Proceedings of CONF-MCEE 2026 Symposium: Advances in Sustainable Aviation and Aerospace Vehicle Automation
DOI: 10.54254/2755-2721/2026.KA36122

Active and Passive Vibration Isolation System Used in Machinery and Construction

Yuansheng Yang

Wuhan Britain-China School, Wuhan, China
Yang200810292022@163.com

Abstract. The vibration is dangerous factor in machinery and construction. As it causes the damages to the machines and even humans. In these cases, people have developed many different kinds of technologies that used to minimize the influence of vibration on the parts of machines and human who operate the machine or construct the devices. In fact, means for vibration isolation contain two main types, the active and the passive methods. Also, there are other solutions, which combining the AI techniques with the passive and active isolation vibration means, not only increasing the effectivity of each method, but also decline the cost of devices. This essay mainly summarizes how passive and active vibration isolation methods take their advantages to create a more stable environment of working and how AI methods just raise the ceiling of the final effect of each method. Moreover, there still some problems exist, so some direction of future research and possible solution also included in this essay.

Keywords: Vibration isolation, Passive system, Active control, Engineering Application

1. Introduction

Vibration is an inherent problem of most machines and engineering equipment. In the long term, it may cause material deformation and structural malfunction, undermine operational safety and may lead to accidents. Long-term vibrational action will easily cause fatigue cracks in mechanical components and structures subjected to cyclic loads [1]. For instance, the shafting crack, equipment precision degradation (optical processing error). Besides, vibration also harms human beings: it produces loud noise which damages human hearing. When the vibration transmitted into body causes discomfort or impacts on humans (low back pain / hearing loss). So, vibration inevitably leads to human fatigues and health problems, making VI become an important way to enhance component and systems durability, stability, comfort [2]. Now's existing active technique includes Passive technology (taking advantage of material property) methods, Active method (making use of counteracting forces) method of generating anti-vibrations, a mixture technique (passive and active together with artificial intelligence), and now there are lots of VI techniques. However, there is still a harsh working condition, attenuation phenomenon, as well as precision-energy consumption problem. Limited by structure, the research on high-efficiency vibration energy harvesting and low-attenuated vibration suppressing always remains a theoretical bottleneck and technical difficulty in this field [3]. How to effectively combine the advantages of both active and passive vibration

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2026.KA36122

isolation to make better effect was always a hotspot and trend in this area many years ago [4, 5]. All above has responded to the core requirement which presented at the initial of introduction called "solving vibration-induced structural damage, health risks and precision machine performance degradations", then we review them all again through reviewing, calculating and projecting, which provides us directions and guides in engineer practicing using vibration isolation, supplies a new inspiration for researchers working on VI area to reach "the higher, broader and lower" of development this direction and helps pushforward and improve the advance of VI tech meeting complex needs of modern engineering equipment and systems that we meet in our daily life.

2. Performance evaluation

2.1. Transmissibility

Its main purpose is the ratio of system output and system input, so that to measure the degree of unpredictable input are altered by the system. Usually, the low transmissibility is efficient. The formula (1) just shows the expression of force transmissibility.

$$T = \sqrt{\frac{1+(2\xi r)^2}{(1-r^2)^2+(2\xi r)^2}} \tag{1}$$

As r < 1: T approach to 1, the most force exerts on the object, which means there is no isolation effects.

As r = 1: T = $\frac{1}{2\xi}$: the resonance effect appears, which brings greater vibration.

As r > $\sqrt{2}$: T < 1 the force is reduced

According to the formula (1), the efficiency of vibration isolation is high when the transmissibility is small.

2.2. Damping ratio

It helps explain the speed of reducing of vibration. Appropriate damping ratio minimum the amplitude of vibration and improve the system stability. When its value just smaller than 1, the system keeps bouncing but the degree of vibration is reducing. When its value becomes 1, which we called the critical damping. In this case, the system back to the balance condition as soon as possible without overshoot. There is over damping when damping ratio value larger than 1, the system has not vibration and back to its balance position slowly. The formula (2) just shows how damping ratio is represented.

$$\xi = \frac{c}{2\sqrt{mk}} \tag{2}$$

2.3. Insertion loss

In the vibration transmission path, the ratio of the vibration response quantity at a specific observation point when no control device is installed to the vibration response quantity at the same

DOI: 10.54254/2755-2721/2026.KA36122

observation point after the control device is installed. The figure1 just show a table to show an example that indicates insertion loss effect.

$$IL = L_{p_0} - L_{p_1} \tag{3}$$

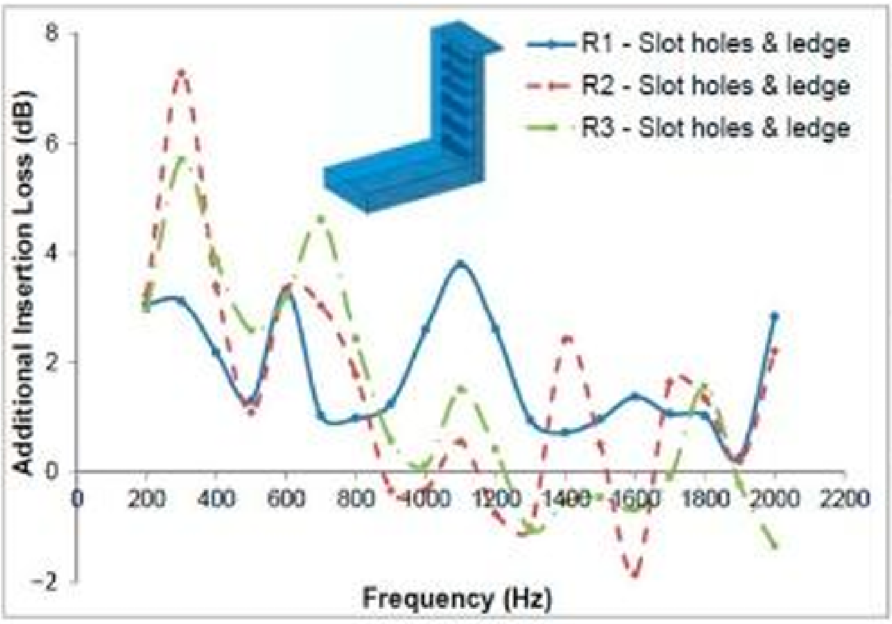

Figure 1. Insertion loss experimental data schematic diagram [6]

3. Passive vibration isolation

The passive vibration isolation methods are most common solutions in cars. The design of suspensions needs to consider many aspects. First, the natural frequency of the vibration isolation system should be much lower than the main excitation frequency; only in this way can vibration transmission be effectively reduced [7]. The formula shows this clearly.

$$r = \frac{\bar{\omega}}{\omega_n} \tag{4}$$

Slow vibration------ $r < 1$

$$D = \frac{1}{\sqrt{(1-r^2)^2 + (2\xi r)^2}} \tag{5}$$

Quick vibration------ $r > 1$

DMF<1

For automotive vibration isolation system, DMF (dynamic magnification factor) plays an important role in the evaluation and design of its performances. It represents how many times the system's response displacement magnitude is expanded relative to the excitation amplitude of

DOI: 10.54254/2755-2721/2026.KA36122

external dynamic. Especially near the resonance frequency [8]. And it unfolds the negative factors of passive vibration isolation. The low frequency isolation. In the low-frequency range, the transmissibility is usually close to 1 or greater than 1, which means that low-frequency vibrations are hardly isolated and may even be amplified [9]. The problems are existing because of the limitations of natural frequency, to effectively isolate low-frequency vibrations, the natural frequency of the isolation system needs to be much lower than the frequency of the vibration being isolated. However, reducing the natural frequency typically requires the use of very soft springs, which lowers the system's load-bearing capacity and easily leads to large static displacements [10]. The vibration isolation in civil structure becomes more important. This relates to the safety of people, so it must be more reliable and endurable. Like the vehicles, the passive vibration isolation in building reduces vibration transmission within a certain frequency range by introducing flexible connections between vibration sources and protected objects to lower the system's natural frequency. Thus, it also performs poorly and may even increase the vibration when it encounters the low frequency vibration.

4. Active vibration isolation

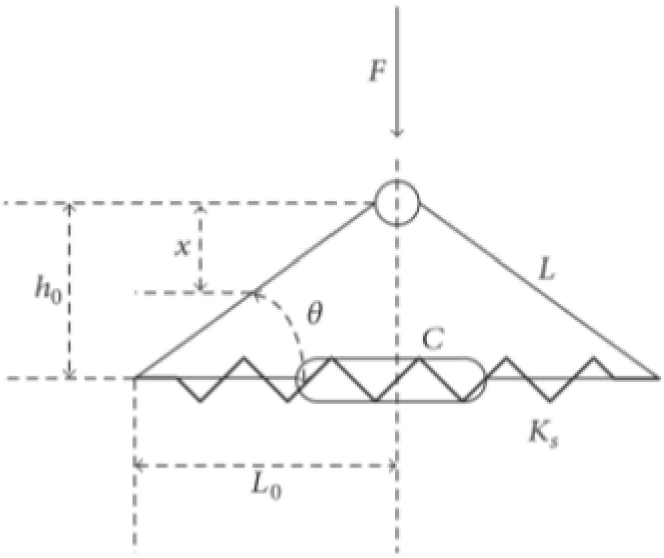

Figure 2. QZS structure schematic diagram [15]

The active vibration isolation appears to solve the problem of passive vibration isolation. Active vibration isolation systems can monitor vibration signals in real-time through sensors and dynamically adjust the output of actuators via feedback control systems, thereby adapting to vibrations of different frequencies [11, 12]. An important technology is Quasi-Zero Stiffness (QZS) technology. The Quasi-Zero Stiffness (QZS) vibration isolation system can bear static loads while achieving efficient isolation of dynamic vibrations [13]. The structural designs of QZS vibration isolators are diverse, including negative stiffness mechanisms in various forms such as magnetic force, inclined springs, and flexible hinges [14]. We can see how QZS vibration are efficient. We can use static characteristic analysis. In response to the challenges of low-frequency vibration isolation, this study proposes a novel Quasi-Zero Stiffness (QZS) vibration isolator. The design innovatively combines a traditional vertical linear spring in parallel with a negative stiffness mechanism

DOI: 10.54254/2755-2721/2026.KA36122

composed of horizontally stretched springs. As shown in Figure 2, this structure can achieve an ideal combination of high static load-bearing capacity and low dynamic stiffness.

The dimensionless stiffness of the system can be expressed by Equation (6)

$$\widehat{K} = 1 + 4\alpha\left(\frac{\lambda^2}{(\lambda^2-\widehat{u}^2)^{\frac{3}{2}}} - 1\right) \tag{6}$$

The system stiffness can be precisely controlled by adjusting the geometric parameter λ and stiffness ratio α. As shown in Figures 3, when the system is near the equilibrium position, its stiffness can be significantly reduced and approach zero, thereby achieving the quasi-zero stiffness characteristic [15].

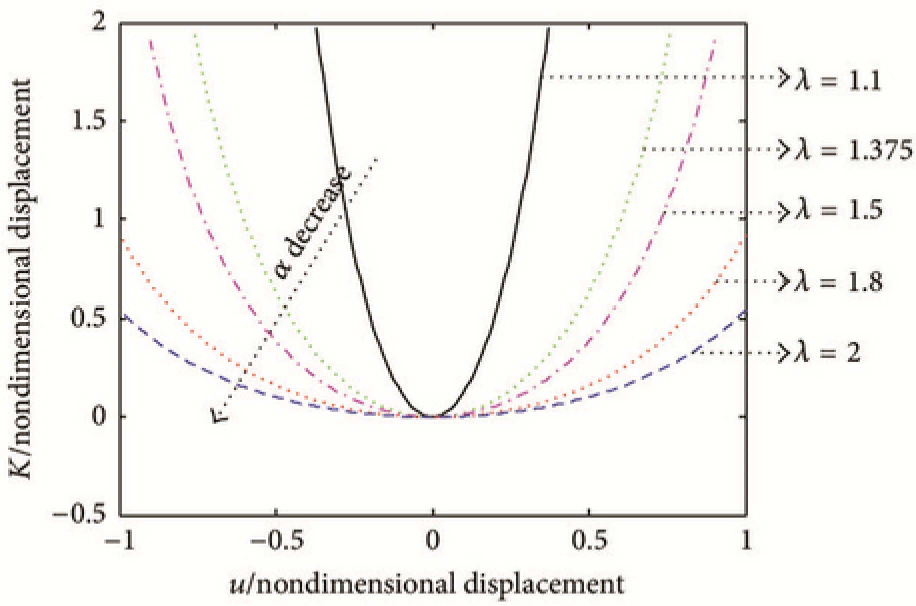

Figure 3. Nondimensional displacement stiffness for a parameter [15]

QZS technology provides extremely low stiffness (quasi-zero stiffness) near the equilibrium position, while offering higher stiffness when far from the equilibrium position. That solves the problem of low frequency vibration. Moreover, by utilizing magnetic levitation technology, six-degree-of-freedom (6-DOF) Quasi-Zero Stiffness (QZS) vibration isolation can be achieved, which solves the design trade-off between load-carrying capacity and vibration isolation performance in traditional passive vibration isolation devices [16]. For example, The Quasi-Zero Stiffness (QZS) vibration isolation technology, with its unique characteristic of "high static stiffness and low dynamic stiffness", holds significant application value in high-precision equipment such as advanced lithography machines [17]. For example, a quasi-zero stiffness (QZS) vibration isolation platform equipped in a certain advanced lithography machine utilizes a combined structure of inclined springs and linear springs to reduce the platform's natural frequency to below 0.5 Hz, and achieves the quasi-zero stiffness characteristic within a displacement range of ±10 μm. Experimental data shows that compared with traditional vibration isolation platforms, this QZS vibration isolation

DOI: 10.54254/2755-2721/2026.KA36122

platform reduces the vibration amplitude of key components of the lithography machine by more than 80%, which significantly improves the lithography precision and ensures the yield rate of chip manufacturing [18]. However, it has also some disadvantages. In terms of the actuator response needs the signal processing speed quickly and precisely, the system needs a higher processing power unit, control method and strategy; and the system becomes complicated [19]. Also, because of complexity of control algorithm may bring some delay for signals processing and generation, which also will affect performance for active vibration isolation to certain extent [20]. Further, although these devices work based on electromagnetic action, they may need a little electricity. Then there exists energy consumption for some time, but generally this energy isn't needed, the system speed may not be fast enough to overcome the vibrations within a specific area frequency such as the vibrations over 400Hz [21]. Besides isolation technology is used into architecture field, active control like passive systems, just only to produce a opposite forces,it can produce force in the opposite direction in vibrating motion which brings energy consuming and noises, meanwhile its benefit is to adaptation of different vibrations environments, precise control and real time control technology [22]. The problem is that the performance of active vibration-isolation systems is dependent on environments, such as electromagnetic interference and changes in temperature [23], especially when the system needs to deal with the huge building and the flexible environment. Active vibration isolation systems require a continuous energy supply, feature relatively complex structures, and incur high maintenance costs. Additionally, active control systems may have poor resistance to strong impacts [24]. For instance, the electric motor, if it is necessary to maintain a large counterforce (e.g., to cope with vibration excitation of more than 100 N), the coil current needs to be stabilized at 1-5 A, and the power of a single actuator can reach 50-200 W (calculated based on a voltage of 220 V). The active vibration isolation also increases the risk of losing the data, that requires the regularly back up the control program (to prevent program loss), update the controller firmware (to fix vulnerabilities), and check the connection stability of the communication bus (e.g., loose connectors of EtherCAT cables may cause data packet loss). Maintenance personnel need to be familiar with the principles of control algorithms, and the training cost is approximately 1,400-2,800 US dollars per person. Although the displacement amplitude of high-frequency vibrations may be small (e.g. at the micrometer level), their acceleration amplitude is extremely large (up to several hundred m/s^2), so that there is a high energy density and a large impact. If the system exhibits response later a little, even a delay of only a few milliseconds may cause vibration energy to transfer to the protected objects (such as precision sensors and microchips), leading to performance failure. Nevertheless, electronic components in active systems may generate electromagnetic interference (EMI), which affects the performance of nearby sensitive equipment. Electromagnetic compatibility (EMC) design is crucial for avoiding these issues.

5. Hybird system and AI integration

Machine learning algorithms can predict the remaining useful life (RUL) of components in vibration isolation systems, thereby enabling predictive maintenance and reducing unplanned downtime while the cost of running decreases [25]. In order to get the precise prediction, high quality data input is crucial. The data should include the environment, running loads and manufacturing variation, so that enough data can be usefid to train the AI model to identify the features of device failure. Therefore, unplanned downtime definitely less and other parts of components are fully used. What's more, AI needs to participate in the vibration isolation procedure. AI algorithms enable vibration isolation systems to automatically adjust parameters, adapting to different operating conditions and external disturbances [26]. There is no need to preset fixed parameters; instead, the system learns the

DOI: 10.54254/2755-2721/2026.KA36122

"optimal vibration isolation strategies under different disturbances" through real-time data. For instance, it recognizes that the system stiffness needs to be reduced when encountering "low-frequency impacts" and that damping needs to be increased when facing "high-frequency vibrations, gradually establishing a matching model between disturbances and parameters. To be specific, in the initial stage, the system will try different parameter combinations to respond to disturbances. For example, when encountering low-frequency impacts, it will first try reducing the stiffness by 10%. If the vibration transmissibility decreases, it will receive a positive reward; if it increases, it will receive a negative reward. As data accumulates, the algorithm will gradually strengthen the "high-reward actions" (such as confirming that reducing stiffness by 20% is optimal for low-frequency impacts) and weaken the "low-reward actions". Eventually, a stable "disturbance type → optimal parameter" mapping model will be formed, without the need for manual presetting of parameter thresholds.

6. Conclusion

Whether the passive or the active vibration isolation, each solution has the positive points that one method can never over the others. Passive systems stand out for their instant response, high reliability, and zero energy consumption—relying on springs, dampers, or quasi-zero stiffness (QZS) structures, they work stably in harsh conditions and require minimal maintenance, making them ideal for low-cost, long-term use. For instance, the instantaneity and reliability of passive method. However, the active way also works efficiently in wide range of frequency. Now, how to combine these two types of vibration isolation way is what people should take our mind.sss Now the active can be based on data from passive vibration isolation, outputting a mixed, well-adapted data to control the system. More importantly, they can be divided into cooperation with one side supporting the other. Challenges are yet to be resolved on avoiding the interference between the passive parts and the active system, decreasing the initial price of the hybrid systems. The next step forward will focus on real-time coordination (model predictive) and further development of the low cost modular designs of such isolation systems. All in all, people must take more efforts and trying in the combination of these vibration isolation systems and then weight and balance the pros and cons for all of them.

References

[1] Wang, L., Burger, R., & Aloe, A. (2017). Considerations of vibration fatigue for automotive components. *SAE International Journal of Commercial Vehicles, 10*(1), 150–158. https://doi.org/10.4271/2017-01-0380

[2] Wu, J. D., & Chen, R. J. (2004). Application of an active controller for reducing small-amplitude vertical vibration in a vehicle seat. *J. Sound Vib., 274*, 939–951. https://doi.org/10.1016/S0022-460X(03)00655-2

[3] Yang, T., Zhou, S., Fang, S., Qin, W., & Inman, D. J. (2021). Nonlinear vibration energy harvesting and vibration suppression technologies: Designs, analysis, and applications. *Applied Physics Reviews, 8*(3). https://doi.org/10.1063/5.0051432

[4] Yong, W., Kai, L., & Shaoqing, C. (2011). Evaluation and experimental research on the vibration-isolation effect of dual layer hybrid vibration-isolation system. In *Process Automation Instrumentation*.

[5] Chunliang, Z., Wen, Z., Deqing, M., & Zichen, C. (2010). Research on vibration transmissibility of vibration isolation system with complex vibration environment. In *Zhongguo Jixie Gongcheng/China Mechanical Engineering*.

[6] Tan, L. B., & Ang, L. Y. L. (2024). Performance evaluation of balcony designs for mitigating ground level noise. *Acoustics, 6*(1), 272–297. https://doi.org/10.3390/acoustics6010015

[7] Lee, D.-O., & Han, J.-H. (2012). A comparison of vibration isolation characteristics of various forms of passive vibration isolator. *Transactions of the Korean Society for Noise and Vibration Engineering, 22*(9), 817–824. https://doi.org/10.5050/ksnve.2012.22.9.817

[8] Chao, Z., Hong, H., Kaiming, B., & Xueyuan, Y. (2020). Dynamic amplification factors for a system with multiple-degrees-of-freedom. *Earthquake Engineering and Engineering Vibration, 19*(2), 363–375. https://doi.org/10.1007/s11803-020-0567-9

[9] Jurevicius, M., Vekteris, V., Turla, V., Kilikevicius, A., & Viselga, G. (2019). Investigation of the dynamic efficiency of complex passive low-frequency vibration isolation systems. *Journal of Low Frequency Noise, Vibration and Active Control, 38*(2), 608–614. https://doi.org/10.1177/1461348418822230

[10] Liu, C., Zhang, W., Yu, K., Liu, T., & Zheng, Y. (2024). Quasi-zero-stiffness vibration isolation: Designs, improvements and applications. *Engineering Structures, 301*, 117282. https://doi.org/10.1016/j.engstruct.2023.117282

[11] Song, H., Shan, X., Hou, W., Wang, C., Sun, K., & Xie, T. (2023). A novel piezoelectric-based active-passive vibration isolator for low-frequency vibration system and experimental analysis of vibration isolation performance. *Energy, 278*, 127870. https://doi.org/10.1016/j.energy.2023.127870

[12] Luo, D., Hu, T., Chang, Y., & Wang, K. (2021). Second order linear active disturbance rejection control for active ultra-low frequency vibration isolation. *2021 36th Youth Academic Annual Conference of Chinese Association of Automation (YAC)*, 852–856. https://doi.org/10.1109/yac53711.2021.9486609

[13] Jiang, Y., Song, C., Ding, C., & Xu, B. (2020). Design of magnetic-air hybrid quasi-zero stiffness vibration isolation system. *Journal of Sound and Vibration, 477*, 115346. https://doi.org/10.1016/j.jsv.2020.115346

[14] Ma, Z., Zhou, R., & Yang, Q. (2022). Recent advances in quasi-zero stiffness vibration isolation systems: An overview and future possibilities. *Machines, 10*(9), 813. https://doi.org/10.3390/machines10090813

[15] Meng, Q., Yang, X., Li, W., Lu, E., & Sheng, L. (2017). Research and analysis of quasi-zero-stiffness isolator with geometric nonlinear damping. *Shock and Vibration, 2017*, 1–9. https://doi.org/10.1155/2017/6719054

[16] Zhu, T., Cazzolato, B., Robertson, W. S. P., & Zander, A. (2015). Vibration isolation using six degree-of-freedom quasi-zero stiffness magnetic levitation. *Journal of Sound and Vibration, 358*, 48–73. https://doi.org/10.1016/j.jsv.2015.07.013

[17] Li, H., Li, J., & Li, Y. (2019). Comparative analysis of vibration isolator with quasi-zero stiffness. In *The 2019 World Congress on Advances in Structural Engineering and Mechanics…*, 2019.

[18] Li, J., Liu, Q., Wang, L., Wang, S., & Wang, J. (2020). Considering operating point variation in 3-D analytical charge model used for design of low-stiffness permanent magnet vibration isolator. *IEEE Transactions on Industrial Electronics, 67*(8), 6732–6741. https://doi.org/10.1109/tie.2019.2934056

[19] Abakumov, A. M., & Miatov, G. N. (2006). Control algorithms for active vibration isolation systems subject to random disturbances. *Journal of Sound and Vibration, 289*(4–5), 889–907. https://doi.org/10.1016/j.jsv.2005.02.038

[20] Zhou, S., Li, Y., Meng, G., & Ding, H. (n.d.). Adaptive switching control method for active vibration isolation. *9th IEEE International Workshop on Advanced Motion Control, 2006.* 462–467. https://doi.org/10.1109/amc.2006.1631703

[21] Rasid, S. M., Mizuno, T., Takasaki, M., Ishino, Y., Hara, M., & Yamaguchi, D. (2016). Active vibration isolation system with an active dynamic vibration absorber. *The Proceedings of the Dynamics & Design Conference, 2016*(0), 422. https://doi.org/10.1299/jsmedmc.2016.422

[22] Shi, X., Zhao, F., Yan, Z., Zhu, S., & Li, J. (2021). High-performance vibration isolation technique using passive negative stiffness and semiactive damping. *Computer-Aided Civil and Infrastructure Engineering, 36*(8), 1034–1055. https://doi.org/10.1111/mice.12681

[23] Zhu, Z., Xiao, Y., Zhou, M., Li, Y., & Yu, D. (2024). Active composite control of disturbance compensation for vibration isolation system with uncertainty. *Actuators, 13*(9), 334. https://doi.org/10.3390/act13090334

[24] Zhang, Q., Zhu, L., Dong, Q., Sui, J., Sun, M., Wang, J., & Yu, X. (2023). Experimental study on the active control and dynamic characteristics of electromagnetic active–passive hybrid vibration isolation system. *Applied Sciences, 13*(19), 10565. https://doi.org/10.3390/app131910565

[25] Machine learning algorithms can predict the remaining useful life (RUL) of components in vibration isolation systems, thereby enabling predictive maintenance and reducing unplanned downtime.

[26] Li, F., Yuan, S., Qian, F., Wu, Z., Pu, H., Wang, M., Ding, J., & Sun, Y. (2021). Adaptive deterministic vibration control of a piezo-actuated active–passive isolation structure. *Applied Sciences, 11*(8), 3338. https://doi.org/10.3390/app11083338