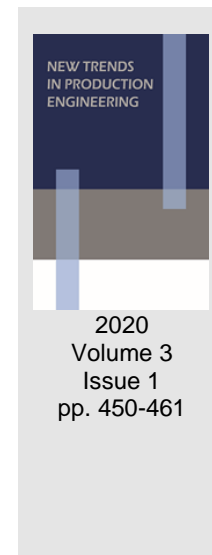


# ANALYSIS OF THE VIBRATION MEASUREMENT AND REDUCTION POSSIBILITIES IN LINEAR INFRASTRUCTURE FOR VACUUM RAIL TECHNOLOGY

**Tomasz KORBIEL, Rafał RUMIN, Jędrzej BLAUT**  
AGH University of Science and Technology  
**Stefan CZERWIŃSKI**  
**Jan KANIA**  
Silesian University of Technology



*Date of submission to the Editor: 10/2020*  
*Date of acceptance by the Editor: 11/2020*

## INTRODUCTION

Hyperloop technology no longer belongs to the sphere of science fiction and it is possible to use this type of transport in reality. Low-pressure rail offers a potential revolution in the transport industry. It can change a perception of distance by allowing aircraft to reach ground level speed in a point-to-point transport system on demand. Hyperloop refers to the concept described by Elon Muska in his paper “Hyperloop Alpha,” published in 2013. It applies to passenger or cargo vehicles travelling inside tubes with evacuated air. Reduced air resistance resulting from a low pressure environment could enable vehicles to reach very high speeds; 2-3 times faster than high-speed rail. The target system could enable direct travel on demand rather than regular services provided by other forms of public transport, could be more environmentally friendly than other modes of transport and could be cheaper than high-speed rail. This idea thrilled many futurists, transport technologists and engineers as well as led to such projects as: Virgin Hyperloop One (Zhou 2018), SwissMetro (Jeker 2019), Sapsan (Kim 2018), Delft Hyperloop (Li et al. 2019) or Hyper Poland (Mielczarek and Foljanty 2019).

## VIBRATION MEASUREMENT AND ANALYSIS

The amplitude and frequency of vibrations will depend primarily on the adopted technology for generating the load capacity. Three possibilities for the way the capsules move inside the tubes with reduced pressure are considered:

1. mechanical system (steel wheels on rails and rubber wheels on raceway)
2. magnetic system (passive and active system)
3. pneumatic system – the air cushion – requires energy to maintain.

Vibration analysis should be carried out to determine the source of vibration and the warning and alarm thresholds. The source of vibrations in case of rail

transport is the drive. In case of mechanical systems, the drive source can be an induction motor 6 FJA 3257 A (power 708kW) from Alstom used in Pendolino trains (maximum speed 250km/h). The most burdensome source of vibrations associated with transport is the rolling of wheels on rails. Therefore, it is necessary to differentiate between the system which is used for:

- testing vibrations related to the operation of drive system (inside the vehicle),
- testing aimed at assessment of the vibration level generated by the rails (along the railroad line).

In case of solutions based on levitation technology, the research collected on the first commercial line in Shanghai showed the dependence of vibrations on train speed and distance from the rail. It is worth emphasizing the fact that not only vertical but also transverse and longitudinal vibrations occur, especially near turns (Guo-Qiang, 2016, pp. 1295-1307). For high-speed rails, an increased vibration level is observed at the beginning and end of rolling stock. In order to eliminate vibrations, it can be proposed to increase the rigidity of vertical shock absorber in the first and last section of the rolling stock (Chang-Sung, Jeon and Sunghoon, 2017, pp. 697-704). To eliminate vibration, semi-active dampers with rheological fluid can also be used. Such silencers allow to control the rigidity of a damper during operation. Simulation tests with mathematical validation have been performed for side absorbers and confirm the reduction of transverse vibrations (Sharma et al. #). Reduction of the vibration level not only affects travel comfort but also reduces wear of mechanical rolling elements.

As mentioned above, two types of sensors are proposed for vibration measurement: these are sensors for measuring vibrations inside the vehicle and for monitoring vibrations along the vehicle route. Both the measurement of vibrations inside the vehicle and along the track will be recorded and sent to the monitoring system.

The development of 4.0 and high-speed rail industry introduces new standards of real time monitoring. This allows for continuous monitoring of key systems in technical devices. In case of high-speed transport, this task has a direct impact on travel safety and reliability of the entire system. One of the common trends is the use of wireless sensors, including systems that do not require external power supply. The use of intelligent sensors with wireless communication powered by train vibrations by means of maglev porous nanogenerator (MPNG) in high-speed rail was presented in Long Jin's paper (Jin et al. #). This solution simplifies the construction of monitoring system and the tested parameter (vibrations) allows to power the measuring and transmitting system.

### **MONITORING SYSTEM, DATA TRANSMISSION TECHNOLOGY**

The system that allows to study vibrations along the track is to inform about the noise and vibration levels caused by the passage of capsule and to provide information about possible para-seismic vibrations that may affect the operation and use of hyperloop infrastructure (Korbiel et al., 2017). The system concept is

based on the possibility to register vibrations and to provide information about the existing danger conditions. Such a system should be characterized by high flexibility and a wide range of measured parameters due to the size of track. The dispersed structure and multi-layer system will allow to assess not only such factors as vibration or noise, but also mass movements of the ground or ground water level. The assumed requirements of flexibility and easiness of integration among different types of sensors are fulfilled by the system based on the MQTT protocol. The structure of monitoring system consists of the MQTT Broker to which information from subsequent measurement systems is sent and sends information to HTTP server, report server, archiving server and subscribers. The two-way information transfer is available from the system administrator panel, which configures the structure. The MQTT Broker, which intermediates between all elements of the MQTT structure can be located anywhere in the ICT infrastructure. Subscription of the report can take on different complexity. This allows for personalized information to be received at different management levels. Collected and analyzed data will allow to react appropriately in case of threat to hyperloop infrastructure. One of the main advantages from chosen concept is the possibility of simultaneous transmission of information about alarm conditions to all persons managing the system. It also allows to create current reports in real time at different levels of detail for authorized users. In order to secure the structure it is possible to separate the report server and archiving. Depending on the consumption of computing power resources of the server with the MQTT broker, it is possible to carry out simultaneous data analysis in a separate mode. The analysis can also take place outside the MQTT server on an external computing unit, which significantly increases the reliability of monitoring system. Communication between subsequent elements of the system can be conducted both wired (e.g. in UTP standard) and wireless (e.g.: ISM, WiFi, LoRa).

Subscriptions can be received by means of terminal devices for field employees. The versatility of proposed MQTT protocol allows to use a smartphone in this role as well. In case of exceeding the warning thresholds, the operator can be immediately informed about the event. The measuring station along with the implementation of measurements simultaneously allows for the initial analysis of data and transmission of obtained results to the MQTT server. Individual measuring stations along the track or inside the capsule can be equipped with different sensor configurations. Each measuring station can also act as a subscriber. The data obtained in this way can be used to configure the measurement session, to determine the observation time, intervals between successive transmissions, warning thresholds, etc. Para-seismic vibrations can be implemented by means of acceleration sensors made in MEMS technology (micro electro mechanical systems). The measuring station, with the measurement, carries out the filtration of signals according to the standard "Evaluation of harmfulness of vibrations transmitted through the ground to buildings" PN-B-02170. In order to obtain information about the speed of

vibrations, the signals are integral in the time domain and then formatted to the JSON standard and sent to the MQTT broker (Korbiel, Pawlik, 2012, pp. 37-40).

## **OVERVIEW OF THE MEASURING AND VIBRATION-REDUCING TECHNOLOGIES USING THE EXAMPLE OF CERN**

Human activity has a significant impact on the environment and the surrounding area in which we operate. The impact of technological development and the use of devices and machines not only leads to environmental degradation and introduces irreversible damage, but also significantly disturbs the balance of the whole system. The impact of human activity on the environment is an extremely important and extensive subject, but it will not be the subject of this study. The focus should be placed on how human impact, as well as other external factors not directly derived from our activities, affect sensitive infrastructure systems. Vibrations generated by machines, traffic, businesses and vehicles can increase and adversely affect sensitive and delicate hyperloop infrastructure components. These are the so-called para-seismic factors, the catalog of which is as follows. These include: vibrations caused by rail, road, construction equipment (especially with a vibrating effect), machine operation, explosions, blasts or collision events. To the elements affecting sensitive infrastructure, apart from the effects caused directly and indirectly by man, it is necessary to add the natural influence of environment and the so-called seismic events. These include earthquakes of varying degrees of intensity, movements of tectonic plates, earth mass shocks and vibrations caused by the expansion of gases lying in rock chambers. All these and many other factors not mentioned above make the construction and preparation of an installation based on the idea of working in a vacuum environment a considerable challenge. Attention should be paid not only to the issues of preparing the infrastructure and protecting it from damage, but also to the application of preventive methods that will allow the system to function properly for a long time. In many cases renovation and maintenance activities can be so time-consuming and difficult that measures should be taken in advance to reduce the seismic and para-seismic impact on the entire system. This study will describe the sensory systems that are already used in some infrastructures around the world. Systems to reduce the vibration impact on infrastructure such as active and passive systems will also be presented (Chunwei Z., Junping O., 2010).

Elastic vibrations of the ground caused by controlled or uncontrolled human operations (e.g. vibrations transmitted by transport) give results in the form of para-seismic waves. The vibrations from operating elements of transport infrastructure and means of transport are transmitted through the ground to environment. Dynamic phenomena generate forces that are transmitted to the infrastructure and can migrate to sensitive components of the hyperloop network, adversely affecting the entire system. Therefore, the basis is an individual study of the entire transport route and specification of the individual impacts to which the transport network and the individual infrastructure components may be exposed. It is also worth considering that due to the

complexity of interactions, it is necessary to create interdisciplinary research teams consisting of specialists in the fields of transport, construction mechanics, ground mechanics or environmental protection, in order to prepare reliable expert opinions on the impact of these elements on the infrastructure in question. The mechanism of formation and transmission of vibrations (e.g. the effect of contact phenomena) in urban space has been discussed in many sources, but it is worth to focus on what such vibrations and forces can affect the infrastructure operating in a state of vacuum and high speeds. In order to discuss such influences in detail, it is necessary to first perform stress analysis and spectral evaluation of vibrations of a given engineering object (Svinking M., 2004). Evaluation methods using MES software are based on detailed micro-level analysis. However, the problem arises when it is necessary to perform a global analysis for the whole line of communication – in this case the whole hyperloop line. For this purpose, detailed guidelines for system construction should be presented with the Dynamic Transport Impact Assessment (DTIES). This system is based on the use of models in the study of dynamic phenomena, such as the treatment of para-seismic vibrations.

It is also worth mentioning the theory introduced by James T.P., who was the first to introduce modern control theory for the control of civil structures vibrations, which initiated a new era of research on active structural control in civil engineering. In the course of almost 40 years of development of the Active Mass Driver/Damper (AMD) system, it has been possible to create a system that allows for a proper and comprehensive vibration analysis of structures and constructions. To date, more than a few dozen tall buildings and large scale bridge towers have been equipped with AMD control along with a system to reduce vibrations caused by wind or earthquakes. In addition, there are quite a few successful applications with passive tuned mass, such as the damper control system (TMD) (Korzeb J., Chudzikiewicz A., 2015).

### **Sensory systems**

Currently, various technologies and systems are used, which allow to capture specific changes in the ground and observe the forces acting on individual elements of infrastructure. The so-called sensory systems, which are currently used in engineering allow you to recognize the type, nature, size and frequency of occurrence of specific forces that may cause adverse effects on elements or the whole sensitive infrastructure (Serluca et al, 2018). This is all the more important in the case of hyperloop system, because the sensory system will allow to properly determine and select the appropriate methods of active or passive elimination of the forces occurring. An excellent example of the use of sensory systems in infrastructure is the scientific and research center CERN (Lopes, 2019) (Fig. 1).

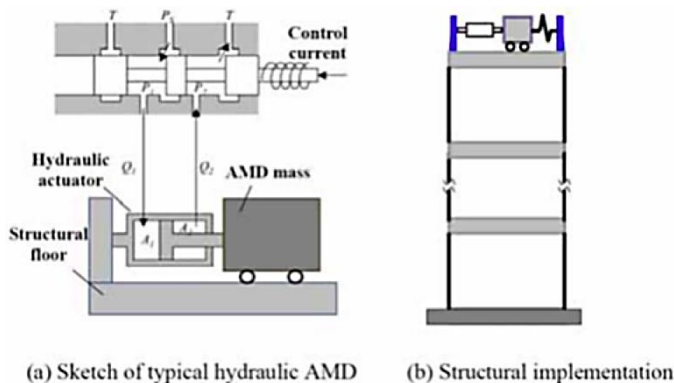


**Fig. 1 CERN Research Centre (Organisation Européenne pour la Recherche Nucléaire)**  
Source: (Virgo Collaboration, 2019)

The sensory systems used in this object turned out to be a milestone and allowed for the development of such devices. It started with a relatively simple goal: to create a prototype of the new type of device for monitoring the movement of underground structures at CERN. However, the project – result of cooperation between CERN and the United Institute of Nuclear Research (JINR) in Dubna, Russia – quickly evolved. The prototype has evolved into several full-scale devices that can potentially be used as early warning systems for earthquakes as well as for monitoring other seismic vibrations. Moreover, devices known as precision laser inclinometers can be used at CERN and elsewhere. The scientists involved in the project are currently testing one device in the Advanced Virgo detector, which recently detected gravity waves – a minor disturbance in the space-time structure that Albert Einstein predicted a hundred years ago. Unlike traditional seismometers, which detect ground movements through their effect on spring suspended weights, a precision laser inclinometer (PLI) measures their effect on the surface of liquids. The measurement is conducted by directing the laser light onto the liquid and checking how the laser beam reflects. Compared to load-spring seismometers, PLI can detect angular movements in addition to progressive movement (up and down and from side to side) and can record low-frequency movement with very high precision. This system is capable of capturing seismic movement from 1 mHz to 12.4 Hz. The accuracy of this system allows the measurement of vibrations, which corresponds to measuring the vertical displacement of 24 picometers (24 billionths of a meter) at a distance of 1 meter. The team assembled and tested the PLI prototype in the JINR and in the TT1 CERN tunnel. After the research, it turned out that the system worked so well that it showed potential as a helpful early warning seismic system for the High Luminous – Large Hadron Collider

(HL-LHC) and other machines and experiments. The Large Hadron Collider and its proton beam are extremely resistant to seismic activity, but the HL-LHC uses narrower beams to increase the number of proton-proton collisions and thus the potential for discovery in particle physics. This means that the beams are more vulnerable to deviation from the center in case of a high-energy earthquake with an epicenter relatively close to CERN. The PLI located at several points around the machine can be used as early warning systems for such events. It is impossible not to notice the enormous potential of such systems. This makes it possible to detect movements of tectonic masses, vibrations caused by para-seismic factors and other forces that may affect sensitive hyperloop infrastructure. Appropriate sensory systems are the basis for a properly optimized system to reduce the environmental impact on hyperloop infrastructure.

Sensory systems are also widely used, which are based on slightly different principles than those used in the CERN research center. It has been commonly recognized that the AMD system is the best control scheme due to its advantages, such as the best ratio of control effect to effort, simple and easy to implement. Typically, an AMD control system consists of a mass element, an actuator element, a stiffness element (coil or commonly used spring), a shock absorber, a stroke limiter, a brake protector and a sensor. The data acquisition and processing system, on the other hand, has real time computerized control software and hardware system. In addition, a power supply system is required to operate all of the aforementioned electrical devices. In a traditional AMD system, the most commonly used actuators are hydraulic cylinders or electric servomotors, which may have the following disadvantages, such as large system volume, complex design, time delay, slow response and limited mass stroke. For this purpose, several new special devices have been proposed to replace the traditional actuators used in the traditional AMD system (Fig. 2). The applied innovative active control system proposed for structural vibration control uses the drive technology of linear electric machines. This modified system, called EMD, allows for an even more accurate vibration reading within the center. Thanks to this, the data is more precise and the system is not too complex (Braz, 2000).



(a) Sketch of typical hydraulic AMD (b) Structural implementation

**Fig. 2 Traditional AMD vibration sensing system**

Source: (Braz, 2000)



## SYSTEMS REDUCING THE VIBRATION IMPACT ON INFRASTRUCTURE

In addition to complex detection systems and sensory systems for the recognition of vibrations and forces that can affect the infrastructure, very important, if not fundamental, are devices that can limit the impact of these forces on the objects concerned. The so-called systems reducing the vibration impact on infrastructure, in combination with sensory systems, constitute a complete protective system against the negative influence of seismic and para-seismic vibrations on the infrastructure in question. There are systems of active limitation of the vibration impact as well as passive limitation systems. Both of these systems and the types and methods they contain will be briefly presented (Elliott, 2010).

### Active reduction systems

#### *Inertial feedback:*

The most popular type of active cancellation system is the inertial feedback system. As a rule, the pneumatic isolators used are usually springs or various types of force compensators. Apart from the input signal and the ground motion sensor, the feedback path consists of a seismometer, filter and actuator. The seismometer measures the displacement between its test mass and isolated load, filters this signal and then applies the force to the load in such a way that the displacement of forces is constant – thus zeroing the seismometer output signal. As the only force acting on the test mass comes from the compression of its spring and the compression is controlled to be constant, it follows that the test mass is actively isolated. Similarly, as the isolated load is forced to track the test mass, it must also be isolated from vibrations. The performance of this type of system is always limited by the servo throughput. It should be noted that structural resonances in the isolated load limit the bandwidth in practical systems to 10-40 Hz (usually near the lower end of the range). As a result, these servo systems have two gain frequencies – usually 0.1 and 20 Hz. As a result, the servo achieves a maximum gain of about 20-40 dB at ~2 Hz – the natural frequency of passive spring fixation of the system. The closed-loop system response has two new resonances at unit gain frequencies of ~0.1 and ~20 Hz. Due to the small bandwidth of these systems, the gain is not too great, except for the natural resonant load frequency. The high gain completely dampens this resonance. For this reason, it is helpful to think of these systems as inertia damping systems that have the property of damping the main resonance of the system without compromising the vibration isolation properties. Passive damping can also suppress this resonance, but significantly increases the transmission of vibrations from the ground.

These servo systems are also limited in how low their frequency of unity amplification by noise in the inertia sensor can be. Virtually all commercial active vibration elimination systems use geophones as inertia sensors. These are simple, compact and inexpensive seismometers used in geophysical research. They even surpass high quality piezoelectric accelerometers at frequencies of 10 Hz and lower. However, their noise performance is not sufficient to push the



bandwidth of an inertia-coupled system below  $\sim 0.1$  Hz. To break through this barrier, much more expensive and advanced sensors would have to be used.

#### *Feedforward vibration reduction systems:*

The performance of an inertia feedback system can be improved by adding feedforward. Generally, feedforward is much more difficult than feedback, but it offers a way to improve system performance when the feedback servo has limited throughput. There are two types of feedforward systems that are quite different, although they have the same name. The feedforward vibration scheme includes the use of a ground motion sensor and is conceptually quite simple: If the ground moves up a certain value, the load feels a force by compressing the spring equal to  $x$ . However, the ground motion sensor detects this movement and applies an equal and opposite force to the load. The forces acting on the load “cancel” and the load remains unchanged. “Cancel” is in quotation marks because it is a very overused term. This means perfect cancellation – which practically never happens. In real systems, it is necessary to consider how well these two forces are tolerated. For various reasons, it is difficult to match the two forces better than about 10%, which would result in a tenfold improvement in system response. Matching these forces to 1% is practically impossible given the technologies available today. There are many reasons for this. However, as a general rule, the following reasons are assumed for the drift level of forces is not perfect: The sensor is usually a geophone that has no “flat” frequency response. Its response must be “flattened” by a carefully selected conjugate filter. The gain of this signal must be precisely matched so that the force produced by the actuator is exactly equal to the force caused by the ground movement. This force and the properties of conjugate filter must remain constant to an exact percent. Matching the gain is also extremely difficult if the mass distribution of a system changes, which is common in semiconductor applications.

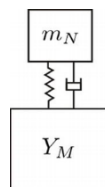
#### **Passive reduction systems**

Passive systems to reduce the vibration impact on sensitive infrastructure are, in addition to active systems, a second way to reduce these forces. The reduction systems presented below are based on the theory of dynamic vibration dampers (mass vibration dampers), using the so-called classical methods of coupling the supporting structure. More technologically advanced methods are also used, which consist in bypassing piezoelectric resonant circuits in order to obtain a composite structure. Thanks to the application of these systems and their proper comparison with the systems of proper vibration detection and active force limitation systems, the negative impact on sensitive infrastructure can be significantly eliminated. This will allow the hyperloop system components and the entire infrastructure to be kept in a vacuum without the risk of failure or damage caused by seismic or para-seismic factors. Passive vibration control solutions, such as tuned vibration dampers, are often limited to a single structural resonance or a specific interference frequency. Active vibration control systems can overcome these limitations, but require continuous electricity for

sufficient performance. Therefore, a passive vibration control system is still preferred in some cases. However, the integration of active components allows the system parameters to be adjusted, for example, the resonance of a tuned vibration damper. These adaptive or semi-active systems require only external energy for adaptation, while the compensating forces are generated by the mass inertia of absorber (Enriquez Zarate, Velazquez, Gutierrez, 2019).

*Tuned vibration dampers (TVA) and fine-tuned vibration dampers (TMD)*

are used since the beginning of the 20th century to reduce unwanted vibrations on buildings or infrastructure such as pipelines or tunnels. In principle, this method uses a mass inertia that is flexibly coupled to a vibrating structure. This resonant spring-mass system can be tuned to certain resonant frequencies of the parent structure. Then this device (usually referred to as a tuned TMD mass attenuator) is used in flexible infrastructure objects, such as towers or bridges. In case of large objects, several TMDs are located in the structure. When an oscillator is tuned to a harmonic interference frequency, it is called a tuned vibration absorber or a vibration neutralizer. Potential applications range from optical disc drives, using a mass of the absorber of about 40 grams, to the vibrations of marine engines requiring more than 10 tons of oscillating mass. The performance of these devices is mainly limited by precise tuning to the target frequency. If a certain bandwidth is to be used, a large mass inertia should be applied, which usually prevents the use of TVA in such cases (Mayer, Herold, 2017) (Fig. 3).



**Fig. 3 Basic diagram of the passive vibration reducer TVA**

Source: (Mayer, Herold, 2017)

If a piezoelectric element is attached to the structure, it is deformed when the structure deforms and part of the vibration energy is converted into electricity. A piezoelectric element behaves electrically like a capacitor and can be connected to the so-called bypass network to control vibrations. Bypassing with a resistor and inductor introduces electrical resonance, which is optimally tuned to structural resonances. The inductive coil is used to tune the bypass circuit to a preset resonant frequency of the structure and the resistor is responsible for reducing the peak amplitude of this particular mode. This configuration is very similar to a classical vibration damper.

*Vibration absorption using TVA and bypass simultaneously*

As mentioned earlier, bypassing with a resistor and coil, along with the internal capacitance, creates a resonant circuit that is analogous to the classic dynamic vibration damper. It is worth noting that the TVA absorbs kinetic energy and the bypass absorbs deformation energy. The use of synthetic inductors, which require an external power supply, is one of methods to overcome the

requirement of high inductance. However, it is possible to use alternative methods that are based on the use of a hybrid passive technique involving TVA and bypasses simultaneously attached to the same structure. The idea is to use TVA to dampen vibrations in modes where bypassing parameters would not be possible. The result is a passive vibration damper that will improve force reduction and reduce the vibration impact on the structure.

The detection methods presented above, i.e. sensory systems for the detection of vibrations that can be transmitted to sensitive structures, as well as systems that allow to reduce these vibrations (actively or passively) are the answer to problems of seismic and para-seismic influences on hyperloop infrastructure. Appropriate selection of available systems and their proper implementation, as in the example of the CERN scientific research center, can significantly reduce the negative impact of direct or indirect forces on sensitive structures. This is certainly a topic for further in-depth analysis, the results of which will form the basis for constructing assumptions aimed at reducing the risk of hyperloop infrastructure operation.

## REFERENCES

- Braz J. (2000) *Using Passive Techniques for Vibration Damping in Mechanical Systems*. [Online]. Available at: [https://www.scielo.br/scielo.php?script=sci\\_arttext&pid=S0100-73862000000300004](https://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100-73862000000300004) (Accessed: 09 November 2020).
- Braz J. [online]. Available at: <https://www.scielo.br/img/fbpe/jbsms/v22n3/a04fig03.gif> (Accessed: 09 November 2020).
- Chang-Sung, Jeon, and Choi Sunghoon. *A study on the Vibration Reduction of the Commercial High-speed Train*. Journal of the Korea Academia-Industrial cooperation Society, 2017, pp. 697-704.
- Chunwei Z., Jinping O., (2010) *Mass Inertia Effect Based Vibration Control Systems for Civil Engineering Structure and Infrastructure*. [Online]. Available at: [https://www.researchgate.net/publication/221905507\\_Mass\\_Inertia\\_Effect\\_Base\\_d\\_Vibration\\_Control\\_Systems\\_for\\_Civil\\_Engineering\\_Structure\\_and\\_Infrastruct\\_ure](https://www.researchgate.net/publication/221905507_Mass_Inertia_Effect_Base_d_Vibration_Control_Systems_for_Civil_Engineering_Structure_and_Infrastruct_ure) (Accessed: 09 November 2020).
- Elliott S.J. *Vehicle Noise and Vibration Refinement*. 2010.
- Enriquez Zarate J., Velazquez R., Gutierrez S., (2019) *Passive vibration control in a civil structure: Experimental results*. [Online]. Available at: [https://www.researchgate.net/publication/333057511\\_Passive\\_vibration\\_control\\_in\\_a\\_civil\\_structure\\_Experimental\\_results](https://www.researchgate.net/publication/333057511_Passive_vibration_control_in_a_civil_structure_Experimental_results) (Accessed: 09 November 2020).
- Guo-Qiang, Li. *Field measurements and analyses of environmental vibrations induced by high-speed Maglev*. Science of the Total Environment, 2016, pp. 1295-1307.
- Korbiel T., Batko W., Baranski R., Pawlik P., Blaut J., *Recognition of the 24-hour Noise Exposure of a Human*. Arch. Acoust., vol. 42, no. 4, 2017.
- Korbiel T., Pawlik P., *Parametryzacja trajektorii fazowych w zastosowaniach diagnostycznych*. Przegląd Mech., no. nr 6, pp. 37-40, 2012.
- Korzeb J., Chudzikiewicz A. (2015) *Evaluation of the vibration impacts in the transport infrastructure environment*. [Online]. Available at: <https://link.springer.com/article/10.1007/s00419-015-1029-0> (Accessed: 09 November 2020).
- Lopes A. (2019) "Sensor used at CERN could help gravitational-wave hunters" [Online]. Available at: <https://home.cern/news/news/engineering/sensor-used-cern-could-help-gravitational-wave-hunters> (Accessed: 09 November 2020).

- Mayer D., Herold S., (2017) *Passive, Adaptive, Active Vibration Control, and Integrated Approaches*. [Online]. Available at: <https://www.intechopen.com/books/vibration-analysis-and-control-in-mechanical-structures-and-wind-energy-conversion-systems/passive-adaptive-active-vibration-control-and-integrated-approaches> (Accessed: 09 November 2020).
- Mayer D., Herold S., [online] Available at: <https://api.intechopen.com/media/chapter/57787/media/F1.png> (Accessed: 09 November 2020).
- Serluca M., Aimard B., Balik G., Caron B, Brunetti L., Dominjon A., Jeremie A., (2018) *Vibration Analysis and Control in Particle Accelerator*. [Online]. Available at: [https://indico.cern.ch/event/694811/contributions/2863859/attachments/1595533/2526938/2018\\_02\\_06\\_FCCee\\_MDI\\_workshop\\_Serluca.pdf](https://indico.cern.ch/event/694811/contributions/2863859/attachments/1595533/2526938/2018_02_06_FCCee_MDI_workshop_Serluca.pdf) (Accessed: 09 November 2020).
- Svinkin M. (2004) *Minimizing Construction Vibration Effects*. [Online]. Available at: [https://www.researchgate.net/publication/245492562\\_Minimizing\\_Construction\\_Vibration\\_Effects](https://www.researchgate.net/publication/245492562_Minimizing_Construction_Vibration_Effects) (Accessed: 09 November 2020).
- Virgo Collaboration [online]. Available at: <https://cds.cern.ch/images/CERN-HOMEWEB-PHO-2019-104-1/file?size=large> (Accessed: 09 November 2020).

**Abstract.**

The paper presents the concept of vibration measurement and reduction system for rails in hyperloop technology. It is based on the experience of measuring vibrations in high-speed rail, the first commercial magnetic rail, and vibration reduction systems for these rails. The authors outlined a conceptual vibration monitoring system based on the MQTT protocol and the vibration reduction method. The vibration reduction systems based on variable-characteristic silencers and solutions used in research centers, especially in CERNie and LIGO, were de-scribed.

**Keywords:** Vibration, Hyperloop, low-pressure ultra-speed trains, vactrain