglev bogies and carriages, the suspension gap, and the current of electromagnets. The monitoring items for the line include the acceleration of the bridge and track in concrete straight section, concrete curve section, tunnel wall and steel turnout. They also include relative displacement between concrete bridge and track, and strain of the track. Piezoelectric accelerometers, laser displacement sensors, fiber Bragg grating sensors and electric eddy displacement sensors are used in the monitoring system. All sensors are connected to data acquisition equipment by signal cable. The online monitoring system detected some unexpected conditions of the train and line, such as over-limit irregularity of the track, vibration resonance between the train and track, and suspension failure of the train. The data collected when the train was operating at different speeds and passing through different sections of the line was analyzed. The online monitoring system helped to speed up the debugging process before the maglev line started its official operation.

INTRODUCTION

With urban residents seeking convenient and safe transportation options, efficient transportation infrastructure has become a crucial factor driving further urbanization [1 2]. Generally, buses and metros serve as the primary modes of urban public transportation [3]. However, buses suffer from slower travel speeds and limited carrying capacity [4], while metros generate environmental noise due to wheel-rail friction and require regular maintenance [5]. Therefore, there is a demand for a new form of public transportation that is fast, environmentally friendly, safe, and capable of accommodating large numbers of passengers. The maglev train meets these requirements by utilizing electromagnetic forces to levitate and move without physical contact with the tracks [6]. Equipped with a unique bogie structure that encircles the track, maglev trains eliminate the risk of derailment. Two popular suspension technologies are used in maglev trains: electromagnetic suspension (EMS) and electrodynamic suspension (EDS) [7]. EMS trains can be suspended at any speed by creating a levitation force between the electromagnets and the steel rail, while EDS trains require a certain speed to achieve suspension. China currently operates four EMS maglev lines, with another one under construction. The suspension gap between the electromagnets and the electromagnetic rail is typically around 8-10 mm. Obtaining real-time data on the coupled dynamic response of vehicles and infrastructure is crucial. The control system can utilize this data to enhance control effectiveness. Additionally, the performance of vehicles and infrastructure can be evaluated based on this data.

Several researchers have proposed various monitoring systems for monitoring maglev trains and tracks. One such system, presented in [8], utilizes the sensors on the maglev train itself to monitor the position of the train's stator and track. Another approach, discussed in [9], applies Internet of Things (IoT) technology to develop a monitoring system that retrieves specific data required by the control system for the maglev train. Additionally, in [10], long-gauge fiber Bragg grating (FBG) sensors are employed to monitor the strain of prestressed concrete girders.

This paper introduces a comprehensive monitoring system that encompasses multiple aspects. It enables the measurement of the suspension gap, acceleration of the maglev bogie and carriage, current of the magnets, acceleration of certain bridges and track, and acceleration of the tunnel wall. The collected data from this system serves several purposes, including providing input to the suspension control system, evaluating the comfort level of the train, and assessing the performance of the bridge and track.

BRIEF INTRODUCTION OF MAGLEV TRAIN SYSTEM

This section provides a concise overview of the structure of a maglev system. Figure 1 illustrates key components of a maglev train's structure. The carriage and maglev bogies are connected using an air spring mechanism, which ensures a comfortable and stable ride for passengers. The linear motor plays a crucial role in the system by delivering the necessary traction force to propel the train forward with remarkable speed and efficiency. The suspension controllers, equipped with specific algorithms, calculate and output the appropriate current to the electromagnets. This current, when applied to the electromagnets, generates a powerful electromagnetic force that attracts the F-type track, resulting in the suspension of the maglev bogie above the track.

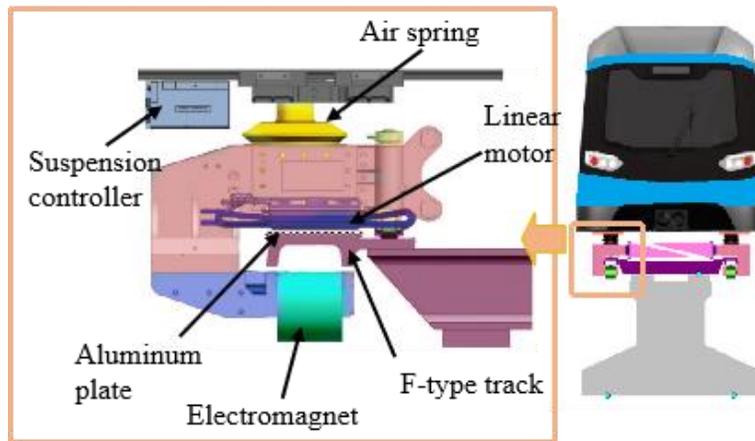


Figure 1. Structural details of short stator maglev.

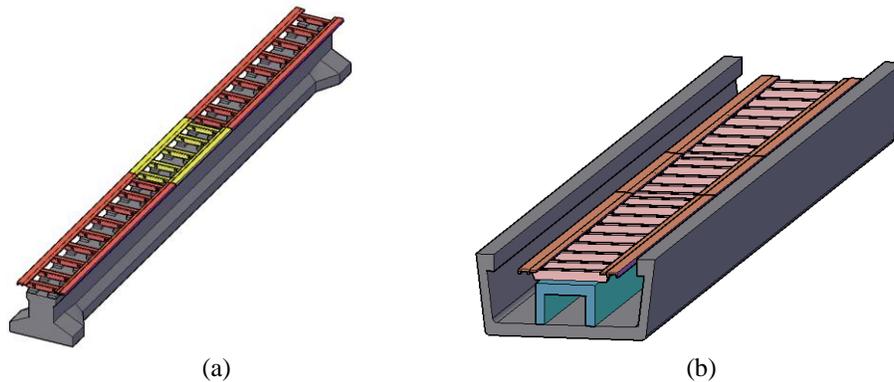


Figure 2. Schematic diagram of invert-T type beam (a) and U type beam (b).

Maglev systems also incorporate various types of beam structures, as depicted in Figure 2. In China's maglev lines, both the inverted-T type and U-type beams are utilized to accommodate different track configurations and operational requirements. In our specific case, we have installed a comprehensive monitoring system on the U-type beams and the corresponding track.

DESIGN OF MONITORING SYSTEM

The sensor layout of the online monitoring system for short stator maglev trains is depicted in Figure 3. The framework of this system follows a similar structure to other conventional structure health monitoring systems, encompassing a sensor system, data acquisition and transmission system, and data processing system.

To capture vibration data and evaluate the comfort level of the maglev train, accelerometers are strategically positioned on the floor of the carriages. These accelerometers record the train's vibrations, which are then utilized to assess the comfort experienced by passengers. Additionally, each bogie of the maglev train is equipped with four suspension gap sensors, positioned at the four end corners. These suspension gap sensors integrate eddy current displacement sensors with accelerometers, enabling them to simultaneously measure the suspension gap and vibration acceleration at their specific locations. All the sensors are interconnected with a vehicle-mounted data logger through signal wires, facilitating the collection of data. The data obtained from the

suspension gap sensors is also transmitted to the control box in real-time. The control algorithm within the system utilizes this data to calculate the appropriate current required for the magnets. This process ensures that the maglev train maintains a stable suspension gap of approximately 8 to 10mm. The vehicle-mounted computer further analyzes the comfort level of the maglev train, identifying any abnormalities that may arise due to track irregularities or air spring malfunctions. This comprehensive monitoring system plays a crucial role in ensuring the safe and optimal performance of the maglev train, enhancing passenger comfort and addressing potential issues promptly.

Figure 4 provides an illustration of the sensor placement for monitoring the beam and track in the maglev system. The beam structure follows a simply supported configuration, with each span spanning approximately 25 meters. The monitoring setup involves the strategic positioning of sensors to capture relevant data during the passage of maglev trains through the designated monitoring points. On the upper surface of the middle span of the beam, accelerometers are installed to monitor the vibrations generated as the maglev trains traverse the monitoring points. Similarly, corresponding accelerometers are placed on the lower surface of the track to capture the vibrations induced by the passing trains. This setup enables the monitoring system to analyze and assess the vibrations experienced by both the beam and the track. To measure the relative displacement between the beam and the track, a laser displacement sensor is utilized. This sensor provides precise data regarding the movement and interaction between the two components, offering valuable insights into their dynamic behavior. Additionally, FBG strain sensors are affixed to the lower surface of the middle span of the track. These strain sensors enable the system to measure and monitor the strain experienced by the track when the maglev trains pass through the monitoring points. To compensate for any temperature effects on the strain measurements, FBG temperature sensors are installed near the strain sensors. All the sensors mentioned above are interconnected with a trackside data logger using signal wires. The collected data is then utilized to analyze the coupled vibrations among the maglev train, track, and beam. This comprehensive monitoring system provides valuable insights into the dynamic behavior of the maglev system, enabling the identification of any potential issues or areas requiring optimization.

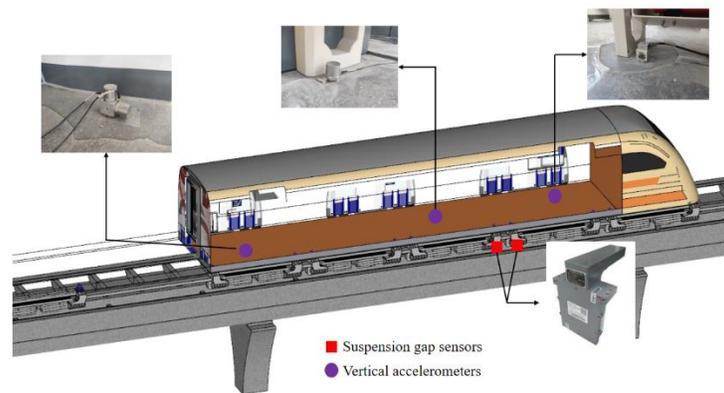


Figure 3. Sensor layout of short stator maglev train.

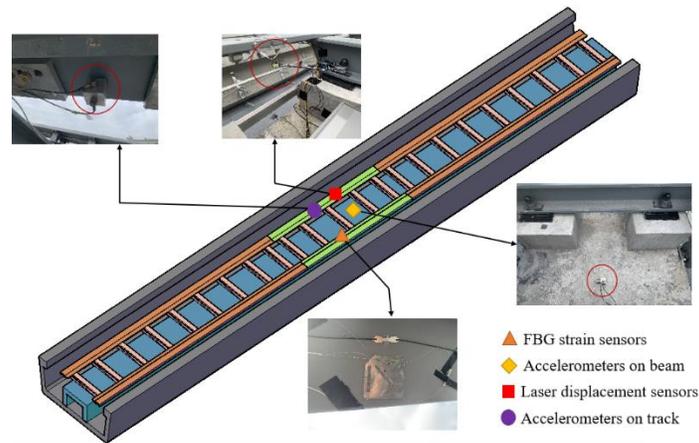


Figure 4. Sensor layout of beam and track.

MONITORING DATA ANALYSIS

The monitoring system described above has been implemented on an operational maglev line in China. Several key findings are presented below, showcasing the acceleration data of the carriage, maglev bogie, track, and beam.

Figure 5 and Figure 6 depict the suspension gap and vertical acceleration data captured by suspension sensor 1 and suspension sensor 2. These sensors are respectively positioned on the front-left and front-right ends of the first bogie of the middle carriage. The suspension gaps consistently fall within the range of 8mm to 10mm, reflecting the stable suspension of the maglev train. Furthermore, the recorded accelerations typically remain below 0.5g, indicating smooth and controlled motion. Notably, there is a noticeable difference in vibration amplitude between sensor 1 and sensor 2. This discrepancy is likely due to variations in irregularities present on the right track and left track, with the right track potentially exhibiting larger irregularities. Figure 7 illustrates the vertical vibration condition of the carriage, with an accelerometer installed at the middle position. The acceleration amplitude primarily remains below 0.1g throughout the monitoring period. The first dominant frequency component of the vibrations is approximately 2Hz, and the majority of the vibration components fall below 30Hz.

Figure 8 and Figure 9 present the vibration conditions observed at the middle span position of a bridge, with a span length of 25m, and the corresponding track when a maglev train passes through the monitoring point. During the passage of the maglev train, it is observed that the vibration acceleration of the bridge exceeds that of the track. The maximum amplitude of the bridge vibration reaches approximately 0.025g, while the track vibration exhibits a maximum amplitude of around 0.9g. Despite the amplitude difference, the bridge and track display similar vibration frequencies, with the dominant vibration frequency observed at approximately 19.5Hz. These findings highlight the dynamic behavior of the bridge and track when subjected to the passage of the maglev train. The vibration amplitudes, although different in magnitude, reflect the interaction between the train and the infrastructure.

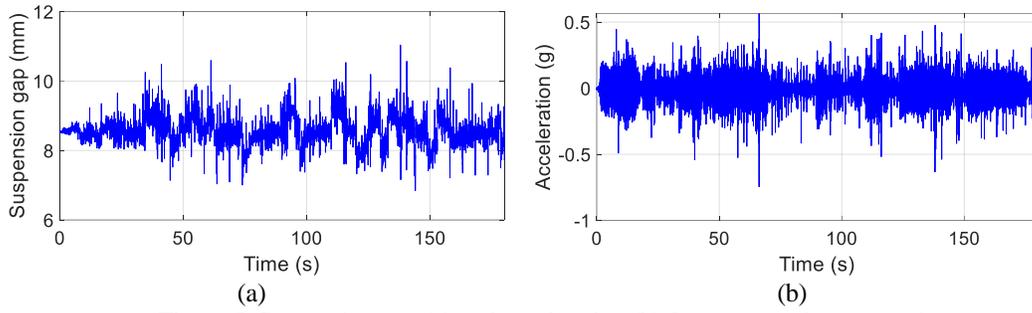


Figure 5. Suspension gap (a) and acceleration (b) from suspension sensor 1.

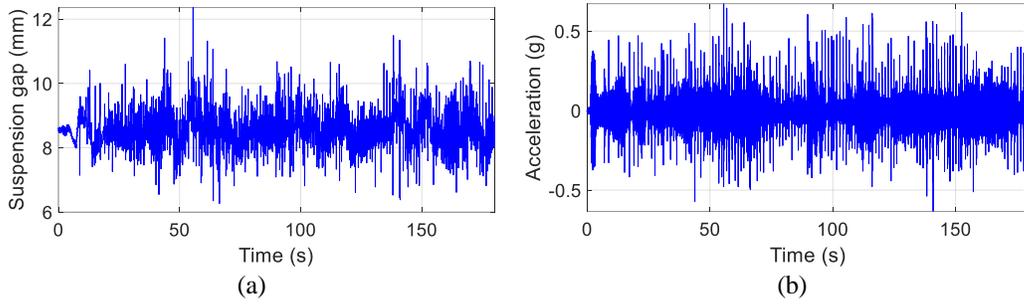


Figure 6. Suspension gap (a) and acceleration (b) from suspension sensor 2.

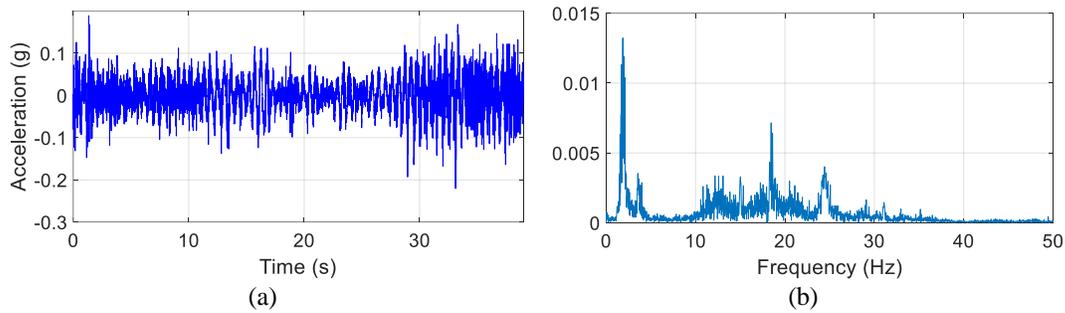


Figure 7. Vertical acceleration and frequency at the middle position of carriage floor.

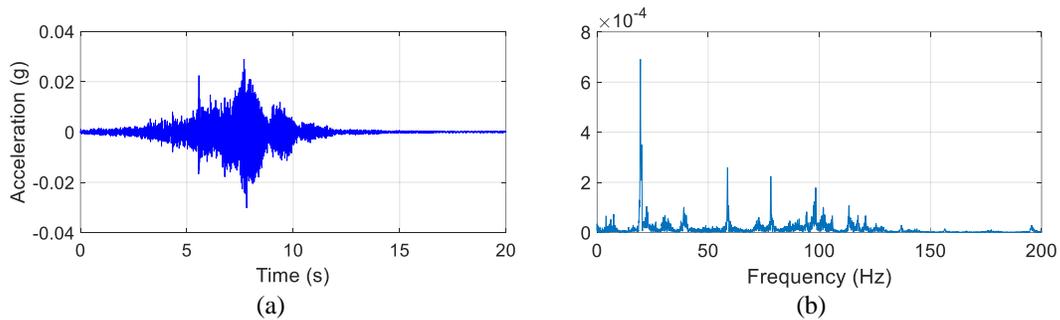


Figure 8. Vertical acceleration and frequency of the bridge at the middle span monitoring point.

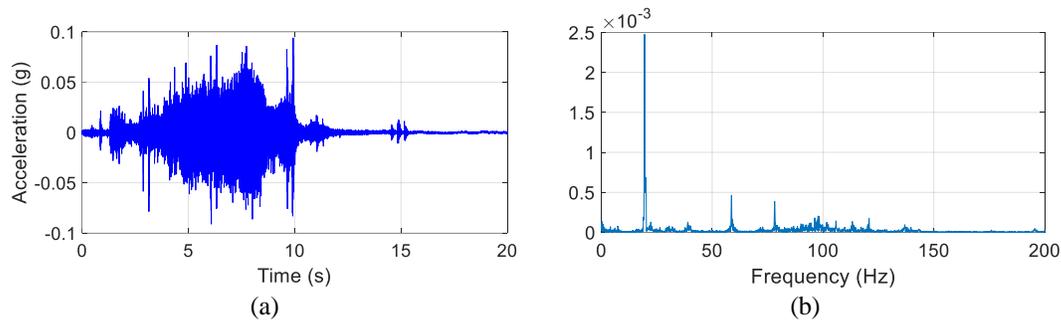


Figure 9. Vertical acceleration and frequency of the track at the middle span of bridge.

CONCLUSIONS

Indeed, the monitoring system plays a crucial role in obtaining the necessary data that the control system requires for the efficient operation of the maglev train. The vibration data collected from the maglev train, track, and bridge provides valuable insights into their respective performance and behavior.

By analyzing the vibration characteristics, operators and maintenance teams can gain a comprehensive understanding of the dynamic behavior of the maglev train. This information enables them to evaluate the train's performance, assess its comfort level, and identify any potential issues or irregularities that may affect passenger experience or safety. Furthermore, the vibration data aids in determining the structural integrity of the bridge and track, helping to identify any potential weaknesses or damages. This knowledge is crucial for implementing appropriate maintenance and optimization measures to ensure the long-term stability and safety of the infrastructure.

The monitoring system serves as a proactive tool in detecting and addressing any deviations or abnormalities in the vibration patterns. By identifying these issues at an early stage, operators can take timely corrective actions, such as adjusting suspension parameters, conducting track inspections, or performing maintenance tasks, to prevent further damage or deterioration. This proactive approach helps in optimizing the performance of the maglev system, ensuring its reliability, and enhancing the overall passenger experience.

REFERENCE

1. Liu, T.Y., and C.W., Su, 2021. "Is transportation improving urbanization in China?" *Socio-Economic Planning Sciences*, 77, p.101034.
2. Song, M., W. Zheng, and Z. Wang. 2016. "Environmental efficiency and energy consumption of highway transportation systems in China," *International Journal of Production Economics*, 181, pp.441-449.
3. Ma, F., W. Shi, K.F. Yuen, Q. Sun, X. Xu, Y. Wang, and Z. Wang, 2020. "Exploring the robustness of public transportation for sustainable cities: A double-layered network perspective," *Journal of Cleaner Production*, 265, p.121747.
4. Aboul-Atta, T.A.L., 2022. "Factors affecting performance improvement of the metro system in cities," *Journal of Engineering and Applied Science*, 69(1), pp.1-18.
5. Suppes, G., 1974. "Perspective on Maglev transit and introduction of personal rapid transit Maglev," *Transportation research record*, 1496, p.103.
6. Lee, H.W., K.C. Kim, and J. Lee, 2006. "Review of maglev train technologies," *IEEE transactions on magnetics*, 42(7), pp.1917-1925.
7. Liu, Z., Z. Long, and X. Li, 2015 *Maglev trains. 1st edn.* Springer.

8. Nieters, W. and K. Hermann, 2004. "Guideway monitoring during operational use on the First Transrapid Line in Shanghai," in *The 18th International Conference on Magnetically Levitated Systems and Linear Drives*, Bangkok, Thailand.
9. Sun, Y., H. Qiang, J. Xu, and G. Lin. 2019. "Internet of Things-based online condition monitor and improved adaptive fuzzy control for a medium-low-speed maglev train system," *IEEE Transactions on Industrial Informatics*, 16(4), pp.2629-2639.