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Differences between active vibration suppression and active vibration isolation

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ABSTRACT

Active vibration control is an essential technology in future for its better performance in vibration suppression and isolation within low frequency range. However, it may be less effective due to the limitations of the size of actuators, the operating rate of controllers and the boundary condition of controlled elastic structures, etc. In this paper, the differences between active vibration suppression and active vibration isolation on the control object are discussed, including the type of actuator and the available space for installing, which show the promising potential of active vibration control technology in low-frequency vibration reduction. Development challenges of active vibration suppression are analyzed. Besides, the key technologies and the difficulties are also discussed.

Keywords: active vibration control, active vibration isolation, active vibration suppression
I-INCE Classification of Subject Number: 46

1. INTRODUCTION

Active vibration control is known for its excellent flexibility, which ensures a good effect in low frequency vibration control. In general, an active vibration control system consists of actuator, controller and sensor. The choices of these devices are determined by the controlled object, permitted installation space, and operation environment. There are two main approaches, including active vibration suppression and active vibration isolation, to meet different vibration reduction requirements in various situations. The

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basic difference of these two approaches is obvious. Firstly, the mechanism of active vibration suppression [1] is different with isolation [2] in dealing with vibrational resonance. Secondly, active vibration isolation is more sensitive to space near the installation site, especially for those high-resolution metrology and precision instrument [3], whereas the active vibration suppression is more flexible in application.

To obtain better control performance of active vibration control, active control system, semi-active control system, active/passive integrated control system of vibration isolation [3-5] and suppression [6-8] are proposed. As Liu [4] described, the isolator with damping and stiffness on-off control is needed to obtain excellent vibration isolation under a broadband excitations. Meanwhile, it can be found that sometimes unexpected effects in the controlling process may appear during active vibration control investments. Sun [9] found that the stiffness and damping of the base should be increased to reduce the required output force of actuators. Chak [10] proposed that the control strategy is associated with spill over effects in the active vibration suppression. Jian [11] proposed that a multi-objective control strategy of active vibration suppression can be beneficial to ensure the balance between excellent controlling output and desired control effect. Marshall [12] considered that the combination of active vibration suppression system and vibration isolation system can be used to enhance the vibration attenuation effect. In order to obtain more vibration attenuation, the control strategy of vibration suppression and isolation can be modified by learning from each other. Thus a better active vibration control system may be obtained through an appropriate combination.

In this paper, the differences between active vibration suppression and isolation are studied in detail to provide a guideline for the design of active vibration system. Both control strategy and component are discussed separately. Besides, the key technologies and the difficulties of active vibration suppression and isolation are illustrated for further comparison. Finally, some suggestions about development of active vibration suppression and isolation are provided.

2. DIFFERENCES IN CONTROL STRATEGYS

Similar to classical vibration isolation system, active vibration isolation system can be effective only if the driving frequency is $\sqrt{2}$ times greater than the natural frequency of isolation system. Moreover, the higher ratio of driving frequency to the natural frequency usually results in better vibration reduction. Active vibration isolation system is designed by adjusting its equivalent isolation stiffness to change its resonance frequency f_0 in real time. Since active vibration isolation system is good at reducing the low frequency vibration, the resonance frequency f_0 is expected to be extremely low. Thus a good vibration isolation effect in low frequency domain is achieved.

The vibration isolation effect can be described by the transfer coefficient between the equipment disturbance and the structural vibration response. The transfer coefficient varies with the ratio of equipment frequency to the natural frequency, as shown in Figure 1. Traditionally, the isolator can be effective when the frequency ratio is greater than $\sqrt{2}$. In this frequency range, it can be seen in Figure 1 that lower transfer coefficient is achieved by the undamped isolator, compared with the other two cases. So an undamped or slight damping isolator is demanded for more effective vibration isolation in practical application. The vibration isolation effect can be reduced with the increasing of damping for isolators. As shown in Figure 2, the structural vibration response is amplified with the increasing of isolator's damping under the same driving frequency of equipment. So the vibration isolation effect is perfect when the frequency ratio is greater than $\sqrt{2}$ and the isolator's damping is close to zero. As the frequency ratio is not a constant, the vibration isolation effect can be changed with driving frequency.

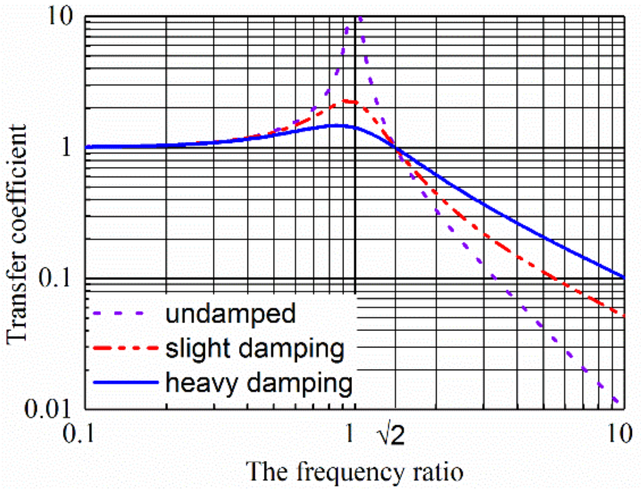

Figure 1: Transfer coefficient of classical isolation system

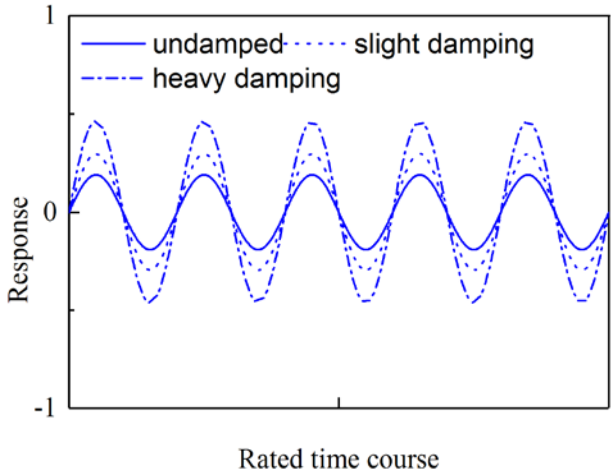

Figure 2: Controlled structure response changed with damping

The normal start and shutdown of rotating equipment are inevitable in practical engineering, which cause continuous change of the transfer ratio as shown in Figure 3. When the rotating equipment is started, the driving frequency can be changed from zero to rated value. In this process, the resonance of structure with mounting base occurs, which is adverse to the performance of structure. At this point, the transfer ratio of isolator reaches a maximum. And reverse process will occur when the equipment is shutdown, in which the driving frequency is changed from rated value to zero. In order to keep the structure stable, it is necessary to take measures to deal with the resonance during start up and shutdown process.

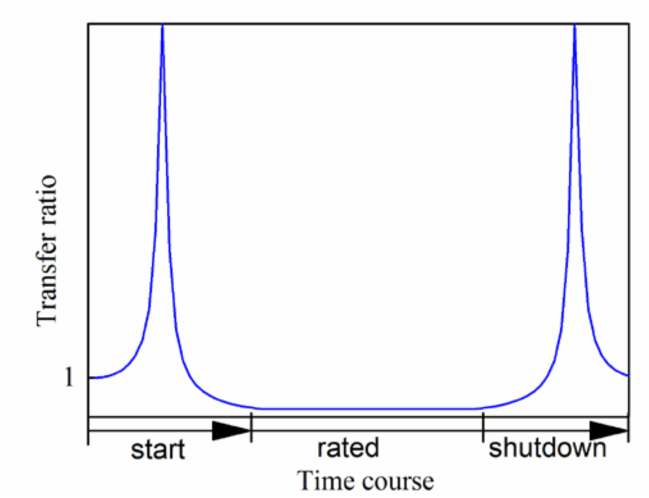

Figure 3: The transfer ratio changed with the equipment state

As shown in Figure 2, the damping is beneficial to attenuate the vibration transfer ratio at a natural frequency. So a variable damping control strategy can be added to the active vibration isolation system to achieve more vibration attenuation during the start process and shutdown process. However, the adopted strategy stated above is barely proposed in the published researches. The variable damping control strategy is asynchronous with active vibration isolation. In general, the active vibration isolation with constant slight damping is applied within rated working time course. Unlike the isolator mentioned above, the variable damping control strategy is to change the damping according to the state of rotating equipment. Via the variable damping control strategy, the damping of isolator is enlarged when the state of equipment is at start-up, shutdown, or suddenly shock state. When the state of equipment is rated, the damping is reduced. Thus the active vibration isolation system with the variable damping control strategy can be more effective to achieve great vibration attenuation under any state of the rotating equipment. As described above, the isolation effect with and without damping control is analyzed and shown in Figure 4. It can be seen that the isolator with damping control has lower vibration transformation than that without damping control in the whole time course of equipment.

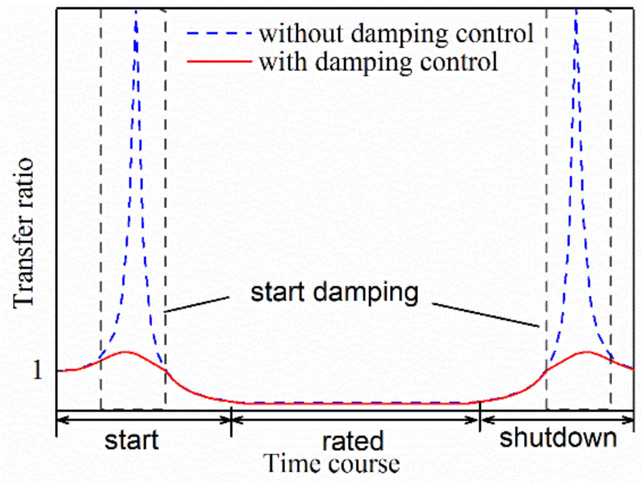

Figure 4: Transfer ratio of isolator affected by damping control

Active vibration suppression pays more attention to low frequency range with a certain bandwidth, which is different from active vibration isolation. In general, the active vibration suppression effect can only be obtained within controlled frequency range. And it is hard to offset the vibration response of structure. An ideal vibration suppression is shown in Figure 5, in which the secondary force is applied to the structure at the opposite site of the primary force. In the ideal model described above, the structural vibration response excited by the primary force is completely suppressed. Nevertheless, it is ideal and almost impossible to be accomplished in practical engineering, because the actual location and exciting type of primary force can hardly be obtained.

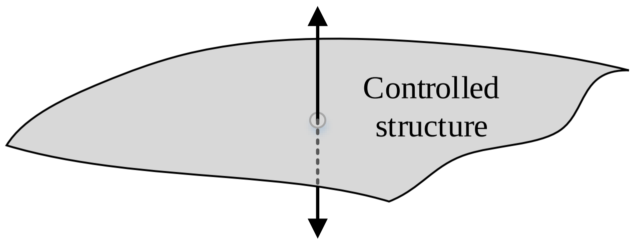

Figure 5: Ideal active vibration suppression strategy

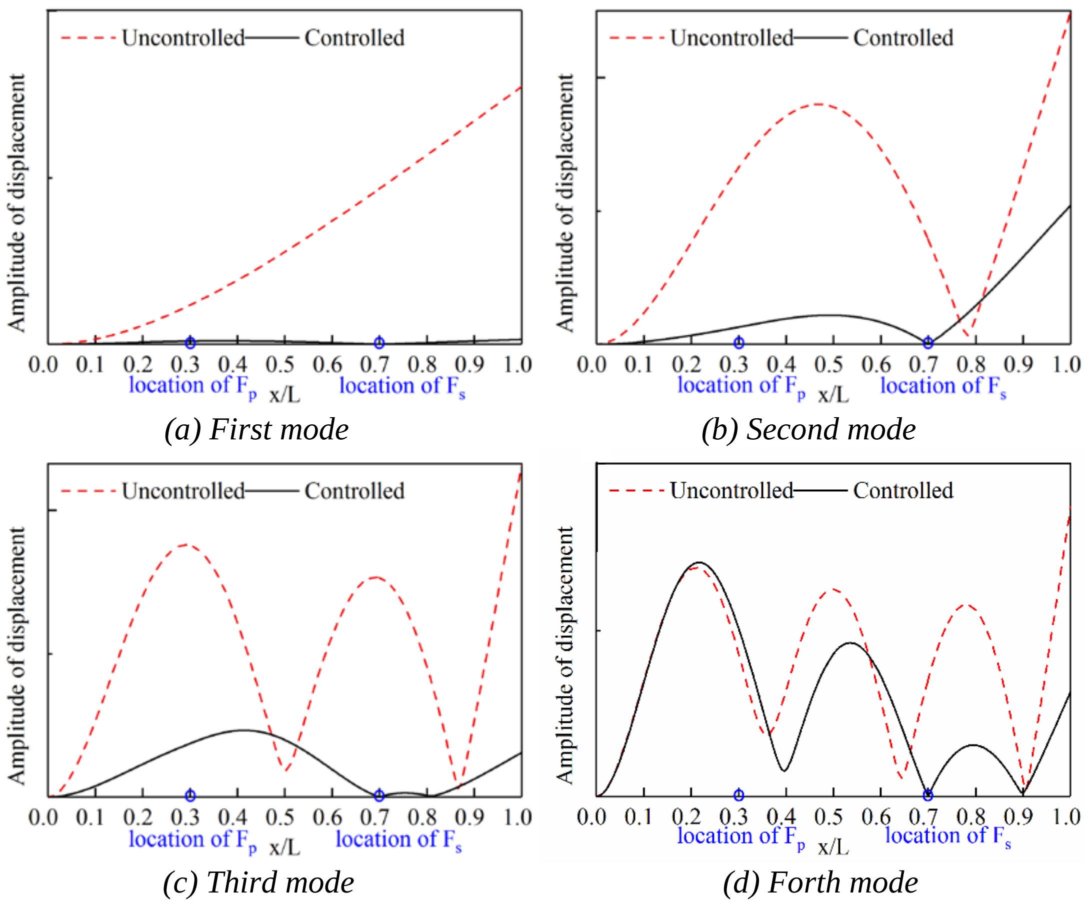

Figure 6: Vibration response comparation of cantilever beam

In order to attenuate the vibration response excited by an unknown primary force, strategies should not be restricted to the location of primary source. Thus, modal control strategy and wave control strategy are widely used in active vibration suppression [13]. Particularly, the modal control making use of the inverse vibration mode shape is the most promising approach to achieve vibration attenuation covering the entire structure. However, modal control cannot be always effective for the entire structure. A particular analysis about active vibration suppression for a cantilever beam is implemented to show those consequences. As shown in Figure 6, vibration responses at some locations are increased with modal controlled.

It is assumed that the length of cantilever beam is L, a primary excitation F_p and a secondary force F_s are applied at $0.3L$ and $0.7L$ away from the fixed end of the beam, respectively. Here F_s is used to offset the vibration response of beam caused by F_p. Vibration responses of cantilever beam for the first four modes are displayed in Figure 6, which show the comparison of uncontrolled and controlled vibration response for the beam. It can be found that the controlled vibration response at some positions of the beam is enlarged. So it is clear that modal control cannot always be used to eliminate the vibration response of the entire structure. Moreover, when the controlled mode is getting more complex, the vibration response of structure is harder to be attenuated. As described in Reference [14], modal control effect is obtained by increasing modal damping. And it can be improved by changing the position of actuator.

3. DIFFERENCES IN COMPONENTS

In this section, components for active vibration suppression and isolation are analyzed, both similarities and differences are demonstrated in detail. The permitted installation space of active vibration isolation is stricter than that of active vibration suppression. A big installation space is needed to ensure enough deformation space of the isolator. In general, active vibration isolator and passive vibration isolator are used together to save the installation space and achieve better vibration attenuation effect, which is shown in Figure 7. In this way, enough support stiffness and controllable frequency band can be obtained. It is clear that no additional space is introduced when the actuator of active vibration isolator is integrated with passive vibration isolation system. In addition, it is useful to protect the actuator and meet the sealing requirements by embedding actuators into passive vibration isolator. Thus the actuator with the proper stiffness and sufficient output force is suitable for active vibration isolation, which is similar with the conclusion in Reference [15].

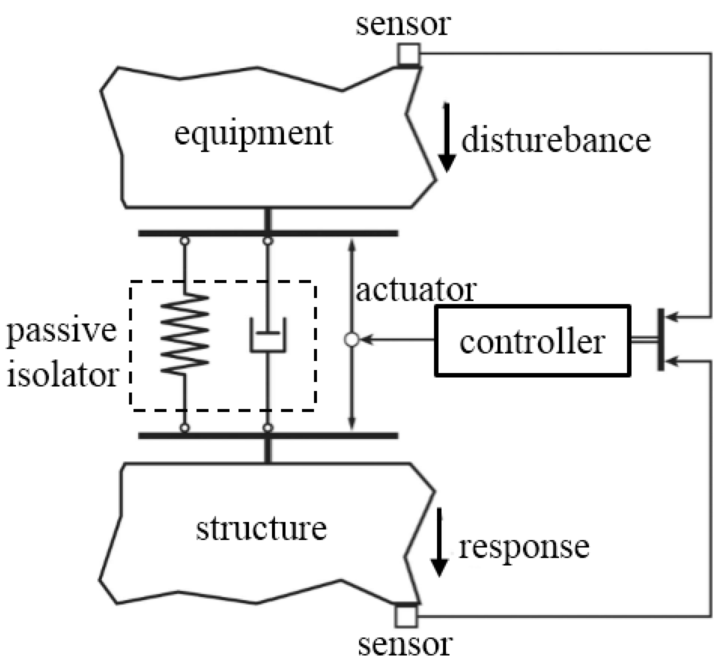

Figure 7: active isolation control [16]

Compared with the limiting conditions of actuator in active vibration isolator, the characteristic requirement in active vibration suppression is stricter, since the availability of actuator is limited by the controlled subject structure. Considering the additional mass of the actuator, large size actuators are not acceptable for active vibration suppression. Besides, actuator for active vibration suppression must be soft and flexible to adapt to the complex surface of structure, as shown in Figure 8. So it is necessary to find a softer, thinner and more suitable force-output actuator to achieve active vibration suppression. So far, available actuators, which can meet the above requirements, are mainly SMA(shape memory alloy), dielectric elastomer VHB, MFC(macro fiber composite), PVDF(polyvinylidne flouride), PZT-5H(pizeoelectric lead zirconate titanate) and magneto-strictive. Their stiffness properties are shown in Table 1. Besides, some measures should be taken to protect the actuator away from water, corrosion, high pressure, etc. As a result, it is clear that the property of actuator in active vibration suppression is quite different from that in active vibration isolation.

In addition to the differences of the actuator, there are also differences between active vibration isolation and suppression in the selection of sensors. The driving frequency is the first consideration when selecting sensors, which should cover the concerned frequency range. The sensor in active vibration isolation should have an excellent low frequency performance as the valid isolating frequency band of active isolator is extremely low. Nevertheless, active vibration suppression focuses on the whole broadband performance of sensors. Furthermore, the permitted installation space of sensor in active vibration isolation is more sufficient, but is limited in active vibration suppression. As a result, most sensors can be appropriate for vibration isolation while only small-sized sensors can be used for active vibration suppression.

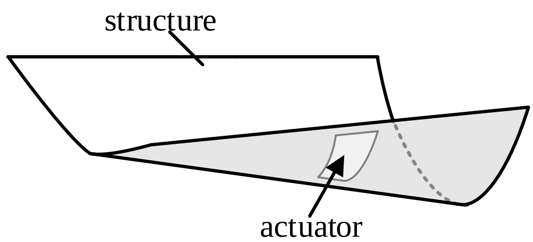

Figure 8: sketch of actuator attached to complex structure for vibration suppression

Table 1: PROPERTY OF SOME ACTUATING MATERIALS

Type	SMA	VHB	MFC [17]		PVDF	PZT-5H	Magneto-strictive
Young's modulus (MPa)	13×10^3	90	E_1: 30×10^3	E_2: 15×10^3	2×10^3	56	25-65

4. DEVELOPMENT OF ACTIVE VIBRATION CONTROL TECHNOLOGY

With the advancement of research, active vibration control technology is maturing. More and more smart materials are available for actuators and sensors, which could bring greater development opportunities to active vibration control. To promote the application of active vibration control, some suggestions are given as follows:

1) Integrated and attachable actuator is urgent and desirable. The integrated actuator can easily adapt to the harsh application environment. In the future, active vibration control will be more attractive through integrating actuators, sensors and controllers.

Thus, the active vibration control technology will be as convenient as passive control technology, such as damping and vibration absorption.

2) The improvement of control strategy is essential. Modal control is not always effective for entire structure, especially for large and complex structures. An active stiffness control method can be used for vibration suppression tentatively. And, of course, structural designers can't be absent from this process of improvement.

Meanwhile, further improvements of active vibration isolation can be implemented. As mentioned above, the variable damping control can be introduced to active vibration isolation technology to obtain a better isolation effect.

5. CONCLUSIONS

When the need of vibration attenuation in low frequency band is becoming increasingly urgent, active control, including vibration suppression and isolation, has received much attention. In this paper, the differences between active vibration suppression and isolation are analyzed on control strategies and components. It is found that the damping and control strategy are key factors for achieving better active vibration isolation or suppression effect. Besides, the requirements of actuator in active vibration suppression are more rigorous than isolation. A variable damping control strategy in active vibration isolation is proposed for the better vibration attenuation effect. In the future, the integrated actuator will be a trend to make active vibration control more convenient. It is convinced that with the progress of both active vibration suppression and isolation, the vibration attenuation will be more encouraging.

6. REFERENCES

[1]. A. Zippo, G. Ferrari, M. Amabili et al., "*Active vibration control of a composite sandwich plate*", Composite Structures, 128. 5 (2015): 100-114.

[2]. S.-Q. Chen, Y. Wang, C.-C. Wei et al., "*An active vibration isolation control method under excitation of multi-line spectra*", Zhendong yu Chongji/Journal of Vibration and Shock, 31. 23 (2012): 128-131+190.

[3]. H. L. Jin, H. Y. Kim, K. H. Kim et al., "*Control of a hybrid active-passive vibration isolation system*", Journal of Mechanical Science & Technology, 31. 12 (2017): 5711-5719.

[4]. Y. Liu, H. Matsuhisa, and H. Utsuno, "*Semi-active vibration isolation system with variable stiffness and damping control*", Journal of Sound & Vibration, 313. 1 (2008): 16-28.

[5]. P. A. Nelson, "*Active vibration isolation*", Vibration Control of Active Structures, 125. 3 (2013): 539–553.

[6]. W. Sun, J. Li, Z. Ye et al., "*Vibration control for active seat suspension systems via dynamic output feedback with limited frequency characteristic*", Mechatronics, 21. 1 (2011): 250-260.

[7]. A. Dominguez, R. Sedaghati, and I. Stiharu, "*SemiActive Vibration Control of Adaptive Structures Using Magnetorheological Dampers*", Aiaa Journal, 44. 7 (2005): 1563-1571.

[8]. Z. Yao, Z. Yue, L. Mou et al., "*Active-passive integrated vibration control for control moment gyros and its application to satellites*", Journal of Sound & Vibration, 394 (2017): 1-14,.

[9]. H. Sun, "*Simplified performance indices and active control force of vibration isolation systems with elastic base*", Shengxue Xuebao/Acta Acustica, 41. 2 (2016): 227-235.

[10]. C. Chantalakhana, "*Stability improvement of modal controllers for suppressing beam vibrations using a hybrid control scheme*", IEEE International Conference on Industrial Technology, (2002).
[11]. X. Jian, Z. Tong-Yi, H. Wei et al., "*Active vibration control with multi-objective control output for typical engineering equipment*", Engineering Transactions, 65. 3 (2017): 405-422.
[12]. P. Marshall, "*Active vibration isolation system*", Review of Scientific Instruments, 69. 6 (1993): 2531-2538.
[13]. K. Nagase, Y. Hayakawa, "*Trends in Active Vibration Control of Flexible Structures: Modal Control and Wave Control for a Damped Mass-Spring System*", Institute of Systems, Control and Information Engineers, 44.5 (2000): 253-258.
[14]. F. Braghin, S. Cinquemani, and F. Resta, "*A new approach to the synthesis of modal control laws in active structural vibration control*", Journal of Vibration & Control, 19. 2 (2012): 163-182.
[15]. L. Sun, W. Sun, K. Song et al., "Effectiveness of a passive-active vibration isolation system with actuator constraints", Chinese Journal of Mechanical Engineering (English Edition), 27. 3 (2014): 567-574.
[16]. W. Kaal, T. Bartel, and S. Herold, "*Active vibration isolation with a dielectric elastomer stack actuator*", Smart Materials & Structures, 26. 5 (2017).
[17]. Smart-Material. "*https://www.smart-material.com/MFC-product-properties.html*", (2019).