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Design Optimization of an Electric Positioning Mechanism

Jiguang Liu[1,2], Zhikuan Yang[1,*], Peipei Liang[1], Xiaogang Fang[1], Tongfei Li[2], Xiaowen Zhao[2], Youwen Yang[1]

[1]*School of Materials Science and Engineering, Hefei University of Technology, Hefei, 230009, Anhui, China*

[2]*Anhui Province Digital Precision Casting Manufacturing Innovation Center, Hefei, 230009, Anhui, China*

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Abstract: The positioning mechanism of conventional transfer vehicles commonly employs a hydraulic or pneumatic driving mode, which requires control valves, actuators and pipe fittings, causing problems such as complex composition, high cost and inconvenient hauling of pipes and accessories when installed on transfer vehicles. In order to avoid the above difficulties, an electrical localization mechanism using electromagnets as power units has been designed. First, it explains its working principles and composition. Moreover, the implementation scheme and the structure of the electromagnetic thrust are then detailed, including the frame, the telescopic components and the power equipment. Next, based on the force analysis of the locator, we introduce the calculation of the electromagnetic thrust to the locator and design a reasonable angle between the locator and the pin. Finally, by switching the electromagnet on and off, the mechanism drives the positioning plate to reciprocate, thus enabling multi-position accurate positioning and rapid un-positioning of the transfer vehicle, contributing to the compact, low-cost and environmentally friendly maintenance of the mechanism.

1. Introduction

In engineering practice, a large amount of material flow needs to be realized by horizontal movement of the transfer vehicle, and accurate docking between the transfer vehicle and the upper and lower stations is required, which requires the transfer vehicle to be able to accurately locate multiple points and bear certain lateral loads [1]. The positioning mechanism of the transporter needs to be established when it uses an electric-driven roller and a guide-rail rolling transmission mode. The traditional positioning mechanism typically adopts hydraulic or pneumatic drive mode, which requires a control valve, drive cylinder (hydraulic cylinder or cylinder), pipeline and accessories, hose drag chain and additional supporting devices [2]. However, there are some problems, such as complex composition, inconvenient drag of pipeline and accessories and high cost [3-6].

The main function of the machine tool positioning mechanism in the industrial field is to place the workpiece quickly and accurately on the equipment, through the bearing of the body and the clamping parts, so that the workpiece is precisely fixed in the predetermined position [7]. The positioning mechanism commonly used at home and abroad are inclined wedge positioning mechanism, screw positioning mechanism, eccentric positioning mechanism, centering and positioning mechanism, hinge positioning mechanism and so on [8-10]. Among them, the oblique wedge localization mechanism is the most basic form of localization mechanism and needs to be combined with other methods in practical production. The screw positioning mechanism has low efficiency and slow action, so it is not suitable for fast positioning. Eccentric localization mechanism forces are relatively small and are only suitable for situations where force is not sufficient; centering and positioning mechanism commonly requires the workpiece to be symmetrical, is mainly used for high requirements of neutralization occasions [11].

Because on the surface of the workpiece contour is different, the basic methods and different kinds of positioning a modeling also is varied, according to its basic model can be divided into the following categories: (a) column pin: the positioning of the workpiece is not smooth, the rules of each edge is not right, need dowel pin as reference edge, on the side can use dowel pin locating piece, but this way of positioning adjustment is bad; (b) plug pile positioning: if there is an accurate hole on the workpiece, the hole can be used as the positioning datum. On the body of the fixture, a plug-pile of suitable diameter is fitted as a positioning piece, and the holes of the workpiece are slid precisely so that the positioning piece is inserted into the holes to control the position of the workpiece; (c) conical positioning: if the section of the workpiece is a regular arc surface, and the precise relationship between the positioning and the center of the arc is needed, the conical modeling positioning piece can be used. This positioning slice can also be simultaneously centered. Thus, in this paper, the conical localization plate and the localization pin touch through the conical surface, which results in a transverse force and then the transport vehicle achieves accurate localization. The surface stress of the locating piece and the locating pin is slight and the wear degree is low [12].

The positioning function needs to be driven by a power source. Hydraulic and pneumatic are commonly used, but have some problems. Pipes for power equipment are more numerous and larger in size, hydraulic drives need to be equipped with hydraulic stations, complex structures, and late maintenance requirements are high. In addition, the disadvantage of low accuracy of traditional hydraulic system has gradually emerged [13-16]. The mechanical limit is required to achieve accurate localization. The electromagnet uses the magnetic leakage principle of the spiral tube [17], and uses the electromagnet moving slide bar and the static iron core to pull together long distance to realize the linear reciprocating movement of the traction bar, which has the advantages of simple structure, simple circuit, rapid action and large force increase [18]. In this paper, the electromagnet is used as the power source and fast and accurate localization of the transfer vehicle can be achieved only by controlling the on and off of the electromagnet.

2. Principles and compositions

The electric positioning mechanism is installed on the transfer vehicle. By controlling the power device of the mechanism push and pull electromagnet on and off, the transfer vehicle is precisely positioned in the desired position. Figure 1 shows the positioning mechanism structure of the transfer vehicle.

The push and pull electromagnet is fastened on the frame with screws, and the telescopic component is installed inside the frame. The upper plane of the frame is connected with plate 1, which is fastened by bolts through the waist hole. The plate 1 is welded at the set position of the transfer vehicle. The locating pin assembly is fixed on the washer plate 2 below by screws. The washer plate 2 is fixed on the embedded foundation plate below by welding after the alignment of the telescopic component and locating pin assembly of the transfer vehicle is properly adjusted.

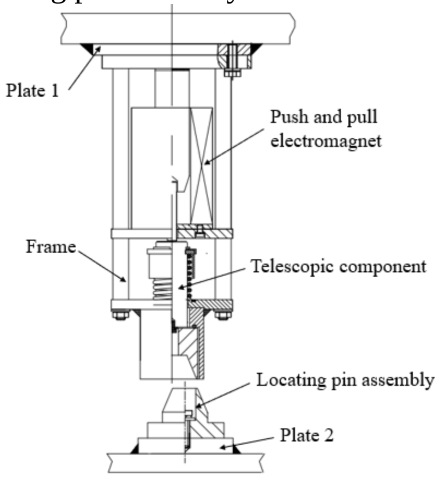


Figure 1: Positioning mechanism structure of the transfer vehicle.

When the push-pull electromagnet is energized, the telescopic component is pushed down under the action of electromagnetic thrust. The lower end of the telescopic component covers the locating pin assembly on the floor to complete the precise positioning and stopping of the transfer vehicle. When the push-pull electromagnet is powered off, the elastic force of the compression spring carried by the expansion component itself makes the expansion component rise, disengage from the locating pin assembly, remove the positioning, and the transfer vehicle can move horizontally.

3. Scheme and structure

3.1 Telescopic Components

The telescopic components include locating pieces, lifting columns, limiting parts and compression springs. The compression springs are set on the outer cylinder surface of the lifting column, between the upper limit parts and the plane of the frame flange. The lower end of the lifting column is fastened with countersunk screws and the locating piece, as shown in Figure 2.

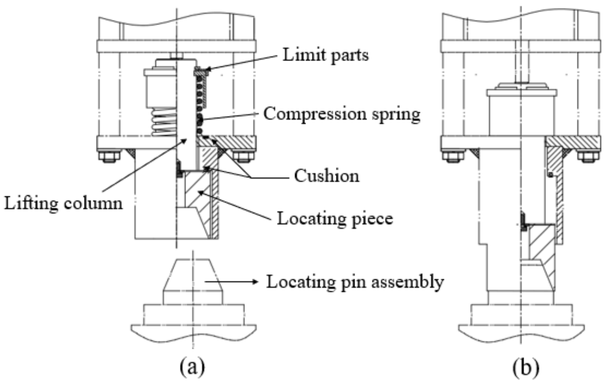
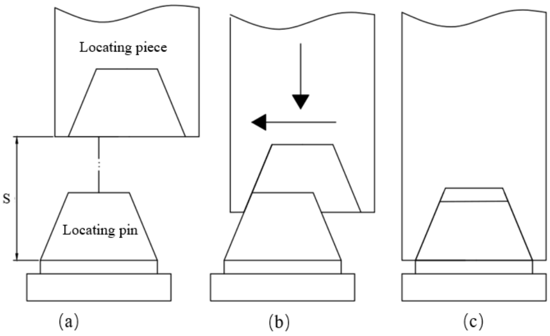


Figure 2: Telescopic components diagram.

(a) Upper view of telescopic component. (b) Positioning view of telescopic component.

The locating piece is used for unilateral contact with the conical surface of the locating pin to generate a lateral force to promote the positioning and stopping of the transfer vehicle. The locating piece is designed as a conical locating piece structure. The conical cavity of the locating piece has an oblique angle, which has high guiding accuracy and positioning accuracy. It can be automatically compensated after wear, and its symmetry is good, and it is convenient to manufacture.

Taking the positioning mechanism installed on the transfer vehicle as an example, Figure 3 is the operation status diagram of the locating piece. When the transfer vehicle stops near the designated place, the locating pin is within the range accessible after the locating piece drops, and is in the positioning relieved state. When the electromagnet is energized, the locating piece drops to the positioning contact state; as the locating piece continues to fall, its left inner cone surface contacts the left side of the outer cone surface of the locating pin, producing a transverse force that drives the transfer vehicle to move horizontally and horizontally to the left until the locating piece is stuck to the locating pin on the ground to achieve accurate positioning of the transfer vehicle. In addition, there is a gap between the bottom of the locating piece and the top of the locating pin, which can play a vertical wear compensation role.



(a) Release state. (b) Contact state. (c) Positioning state.

Figure 3: Operating state diagram of locating piece.

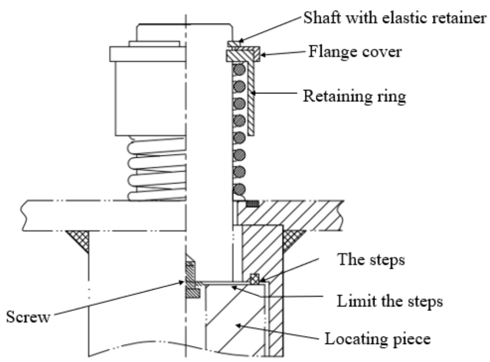


Figure 4: Limit map of scaling components.

The lower end of the lifting column is precisely installed in the sink at the top of the locating piece with screws to ensure the council after assembly; in order to prevent the lifting column from rushing out of the cylinder in the process of falling and impacting the mounting plate in the process of rising, limit measures are set on the upper and lower ends of the lifting column, as shown in the limit diagram of the telescopic component in Figure. 4. The rising limit of the telescopic component by increasing the diameter of the lower end of the lifting column, the rising limit of the telescopic component is realized by the steps limit on the frame, so as to prevent the lifting column from rising and hitting the end face of the electromagnet, causing damage, which plays the role of the end limit of the rising movement. The drop limit of the telescopic component is composed of an elastic retaining ring, a flange cover and a retaining ring. The retaining ring is stuck in the groove at the upper end of the lifting column, and the flange cover is buckled in the outer ring of the retaining ring, and the upper plane installation shaft is fixed with an elastic retaining ring. After the push and pull electromagnet is powered off, in order to prevent the lifting column and the locating piece from rising and recovering to the retracted state due to the action of gravity, a pressure spring is installed on the upper end of the lifting column, and the lower part of the pressure spring is fixed on the plane of the frame flange to prevent its free fall.

3.2 Power Device

The push and pull electromagnet is mainly composed of coil, moving slide bar, static iron core and power controller accessories, as shown in Figure. 5. It uses the principle of magnetic leakage of spiral tube, and makes use of electromagnet moving slide bar and static iron core to pull the long distance, so as to realize the linear reciprocating movement of the traction bar. The push and pull electromagnet is based on the principle of electromagnetic power to control the overall action and power size. The role of the electromagnet is to generate magnetism through the current, using different magnetic coils and power supply to control the size of the magnetism, forming a push and pull action, so that it runs in a whole, just like the piston movement.

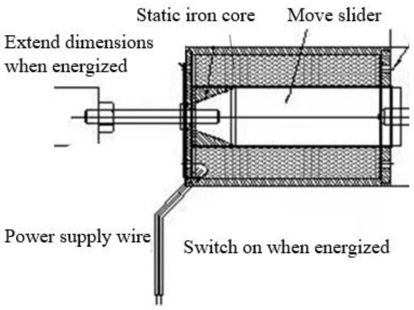
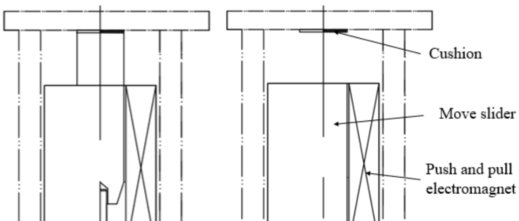


Figure 5: The push and pull electromagnet diagram.



(a) Push-pull electromagnet power off. (b) Push-pull electromagnet power on.

Figure 6: Power device diagram.

The power device of the positioning mechanism provides axial force by the push and pull electromagnet, driving the lifting column and locating piece movement; when the electromagnet is energized, the sliding rod can reach the stroke directly under the action of the electromagnetic force. The copper rod on the sliding rod moves the telescopic assembly. The copper rod with a smaller diameter is installed in the front of the sliding rod, which aims to prevent the sliding rod from rushing out of the electromagnet when energized. Fast return to position under spring force when power is off [19]. In addition, the push and pull electromagnet has a relatively small volume and is easy to install in some small space places. The push and pull electromagnet is installed on the rack, and the specific structure is shown in Figure 6.

3.3 Frame

The frame is used to assemble the power unit and telescopic assembly into a positioning assembly, which is then mounted on the transfer vehicle. Moreover, the frame comprises a cylinder, plate 1 and the base plate, which are used to connect the telescopic assembly, the power plant, and fix it with the transfer vehicle, as shown in Figure 7.

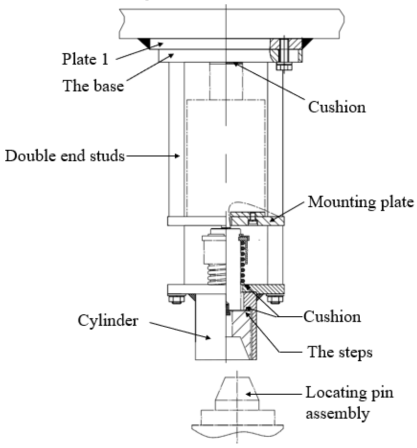


Figure 7: Frame structure diagram.

The cylinder, base, and plate 1 are fixedly connected with four double end studs; in the process of docking between the locating piece and the locating piece pin, a transverse force is generated. The cylinder can provide a certain lateral support force for the locating piece to improve the lateral bearing capacity of the locating piece and prevent the lifting column from twisting. In addition, the lower end of the cylinder body is provided with a stepped through hole, the middle is provided with a through hole flange. Its purpose is to lift the column that can move up and down freely within the range of travel. Polyurethane cushion material should be selected, which has light weight, good compression resistance, simple installation, good buffering effect, impact resistance, no noise, no spark in the buffering process, good explosion-proof, safe, reliable and stable [20-23]. There are three buffer pads on the frame of the mechanism: (a) at the steps inside the cylinder body, the purpose is to prevent the impact of the lifting column movement in place, which can prolong the service life of the lifting column and cylinder body; (b) The flange in the middle of the cylinder body is to prevent the impact of the retaining ring on the lifting column and the flange of the frame when the electricity is energized; (c) A cushion is installed on the base to prevent the impact of the sliding rod and the base when power is cut off.

4. Force analysis and calculation

Assume that the gravity of the transfer vehicle is G, the stroke is S, the height of the locating pin is h, and the total weight of the contraction component (including the locating piece, lifting column and moving slide rod, etc.) is G1. The angle design of the locating piece is related to the vertical thrust. Generally, the electromagnet with small vertical thrust is selected as far as possible under the condition that the requirements can be met. The force analysis of the locating piece when the locating piece is in contact with the locating pin is shown in Figure 8.

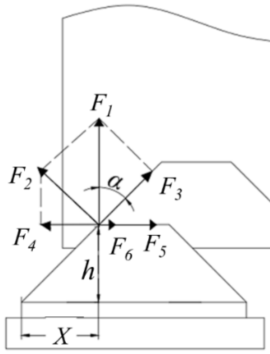


Figure 8: Stress analysis of locating piece.

Where, F1 is the reaction force of the vertical thrust, the resultant force of G1 and the spring elastic F7, F7 is slightly larger than G1, F3 is the friction force generated when the locating block contacts the conical surface of the locating pin, F2 is the normal force generated when the locating piece contacts the locating pin and is perpendicular to the contact surface, F4 is the horizontal component force generated by F2. This force is used for the rolling friction that the transfer vehicle needs to overcome when positioning and moving and the inertia force required for starting and accelerating. F5 is the rolling friction of the transfer vehicle, F6 is the force generated by the transfer vehicle from rest to start, which is very small and negligible, and f is the rolling friction coefficient of the transfer vehicle. The calculations are as follows:

$$\begin{cases} F_4 = F_5 + F_6 = G * f \\ F_4 = F_2 * \cos\alpha \\ F_2 = F_1 * \sin\alpha \\ F_1 = F_8 - F_7 - G_1 \end{cases} \quad (1)$$

According to the above calculation:

$$F_8 = \frac{2 * G * f}{\sin 2\alpha} + F_7 + G_1 \quad (2)$$

The rolling friction coefficient of transfer vehicle movement: f=0.002, telescopic components: G1=25N, compression spring tension: F7=50N, then:

$$F_8 = \frac{0.004G}{\sin 2\alpha} + 75 \quad (3)$$

In the sin2α function, 2α increases from 0 to π/2, and the value of α ranges from 0 to π/4. In equation 4.6 above, when the function of F8 is inversely proportional to sin2α, it gradually decreases from 0 to π/4. When α approaches 0, F8 is infinite.

Table 1: Relation of Gravity G, Angle α and F8

G (N)	*α* (°)	*F*8 (N)
	15	155
G=10000	30	121
	45	115
	15	235
G=20000	30	167
	45	155
	15	315
G=30000	30	213
	45	195

The gravity G is 10000N, 20000N, 30000N, the angle α is 15°, 30° and 45° respectively. Plug that into formula 4.6, the results are shown in TABLE 1.

According to Table 1, the change of angle α with F8 can be drawn when gravity G is determined, as shown in Figure 9.

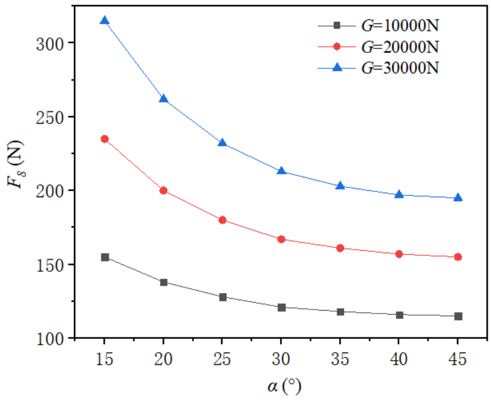


Figure 9: Variation of Angle α with F8.

As can be seen from Figure. 9, no matter how big the gravity G of the transfer vehicle is, as long as the angle α is larger, the electromagnetic thrust F8 will be smaller, so α=45°.

Set the height of the locating pin h=15mm, the travel of the expansion component S=25mm, and the transfer vehicle G=10000N, then the horizontal and lateral moving distance of the transfer vehicle X< h*tanα=15mm, F8=115N. Therefore, according to the electromagnet thrust greater than 115N, stroke greater than 25mm, to select the appropriate push and pull electromagnet.

5. Conclusion

The electric positioning mechanism of the transfer vehicle designed in this paper only needs to be attached with the cable shared with additional actuators or signal devices on the transfer vehicle, avoiding the installation and dragging of large special pneumatic or hydraulic pipelines and tow chains. A set of the mechanisms is installed on the transfer vehicle, and the corresponding locating pin is installed on the ground of the designated parking position. Through the control of the power supply, the moving slide rod in the electromagnet drives the lifting column and the locating piece and the locating pin are connected in the middle, and the multi-position accurate positioning of the transfer vehicle can be realized.

References

[1] Dušek, F., (2020). Mobile Positioning Device Powered by an Electromotor. Current Methods of Construction Design, p.31-37.
[2] Shi, J. C., Ren, Y., Tang, H. S., et al., (2022). Hydraulic directional valve fault diagnosis using a weighted adaptive fusion of multi-dimensional features of a multi-sensor. Journal of Zhejiang University-SCIENCE A, 23(4): 257-271.
[3] Yu, K., Wang, S., Wang, Y., et al., (2018). A flexible fixture design method research for similar automotive body parts of different automobiles.Advances in mechanical engineering,10(2).
[4] Lu, S., Ahmad, Z., Zoppi, M., et al., (2016). Design and testing of a highly reconfigurable fixture with lockable robotic arms. Journal of Mechanical Design, 138(8): 085001.
[5] Jiang, Z., Tang, X., (2019). Optimization of fixture flexibility for irregular geometries of workpiece based on metamorphic mechanisms. The International Journal of Advanced Manufacturing Technology, 103(1): 325-342.
[6] Yuan-zhao, Y., Chuan-Yu, W. U., Xu-Dong, H. U., (2005). Study of Web-based integration of pneumatic manipulator and its vision positioning. Journal of Zhejiang University-SCIENCE A, 6(6): 543-548.
[7] Ramachandran, T., Surendarnath, S., Dharmalingam, R., (2020). Engine-bracket drilling fixture layout optimization for minimizing the workpiece deformation. Engineering Computations, 38(5): 1978-2002.
[8] Lee, S., Kross, B., McKisson, J. E., et al., (2015). Development of a motorized variable angle slant-hole collimator.

2015 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), p.1-3.
[9] Hojjat, Y., Shirkosh, M. (2021). Application of Threadless Screw to Precise Linear Positioning. International Journal of Precision Engineering and Manufacturing, 22(2): 355-364.
[10] Wang, G., Wang, Y., Lv, B., et al., (2020). Research on a new type of rigid-flexible coupling 3-DOF micro-positioning platform. Micromachines, 11(11): 1015.
[11] Peiyuan, M., Yuguang, L., Chuanjun, X., (2020). Research on the technology of fixed stroke lead screw transmission mechanism with self positioning function. 2020 5th International Conference on Mechanical, Control and Computer Engineering (ICMCCE), p.602-605.
[12] Pshenichnikova, V. V., Martemjanov, D. B., Panin, J. N., (2018). Pin joints geometric characteristics influence on the compressor assembling. AIP Conference Proceedings, 2007(1): 050012.
[13] Li, X. G., Wang, W. H., Zhang, W. F., et al., (2013). Reliability analysis on the chassis hydraulic system in hydraulic loader. Applied Mechanics and Materials, 299: 35-37.
[14] Bogatu, L., Rizescu, C., Grămescu, B., et al., (2018). Innovative Solutions for Pneumatic Positioning Systems. International Conference on Innovation, Engineering and Entrepreneurship, p. 530-536.
[15] Guo-liang, T., Xuan-yin, W., Yong-xiang, L. (2001). Research on the continuous positioning control to servo-pneumatic system. Journal of Zhejiang University-SCIENCE A, 2(2): 128-131.
[16] Tong, Z. M., Wu, S. S., Tong, S. G., et al., (2020). Energy-saving technologies for construction machinery: a review of electro-hydraulic pump-valve coordinated system. Journal of Zhejiang University-SCIENCE A, 21(5): 331-349.
[17] Huang, X., Hu, Y., Ma, J., et al., (2021). An inertial piezoelectric rotary actuator based on active friction regulation using magnetic force. Smart Materials and Structures, 30(9): 095014.
[18] Ji-Guang, L, Pei-Pei, L., Tian-Yu, W., et.al. (2022) The invention relates to a positioning mechanism of a transfer vehicle and its application: China, CN113602339B [P]. (in Chinese)
[19] Shou, M., Liao, C., Zhang, H., et al., (2019). A design methodology based on full dynamic model for magnetorheological energy absorber equipped with disc springs. Smart Materials and Structures, 28(6): 065020.
[20] Mester, E., Pecsmány, D., Jálics, K., et al., (2021). Exploring the Potential to Repurpose Flexible Moulded Polyurethane Foams as Acoustic Insulators. Polymers, 14(1): 163.
[21] Qian, H. T., Feng, S. S., Shao, Z. Y., et al., (2019). Experimental Study on the Mitigation Effect of Polyurethane Foam Densities on the Cylindrical Objects Entering Water at High Velocity. Materials Science Forum, 950: 103-109.
[22] Li, T. T., Dai, W., Huang, S. et al., (2019). Preparation and characterization of SEBS-g-MAH-filled flexible polyurethane foam composites with gradient-changing structure. Materials & Design, 183: 108150.
[23] Wang, J., Du, B. (2022). Sound Insulation Performance of Foam Rubber Damping Pad and Polyurethane Foam Board in Floating Floors. Experimental Techniques, p.1-12.