MT 26 International Conference on Magnet Technology
Vancouver, Canada | 2019

Study for different YBCO Bulk Arrangements with a Fan-shaped Electromagnetic Guideway of HTS Maglev

Wei Hong, Ying Xin, Changqi Wang**, Wenxin Li, Yuyan Wen and Chaoqun Zhao*

School of Electrical and Information Engineering, Tianjin University, Tianjin 300072, China
** Speaker, Email: wei_hong0816@hotmail.com*
***Corresponding author, Email: wangchangqi79@tju.edu.cn*

Abstract

The application of High Temperature Superconducting (HTS) technology in the maglev field has met a giant improvement in the recent years. With the success in the laboratorial test lines, the scientists started to focus on the research of practical issues on reality applications. Lately, our team devoted ourselves into the study of Electromagnetic Guideway (EMG) for improve the flexibility and the practicability of guideway in a HTS maglev system. In this paper, a fan-shaped EMG was proposed, its basic unit was analyzed through magnetic equivalent circuit method, in order to decide the rated magnetomotive force. Afterward, a prototype was made to verify the design feasibility, the comparison among three arrangements of HTS bulks were carried out with the experiments under different measuring conditions. The levitation and guidance performances of each arrangement was comprehensively discussed as the summary.

The electromagnet structure

The electromagnet includes **a fan-shaped iron core** and **three coils.** The iron core has three pillars, one center pillar and two side pillars. **The guideway surface is designed to cover the thickness of the coils**, in order to ensure the guideway units constructing a consecutive guideway. The 3D diagram is shown in **Fig. 1**.

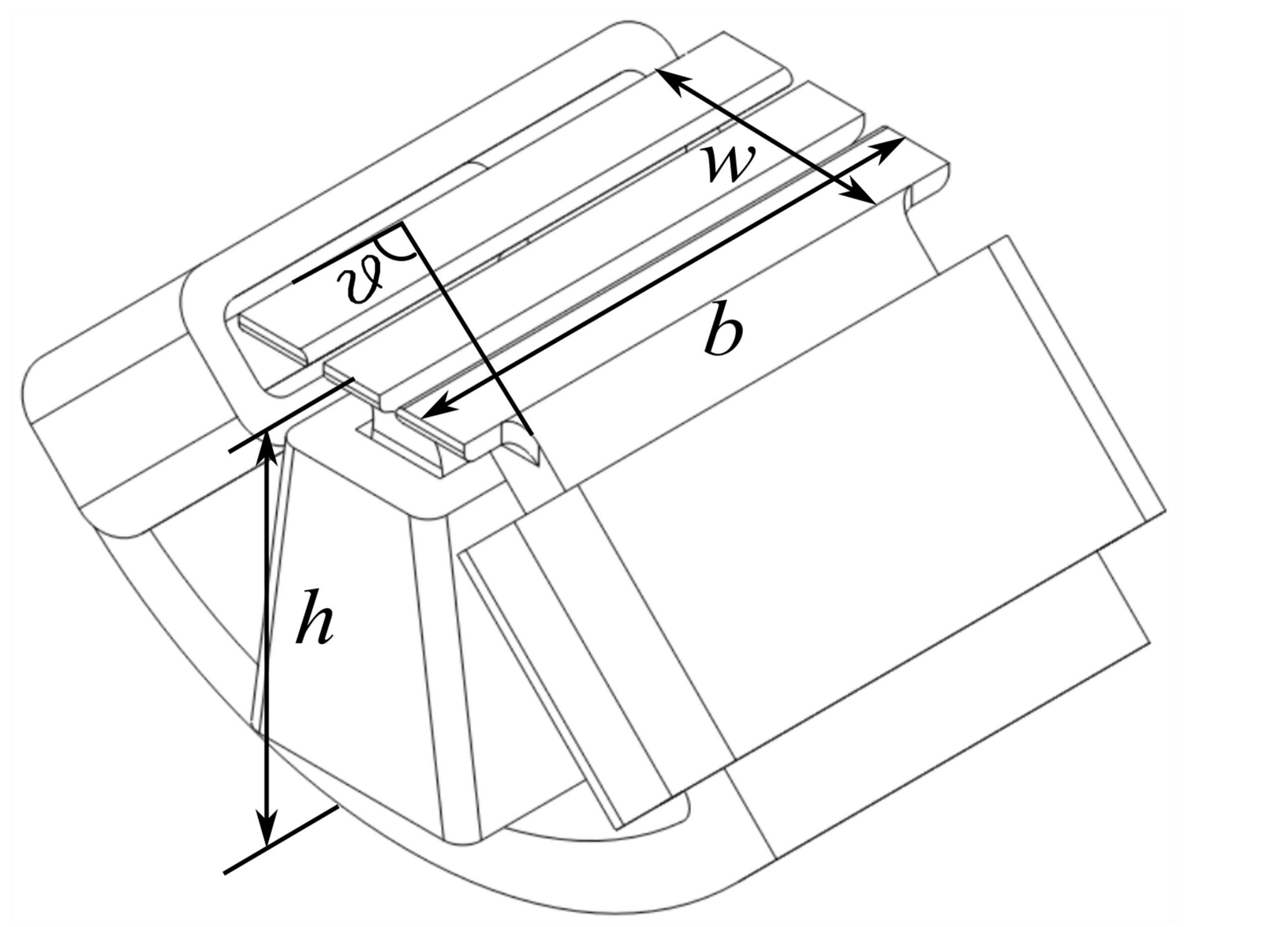


Fig. 1. General structure.

The electromagnet parameters

The number of ampere turns can be estimated through the Magnetic Equivalent Circuit (MEC) method, as shown in **Fig. 2**. There are four parallel branches and merely the branch 1 is effective in ampere turns estimation.

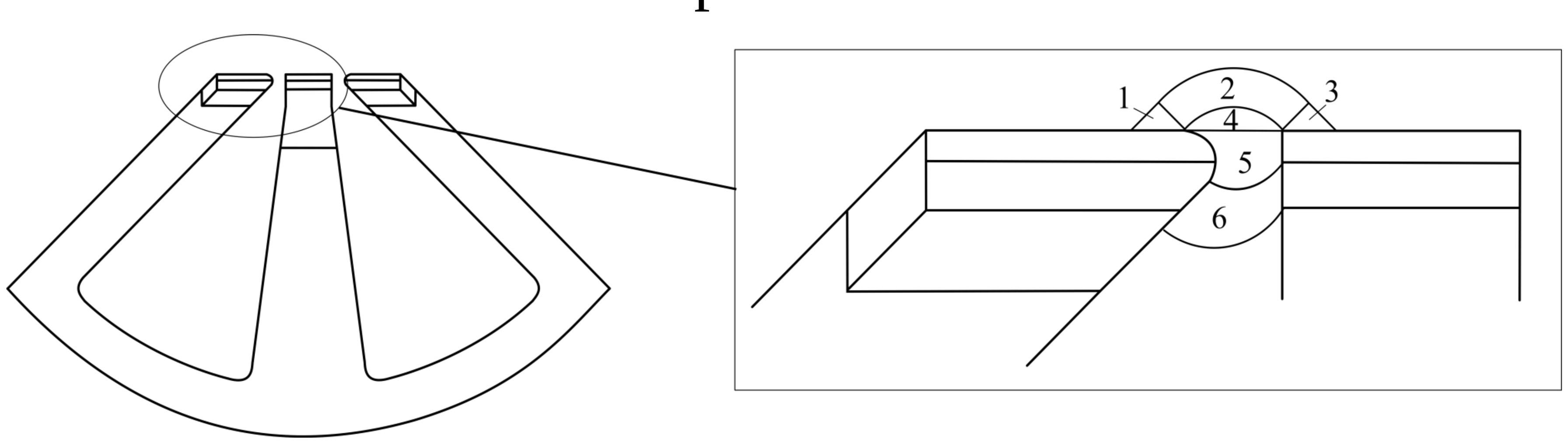


Fig. 2. Analysis of the magnetic circuit.

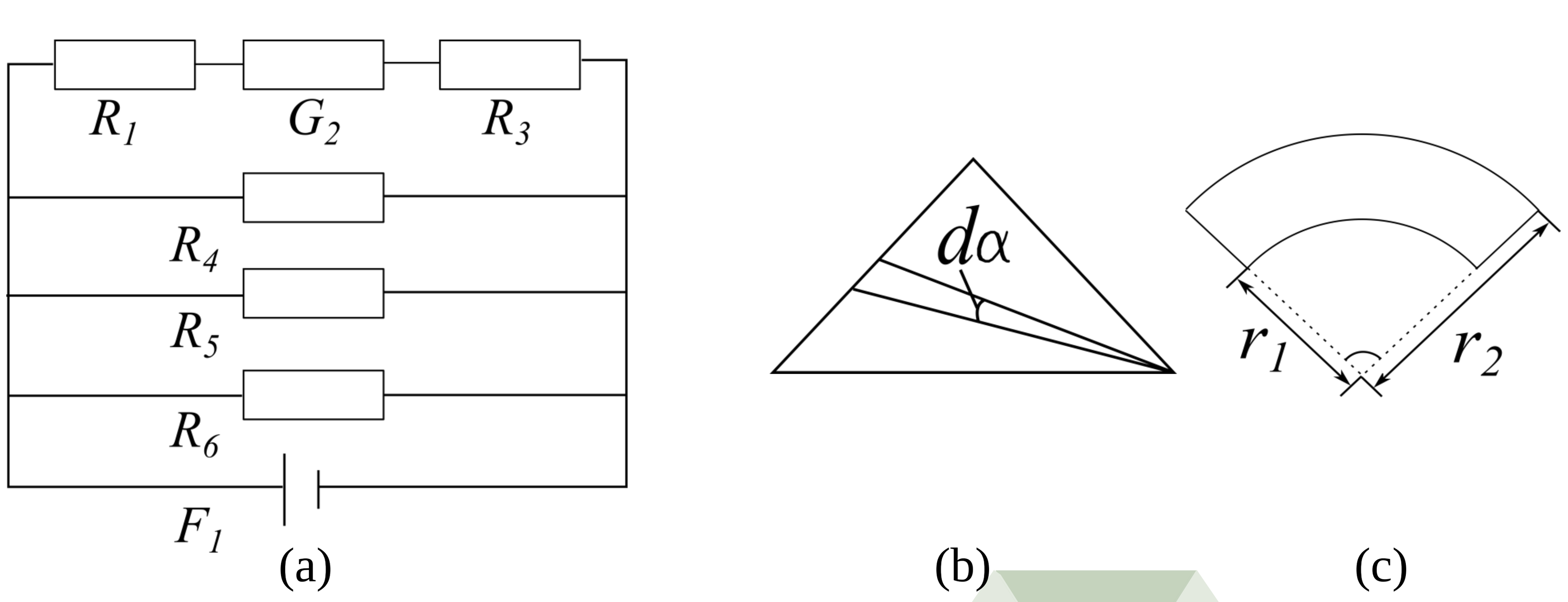


Fig. 3. (a) The MEC model. (b) The calculation scheme of R_1. (c) The calculation scheme of G_2.

With the anticipated surface magnetic flux density B_S of 0.22 T, The estimated value of ampere turns is 5000. The relevant electrical parameters are listed in **TABLE I**.

In this branch, tube 1 and tube 3 are triangles, their reluctance values can be calculated as

$$R_1 = \int_0^{\pi/4} \frac{1}{2\mu_0 b} \cdot d\alpha = \frac{\pi}{8\mu_0 b}$$

The tube 2 is a quarter of annulus, whose permeance can be calculated through empirical formula

$$G_2 = \frac{\mu_0 b}{\pi/2} \cdot \ln\left(1+\frac{r_2-r_1}{r_1}\cdot\tan\frac{\pi}{2}\right) = 0.81\frac{\mu_0 b}{\pi}$$

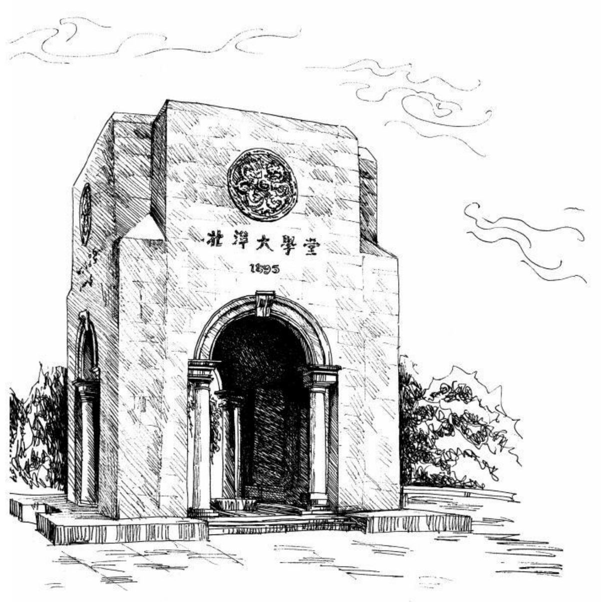
The total reluctance can be calculated as

$$R_\Sigma = 2\cdot R_1 + \frac{1}{G_2} = \frac{1.48\pi}{\mu_0 b}$$

TABLE I Parameters of the electromagnet

Parameters	Values	Unit
The length of guideway b	130	mm
The height of iron core h	96	mm
The width of guideway w	60	mm
The angle of fan shape θ	$\pi/2$	
The turns number in side pillar	370	
The turns number in center pillar	520	
The rated operation current I	4	A
The resistance of electromagnet R	8.5	Ω

This work was supported in part by the National Natural Science Foundation of China (Grant No. 51677131) and National Key Research and Development Program 2018YFB0904400..



Presentation ID：Mon-Mo-Po1.10-10 [118]
Speaker: Wei Hong(wei_hong0816@hotmail.com)

MT 26 International Conference on Magnet Technology
Vancouver, Canada | 2019

Measurement system

The force measuring platform is a three dimensional sliding table with force measuring sensors. The levitation force is measured by the weighing sensor, while the guidance force is measured by the yawing force sensor. **Fig. 4** shows the overall structure of the measurement system including the measuring platform and the electromagnet prototype. The HTS bulk used in experiment is the melt-textured YBaCuO large grain pellet with **the diameter of 30 mm** and **the height of 10 mm.**

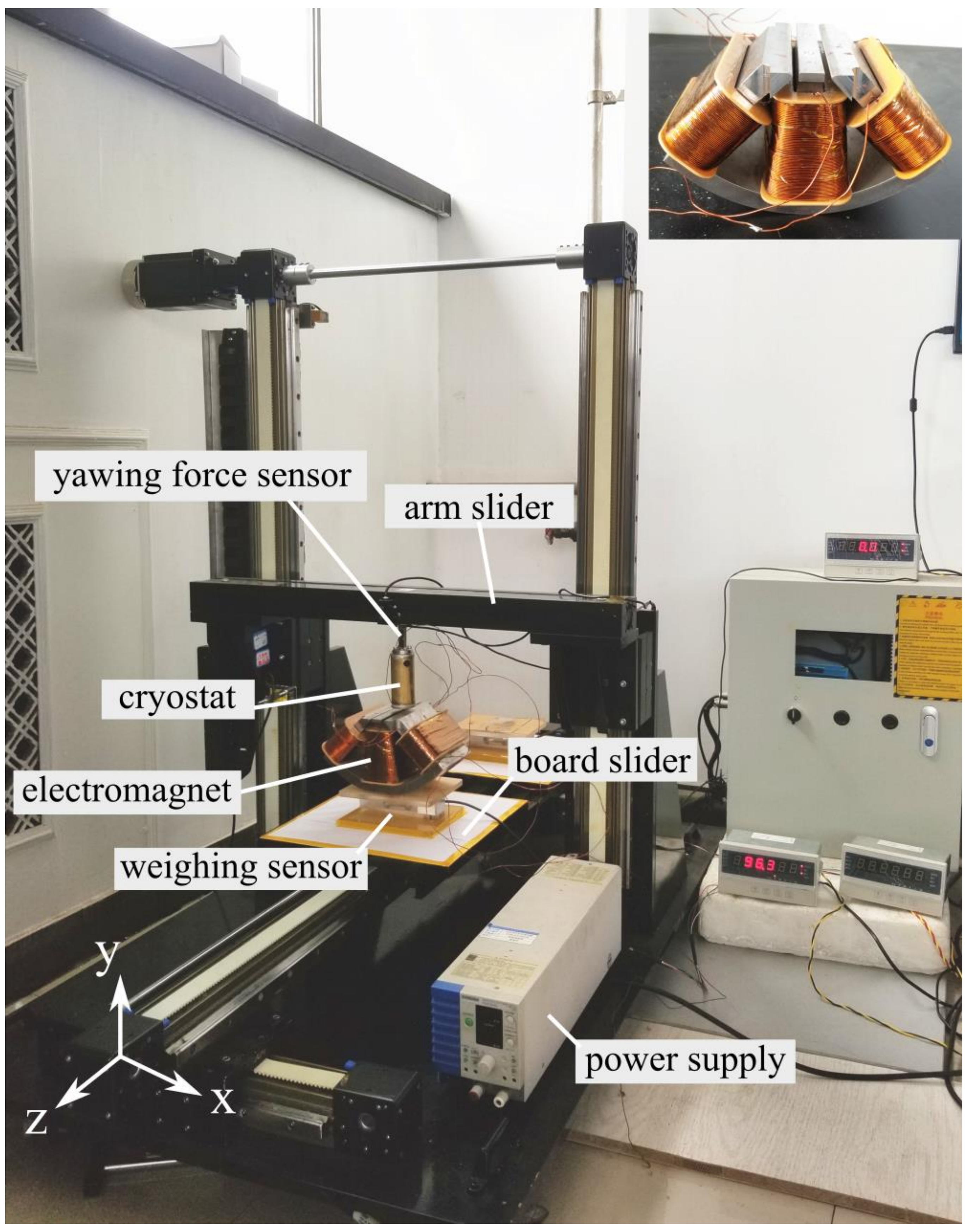


Fig. 4. The measurement system.

The magnetic distribution

The absolute value of magnetic flux density $|B_x|$ and $|B_y|$ from simulation results are plotted in **Fig. 5**. It can be seen that the high value of $|B_x|$ appears above the air gap, while the one of $|B_y|$ is above the center pillar.

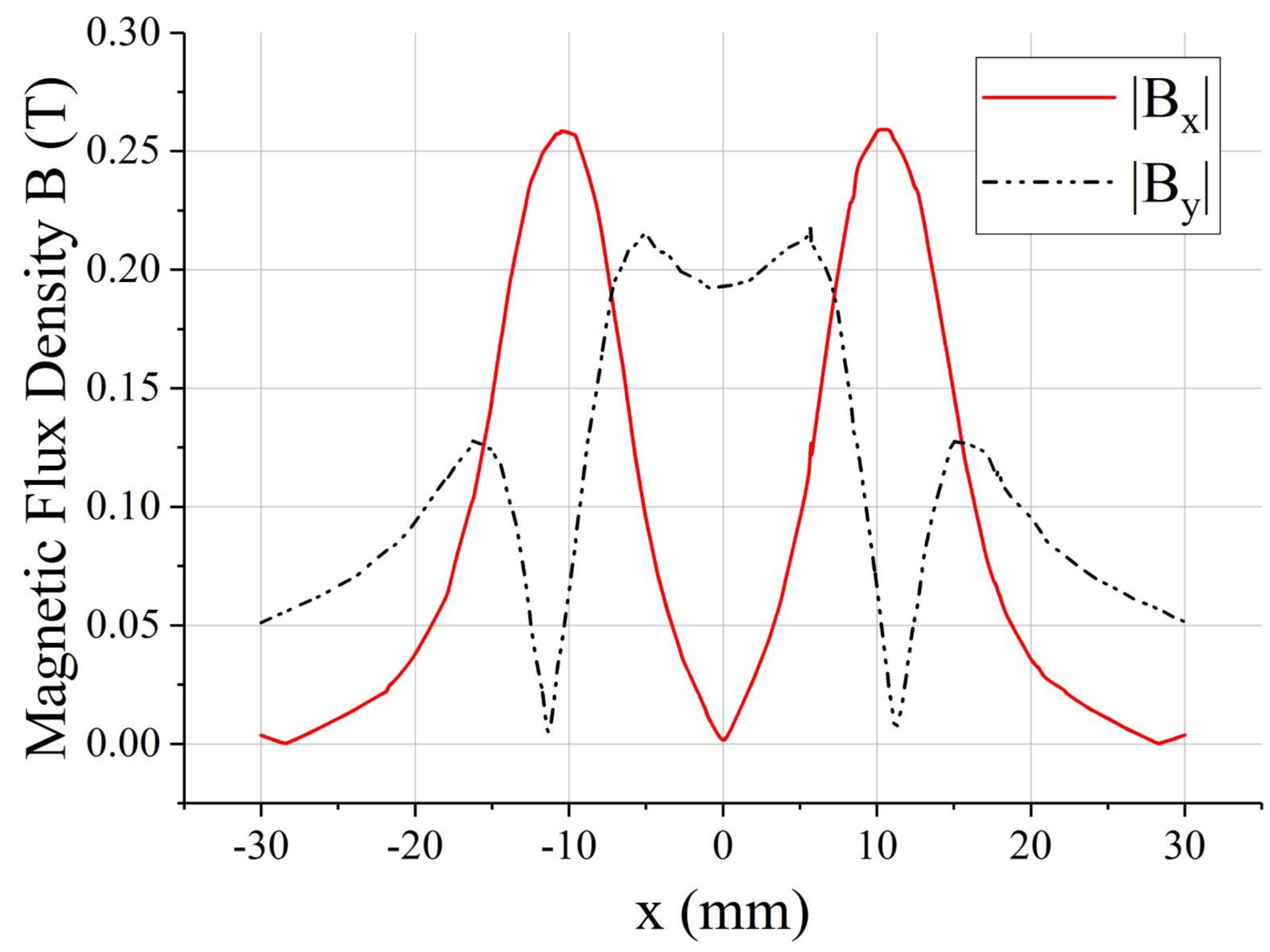


Fig. 5 Magnetic flux density at the height of 3 mm.

Three HTS bulk arrangements

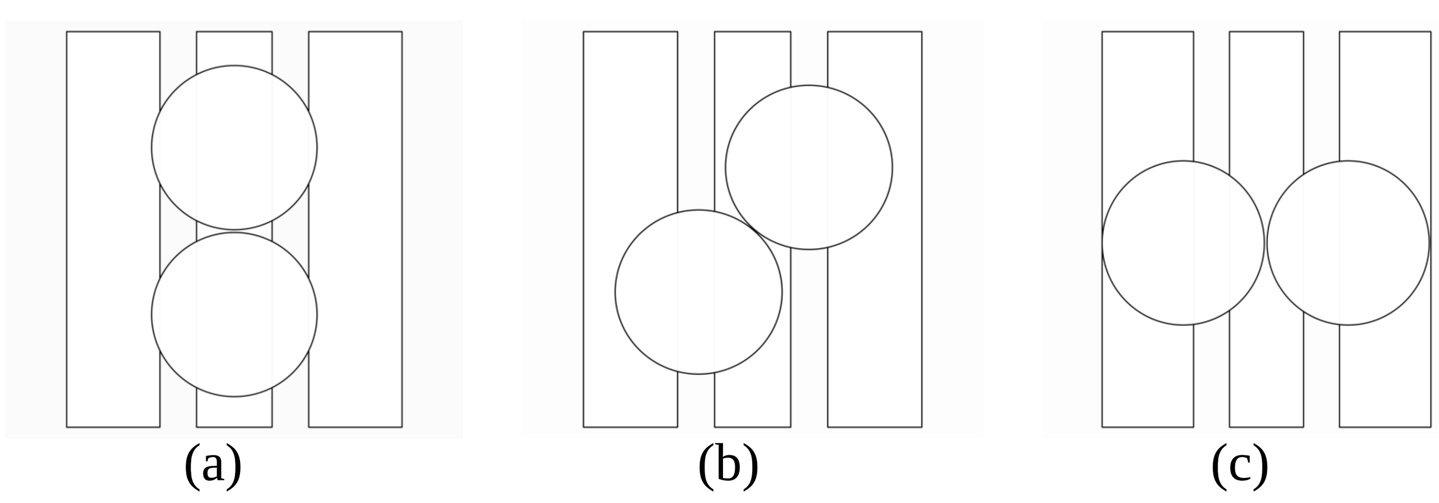


Fig. 6. (a) The arrangement 1 (arr. 1). (b) The arrangement 2 (arr. 2). (c) The arrangement 3 (arr. 3).

For this type of EMG, there are **three typical arrangements** of HTS bulk in the levitation area. **Fig. 6** shows the schematic diagram of these arrangements. For arr. 1, the both two bulks are aligned at the center pillar. For arr. 2, the bulks were placed right above the air gap in the left and right sides, respectively. For arr. 3. two bulks were placed parallel in one row and covered the whole guideway surface in lateral direction.

Levitation force with different arrangements

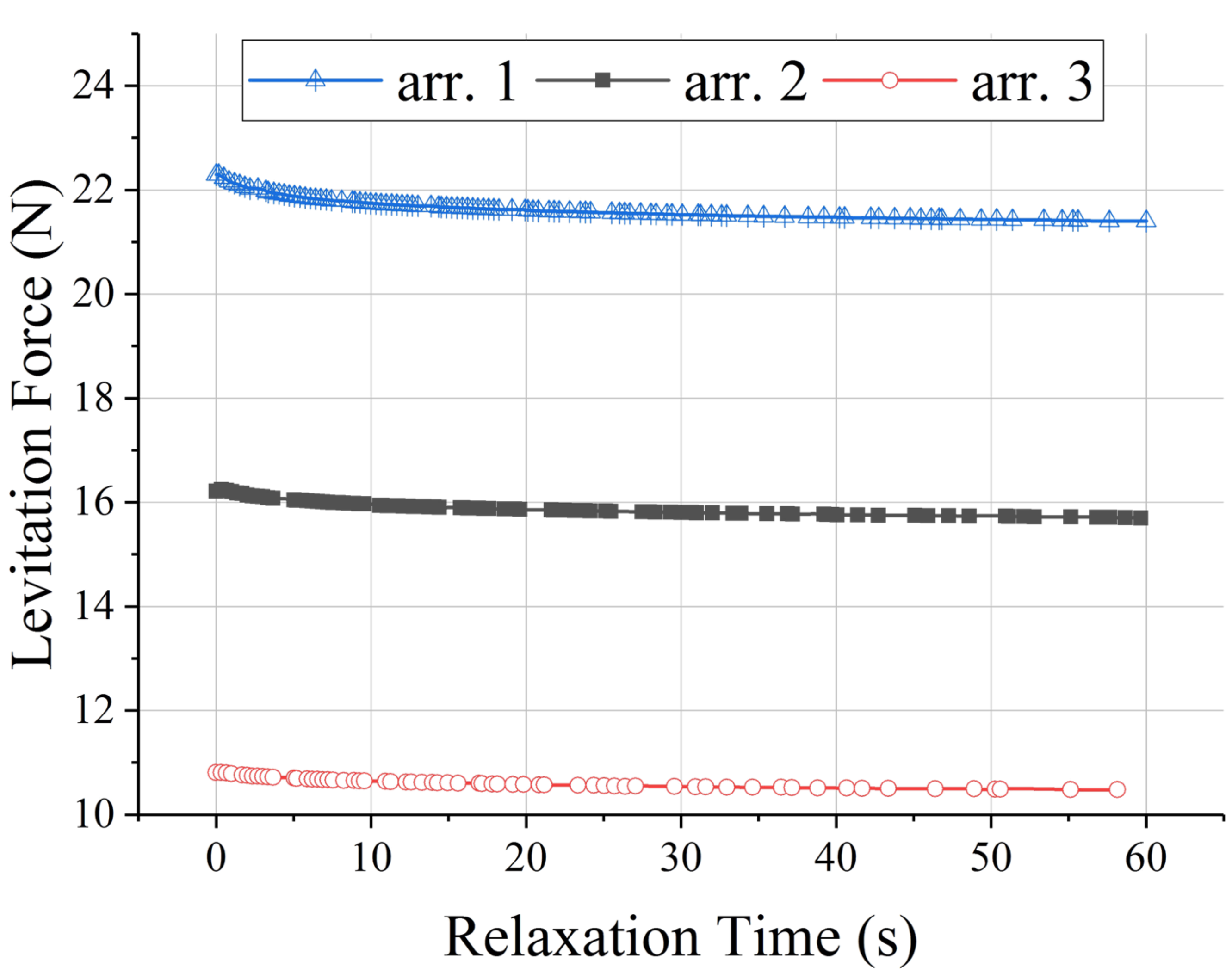


Fig. 7. Levitation forces of three arrangements.

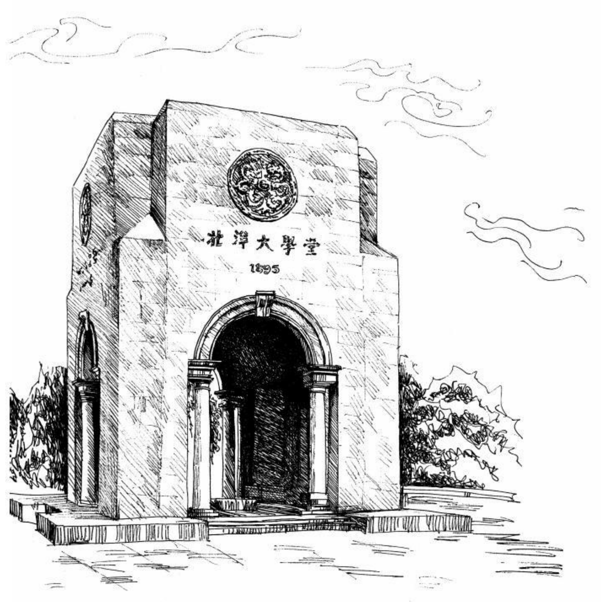
The levitation forces were measured at the Zero Field Cooling (ZFC) condition. The levitation height is 3 mm. The relaxation time is 60 s. As seen in **Fig. 7**, from arr. 1 to arr. 3, the HTS bulks gradually leave the area of high $|B_x|$, which has a great affect in levitation calculation. Therefore, the levitation force decreases from arr. 1 to arr. 3. The value of arr. 1 is almost twice larger than that of arr. 3.

Cooling conditions

TABLE II Descriptions of three cooling conditions

Cooling conditions	Descriptions
ZFC	cooled at I=0A, levitated at I=4A
PFC	cooled at I=2A, levitated at I=4A
FFC	cooled at I=4A, levitated at I=4A

For the force measuring experiments, three field cooling conditions were taken into account for each arrangement, the ZFC, the partly FC (PFC) and the full FC (FFC). The detailed descriptions of cooling conditions are listed in **TABLE II**.



Presentation ID：Mon-Mo-Po1.10-10 [118]
Speaker: Wei Hong(wei_hong0816@hotmail.com)

Guidance force with different arrangements

Figs. 8-10 shows the experiment results. The maximum guidance force of arr. 1 and arr. 2 have similar in FFC and PFC and stronger than that of arr. 3. However, the force value of arr. 2 and arr. 3 increase faster than that of arr. 1 within 10 N. It is concluded that in FFC and PFC, the arr. 1 fits more for the disturbance with large offset, while arr. 2 fits more for the one with large impulsion force.

When at the **ZFC** condition, the guidance force of three arrangements behaved totally different.

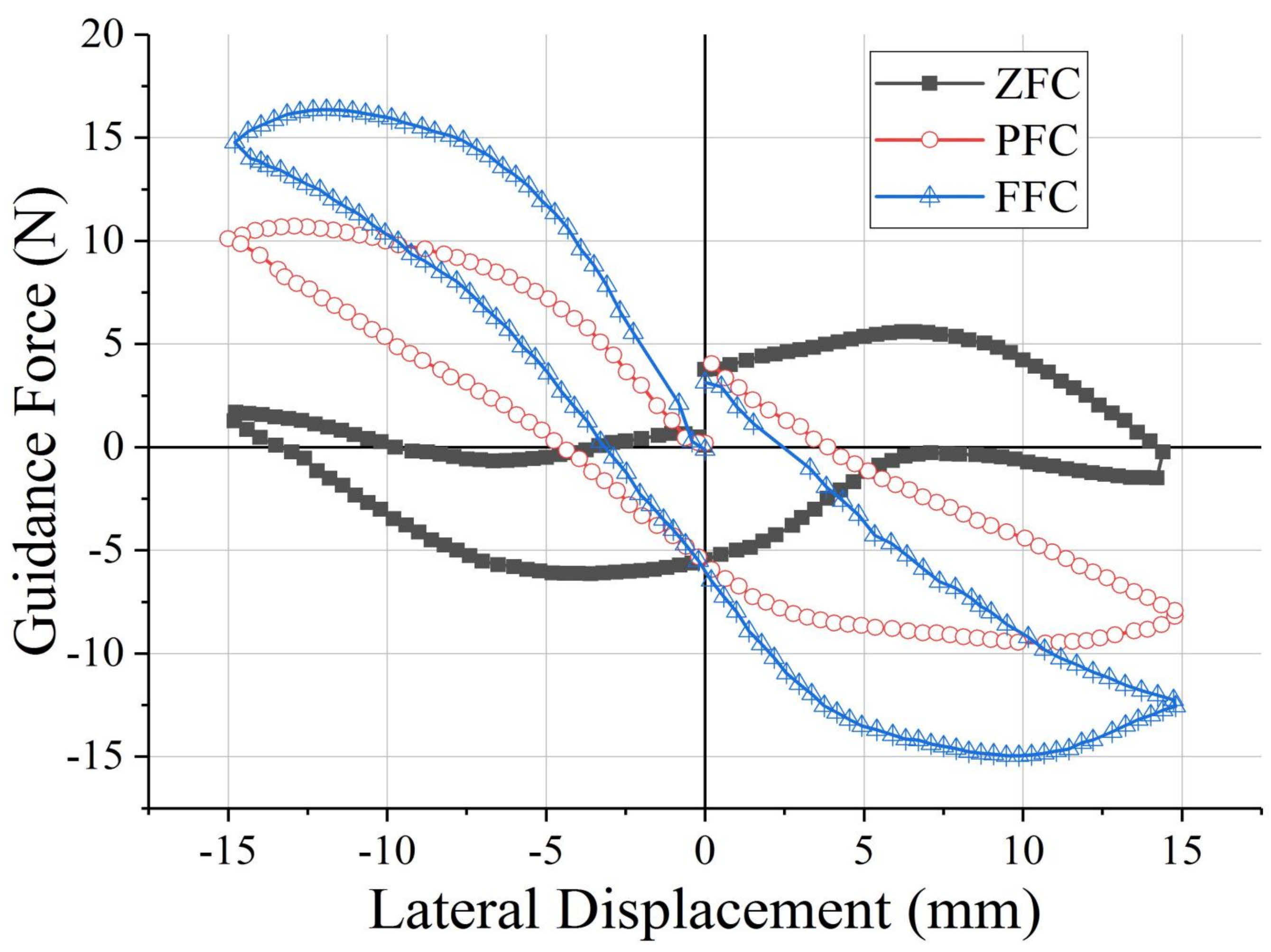


Fig. 8. The guidance force of arr. 1.

For arr. 1, the guidance force turned to negative at the very beginning of the movement, the self-stable state was broken.

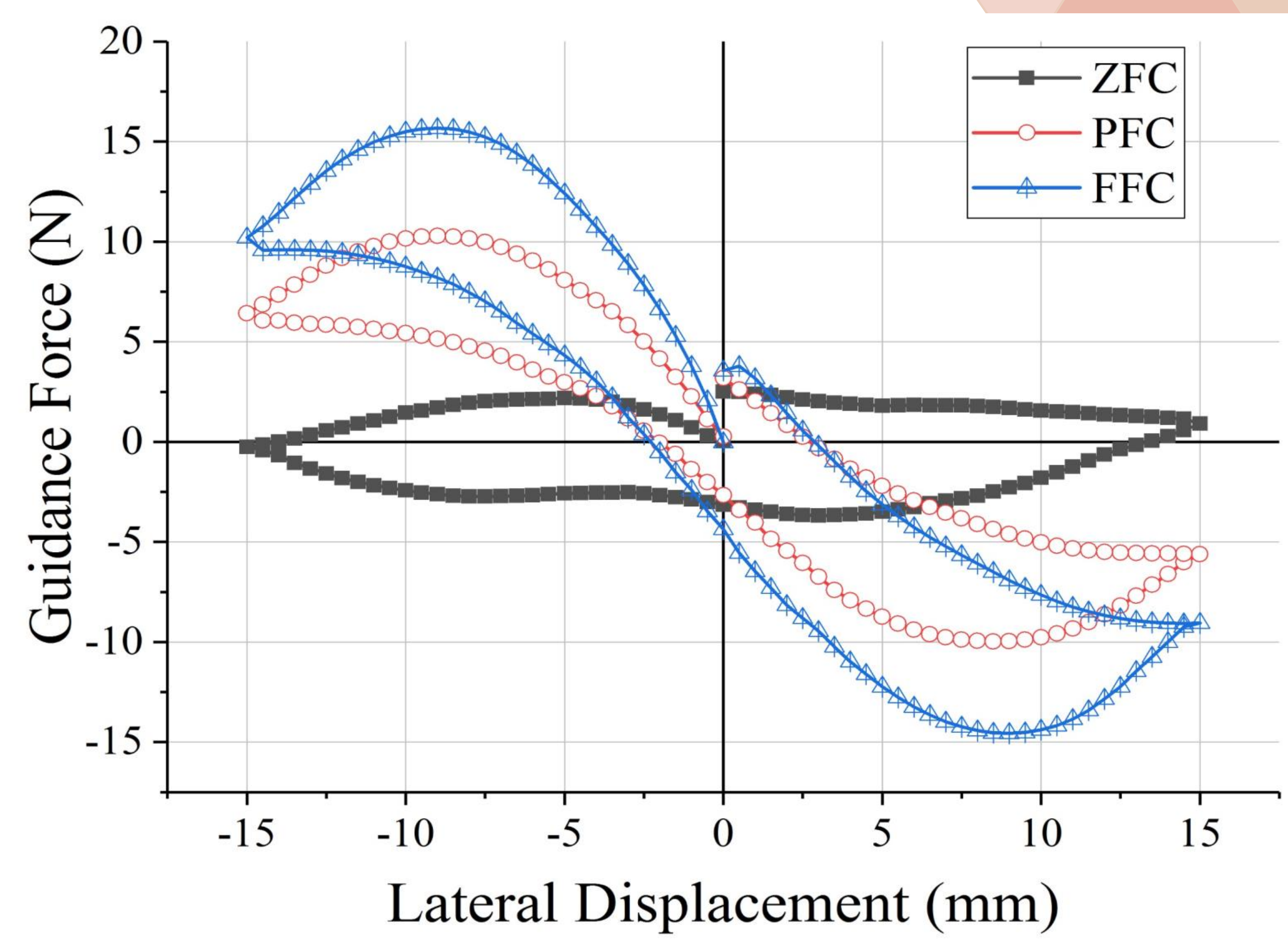


Fig. 9. The guidance force of arr. 2.

For arr. 2, the guidance force was positive when the HTS bulk was moving to the left. However, the position that the force reached the highest value moved closer to the origin point and the force value reduced heavily. The lateral stability can be maintained merely under very small disturbance.

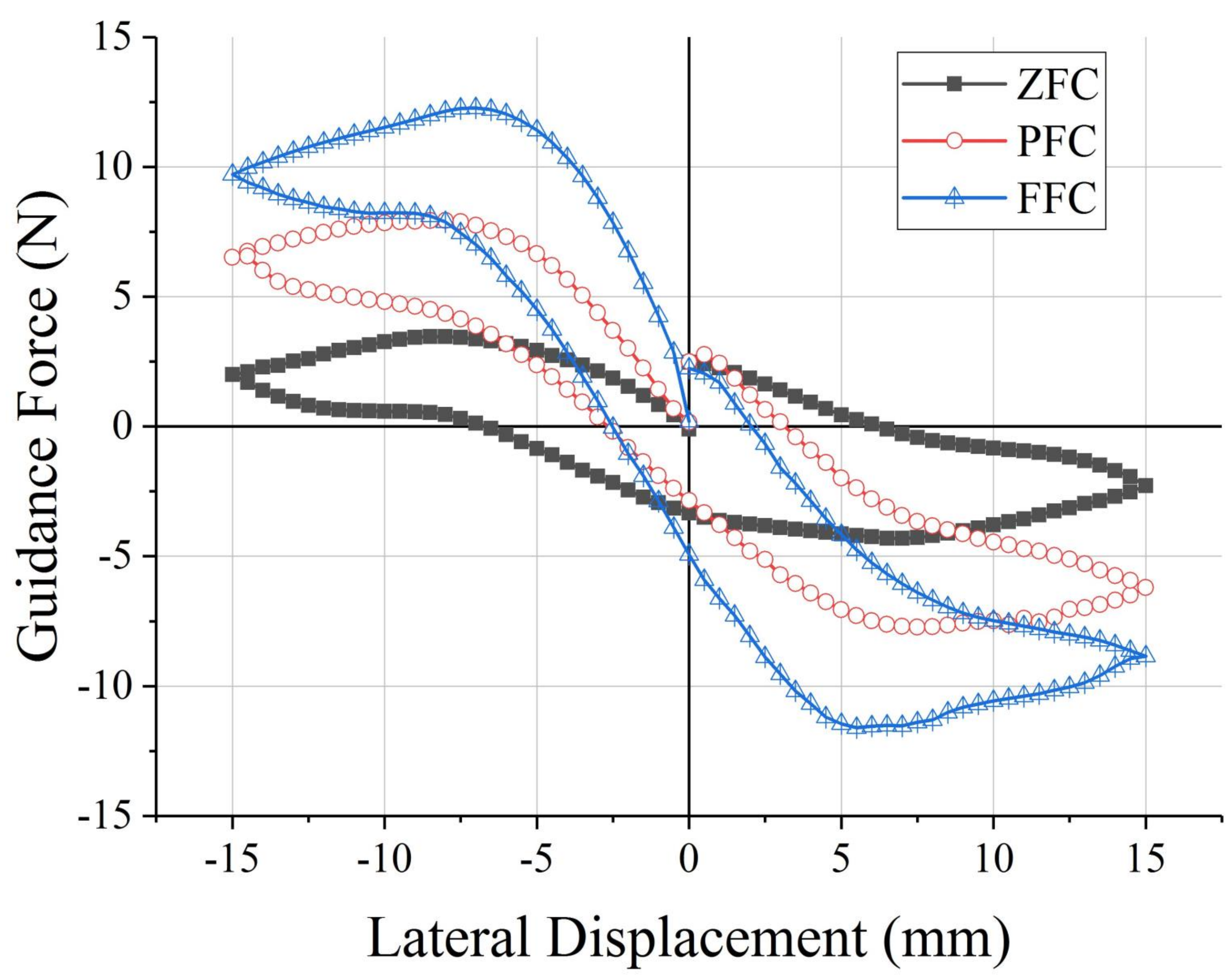


Fig. 10. The guidance force of arr. 1.

For arr. 3, the guidance force curve is similar as in PFC and FFC. The highest force value was obtained at same lateral displacement . Additionally, the maximum force value turned to be the largest among three arrangements. As a result, the arr. 3 has the best guidance performance among the three in ZFC conditions.

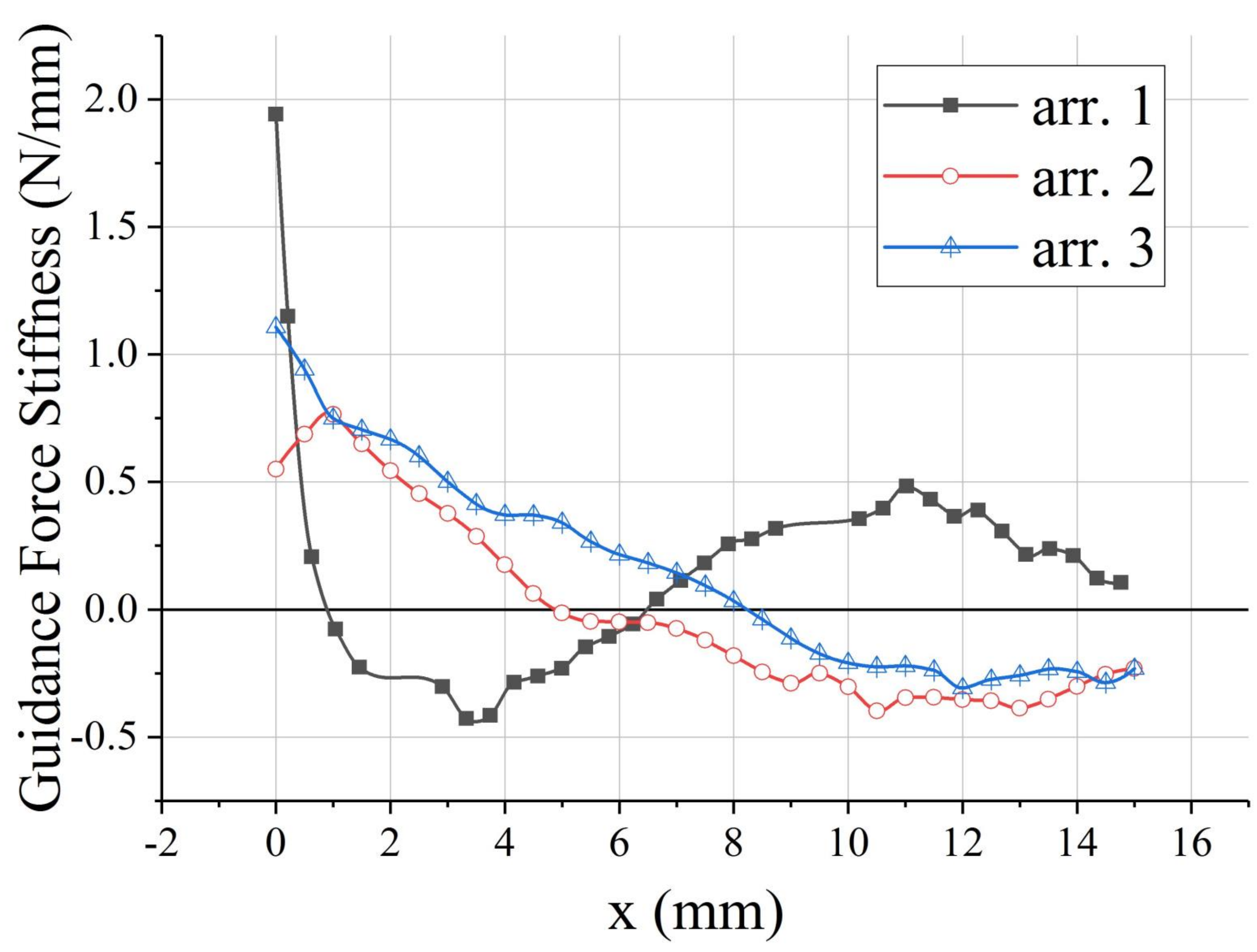


Fig. 11. Guidance force stiffness of three arrangements in ZFC condition.

A guidance force stiffness are plotted in **Fig. 11.** The force stiffness is calculated by the formulation of dF/dx. The stiffness of arr. 1 oscillated around the zero point, which indicates its instability. For arr. 2 and arr. 3, the stiffness turn to negative after the guidance force reach its maximum value and the stiffness of arr. 3 is visible higher than that of arr. 2.

Conclusion

In this paper, a fan shaped electromagnetic guideway unit was proposed and three arrangements of HTS bulks were tested to discuss the levitation and guidance performance. It can be summarized that

1. The fan shaped EMG unit that can solve the gap restriction problem of normal electromagnet performs well in an HTS levitation system.

2. There are three basic HTS bulk arrangements that can be used for this type of EMG. The closer to the central line (along the guideway direction) of the EMG the HTS bulk is placed, the stronger levitation force can be achieved. On the other hand, at ZFC condition, the farther the HTS bulk is to the central line, the better guidance performance the system can obtained. The advantages and disadvantages of each arrangement should be considered comprehensively according to different application situations.