Study on support for HALF beam position monitor displacement measurement system

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Abstract
Hefei Advanced Light Facility (HALF), a fourth-generation vacuum ultraviolet and X-ray diffraction limit synchrotron radiation (DLSR) light source under preliminary research and construction. Beam position monitor (BPM) displacement measurement system with nanometer resolution is used to correct the BPM data and achieve sub-micron beam orbit stability. In order to make full use of the performance and meet the requirement of HALF's beam orbit stability, the supports of the system are particularly crucial. The purpose of this paper is to develop a set of support for the BPM displacement system that meet the stability requirements of HALF. A hybrid support with Invar 36 and carbon fiber/epoxy is creatively proposed to achieve stability requirements. Through the calculation of thermal expansion, the analysis of mechanical vibration and finite element analysis (FEA), the hybrid support is adjusted to higher stability. Experiments are conducted and show that the hybrid support has higher stability than traditional support. On the existing experimental platform, the vibration RMS of the hybrid support was measured at 42.6 nm in horizontal and 29.9 nm in vertical and the hybrid support could meet the requirement of HALF's beam orbit stability.

Keywords
HALF, BPM displacement measurement system, mechanical stability, FEA

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Introduction
Hefei Advanced Light Facility (HALF), a fourth-generation light source based on the diffraction-limited, is pre-researched and constructed by University of Science and Technology of China National Synchrotron Radiation Laboratory. Parameters of HALF are shown in Table 1.

For the synchrotron radiation storage ring, the stability of the beam orbit is a key parameter to evaluate the operating state of the light source. In general, the beam orbit stability (Δσ/σ) is required to be less than 10%. With the development of synchrotron radiation light source from the second generation to the fourth generation, the beam size is reduced by two orders of magnitude and the emittance is reduced by three orders of magnitude.
Table 1. Parameters of the storage ring of HALF.

| Parameters                        | Symbol | Value        |
|-----------------------------------|--------|--------------|
| Circumference (m)                 | C      | 480          |
| Energy (GeV)                      | E      | 2.2          |
| RF frequency (MHz)                | f_{rf} | 500          |
| Harmonic number                   | h      | 800          |
| Current (mA)                      | I      | 500          |
| Natural beam emittance (pm\text{rad}) | \varepsilon | 86.3        |
| Horizontal beam size (\mu m)      | \alpha_x | \geq 5       |
| Vertical beam size (\mu m)        | \alpha_y | \geq 2       |
| \beta_x (m)                      | \beta_x | 6.181/2.900  |
| \beta_y (m)                      | \beta_y | 2.591/1.925  |
| Horizontal tune                   | Q_x    | 48.15        |
| Vertical tune                     | Q_y    | 17.15        |
| Lattice number                    | N      | 20           |
| Focal length of quadrupoles (m)   | F      | 2.02/0.88    |

magnitude. HALF requires the beam orbit stability to be less than 0.5 \mu m in horizontal and 0.2 \mu m in vertical.

BPMs are used to measure beam position and provide input to feedback system. However, the irradiation of synchrotron radiation and the changes in ambient temperature lead to the thermal deformation of the vacuum chamber and the vibration of ground and other systems leads to the vibration of vacuum chamber. Both deformation and vibration introduce a bias into the measurements of the BPMs fixed on the vacuum chamber and the beam orbit stability is affected. BPM displacement measurement system\textsuperscript{7} is used to measure the bias and correct the BPM measurement. The BPM displacement measurement system has nanometer scale resolution and the errors in the measurement results are mainly due to the thermal expansion and the vibration of the support structure. In order to better suppress the influence of the deformation and vibration of the vacuum chamber on the beam orbit stability, it is the key to improve the stability of the support of the BPM displacement measurement system.

At present, three materials, stainless steel, invar steel and carbon fiber, are mainly used in the support structure of the storage ring. As a support material, stainless steel is sufficient to meet the stability requirements of the beam orbit for the second-generation light source and is widely used on the support platform of the storage ring,\textsuperscript{6,7} but the coefficient of thermal expansion of stainless steel is too large for precision instruments. In the third-generation light source, Invar alloy is widely used in the support of precision devices, due to their low thermal expansion coefficient. Invar 36 is used as BPM support in SOLEIL\textsuperscript{8} and SSRF.\textsuperscript{9,10} However, the close-proximity of the Invar alloy to magnets has an adverse effect on the magnets field. In recent years, Carbon fiber/epoxy has been applied in various fields of industry due to excellent chemical, physical and mechanical properties and thermal stability.\textsuperscript{11,12} In storage ring, it was processed into chamber supports in NSLS II.\textsuperscript{13} However, due to the difficulty of processing and the limitation of the thickness (\leq 50 mm), carbon fiber/epoxy is not unsuitable as a material for the whole support.

A hybrid support combining Invar 36 and carbon fiber/epoxy is proposed in this article. While maintaining low thermal expansion, a carbon fiber/epoxy top is used to keep the Invar 36 away from the magnets, and an Invar 36 base is used to hold the carbon fiber to improve mechanical stability. The hybrid support combines the advantages of two materials and overcomes the limitations. The purpose of this article is to improve the stability of the support of BPM displacement measurement system through the modeling, optimizing and testing of the support of the BPM displacement measurement system and to provide feasible suggestions and references for the design of in the fourth-generation light source precision device support.

FEA is widely used in mechanical analysis of composite materials and modal analysis of mechanical structures. With the development of computers and the improvement of computing power, the FEA simulation software is also more powerful. Goharil et al.\textsuperscript{14} developed an analytical solution for electro-mechanical flexural response of smart laminated piezoelectric composite rectangular plates encompassing flexible boundary conditions at two opposite edges and validated the analytical results with Abaqus Finite Element (FE) package.\textsuperscript{15} Tripathi et al.\textsuperscript{16} demonstrates the modal analysis of a single point cutting tool using the FEA. In this article, the modal analysis of the hybrid support and the optimization of its structure are carried out using the method of FEA.

This article is organized as follows. In Chapter II, the model of the BPM displacement measurement system and its support are established and the stability requirements of the support is calculated through the storage ring parameters. Then, the hybrid support is adjusted and optimized from the perspective of thermal stability and mechanical stability, and the final structure of the support is determined. In Chapter III, comparative experiments with traditional supports are conducted on the bench platform as that of HALF, as shown in Figure 1. Eigen-frequency and root mean square (RMS) vibration are mainly focused on. Finally, a brief summary is given in Chapter IV.

Analysis and optimization

Requirements for supports stability

Due to the thermal effect and the mechanical vibration of synchrotron radiation on the wall of the vacuum chamber, BPM will move with the vacuum chamber, as it is shown in Figure 2. We define that the BPM reading is positive when the particle is outside the BPM center.
and the BPM displacement is positive when the BPM is moving inward. The BPM displacement $x_d$ is numerically equal to the difference between BPM actual reading $x_{BPM}$ and real beam position $x_{beam}$:

$$x_{beam} = x_{BPM} - x_d \quad (1)$$

Assuming the orbit feedback system could correct the beam to the golden orbit based on the BPM data, there is an error of $x_d$ between the corrected beam orbit and golden orbit. The rms closed-orbit distortion $\sigma_{co}$ has been shown to be$^{17,18}$

$$\sigma_{co} = \beta \frac{x_d}{2 \sqrt{2 \pi \alpha Q F}} \sqrt{N} \quad (2)$$

where $\beta$ is the beta function, $Q$ is the betatron tune, $F$ is focal length of quadrupoles, and $N$ is the number of identical lattice sections. $\beta$, $Q$, $F$, and $N$ are shown in Table 1.

With the correction of BPM displacement measurement, the error of $x_d$ will be reduced to the measurement error of the probe, which is mainly contributed by the probe vibration $x_2$. The corrected rms closed-orbit distortion is changed into equation (3)

$$\sigma_{co} = \frac{\beta}{2 \sqrt{2 \pi \alpha Q F}} \sqrt{N} \quad (3)$$

In order to meet the requirement of the beam orbit stability of 10% beam size,

$$\sigma_{co} < \Delta \sigma \quad (4)$$

Substituting equation (3) into equation (4), we get $x_2$ should be less than 45.85 nm in horizontal and 36.88 nm in vertical at least.

**Thermal analysis**

For such a limited scope, thermal expansion coefficient and mechanical parameters of the support materials are particularly critical. According to the definition of thermal expansion coefficient, the thermal expansion of the support material can be calculated by equation (5),

$$\Delta L = \alpha \cdot L \cdot \Delta T \quad (5)$$

where $\alpha$ represents for thermal expansion coefficient, $L$ is equal to 400 mm, indicating the height of the supports $L$ and $\Delta T$ represents for the change of temperature. The thermal expansion coefficients of SUS 304, Invar 36, and carbon fiber/epoxy are listed in Table 2.$^{19-22}$ Within 0.1°C change in temperature, the height of the support with SUS 304 changes in 680 nm, the support with Invar 36 change in 64 nm and the support with carbon fiber/epoxy changes in 8 nm. However, due to the difficulty of carbon fiber/epoxy processing, it cannot be used as a whole support and a hybrid support combining Invar 36 and carbon fiber/epoxy is proposed. The hybrid support is made by inserting carbon fiber/epoxy into grooved Invar 36 and fixing with screws and glue. The thermal expansion of the hybrid support can be calculated by equation (6),

$$\Delta L = (\alpha_{carbon} \cdot L_{carbon} + \alpha_{Invar \ 36} \cdot L_{Invar \ 36}) \cdot \Delta T \quad (6)$$
Table 2. Properties of the material.

| Material     | SUS 304 | Invar 36 | Carbon fiber/epoxy |
|--------------|---------|----------|--------------------|
| Density (kg/m³) | 7750   | 8050     | 1380               |
| Thermal expansion coefficient (× 10⁻⁶/°C) | 17      | 1.58     | Y: 0.02            |
| Young’s modulus (GPa)  | 192.7   | 141.0    | X: 5.45            |
| Poisson’s ratio       | 0.31    | 0.26     | X: 6.96            |
| Shear modulus (GPa)   | 73.5    | 55.9     | Z: 4.87            |

Figure 3. Relationship between ΔL and L_invar 36; the red dot indicates the critical point where the thermal expansion of the support does not exceed 36.88 nm.

where α_carbon and α_Invar 36 represents for thermal expansion coefficients of carbon fiber/epoxy and Invar 36, L_carbon, and L_invar 36 represents for the height of each part and L_carbon + L_invar 36 = 400 mm. The relationship between ΔL and L_invar 36 is shown in Figure 3.

In order to satisfy the vertical stability requirement of 36.88 nm, Invar 36 should be no higher than 231 mm.

Mechanical analysis

From the perspective of vibration response and Eigen frequency, the support of BPM displacement measurement system is modeled, analyzed, and optimized.

Model of support structure for BPM displacement measurement system. According to the sample platform, as shown in Figure 1, the support of BPM displacement measurement system was modeled. The support structure could be simplified to the structure shown in Figure 4.

![Figure 4. Model of the support structure.](image)

The support for BPM displacement measurement system is fixed on the platform. The ground vibration x_gr is transmitted to the support through the platform, and then to the probe through the support. x_1 and x_2 represent for the vibration on the upper surface of the platform and the support.

The following formula is obtained by analyzing the forces on m_1 and m_2,

\[ m_2 \ddot{x}_2 + c_2 \left( x_2' - x_1' \right) + k_2 \left( x_2 - x_1 \right) = 0 \]  \hspace{1cm} (7)

\[ m_1 \ddot{x}_2 - c_2 \left( x_2' - x_1' \right) - k_1 \left( x_2 - x_1 \right) + c_1 \left( x_1 - x_{gr} \right) + k_1 \left( x_1 - x_{gr} \right) = 0 \]  \hspace{1cm} (8)

where k and c represent for the stiffness damping coefficient.

x_gr, X_1, X_2 donate the vibration amplitude of the ground and ϕ_1, ϕ_2 donate the phase between m_1 and m_2. With \( x_{gr} = X_{gr} e^{i\omega t} \), \( x_1 = X_1 e^{i(\omega t + \phi_1)} \) and \( x_2 = X_2 e^{i(\omega t + \phi_2)} \), equations (7) and (8) leads to

\[ (-m_2 \omega^2 + ic_2 \omega + k_2)X_2 e^{i\phi_2} = (ic_2 \omega + k_2)X_1 e^{i\phi_1} \]  \hspace{1cm} (9)

\[ (-m_1 \omega^2 + ic_1 \omega + k_1)X_1 e^{i\phi_1} - m_2 \omega^2 X_2 e^{i\phi_2} = (ic_1 \omega + k_1)X_{gr} \]  \hspace{1cm} (10)

By substituting equation (9) into equation (10), the relationship between the amplitude and phase of x_gr and x_2 is obtained and shown in equation (11),

\[ X_2 e^{i\phi_2} = \left( \frac{-m_1 \omega^2 + ic_1 \omega + k_1}{ic_1 \omega + k_1} \right) X_{gr} \]  \hspace{1cm} (11)

Define α as the ratio of m_1 and m_2, \( \alpha_1 = \frac{c_1}{2\sqrt{k_2/m_2}} \), \( \alpha_2 = \frac{c_2}{2\sqrt{k_1/m_1}} \), \( \omega_n_1 = \sqrt{k_1/m_1} \), \( \omega_n_2 = \sqrt{k_2/m_2} \) are the damping ratio and Eigen-frequency for m_1 and m_2. By substituting α, α_1, α_2, ω_n_1, and ω_n_2 into equation (11), the relationship between x_gr and x_2 is given by equation (12)
Generally, the damping ratio of metallic materials is rather small in the order of $10^{-4}$. Assuming the value of $\alpha$ is 0.01, the ratio of the amplitude of the ground vibration to the amplitude of the probe vibration is obtained. $X_{gr}$ is treated as a function of $v_{n1}$ and $v_{n2}$ and the relationship is shown in Figure 5. Figure 5 shows that the value of $X_{2}/X_{gr}$ is particularly large when $v_{n1}/\omega$ and $v_{n2}/\omega$ are close to 1, which means the support structure will amplify the vibrations with frequencies $\omega$ close to the Eigen frequency $v_{n1}$ and $v_{n2}$. Since the ground vibration is mainly concentrated in the low frequency region, a higher $v_{n1}$ and $v_{n2}$ could avoid more vibration peaks will get a smaller probe vibration amplitude $X_{2}$.

BPM displacement measurement system is used to eliminate the effect of the deformation and vibration of the vacuum chamber on the BPM measurement. As for the support, the stability in horizontal and in vertical is concerned and the simulations and the experiments are focus on the horizontal and vertical directions.

**Ground vibration measurement.** The ground vibration is the input of the vibration response and is measured at the location selected by HALF. The vertical and horizontal vibration power spectral density (PSD) is shown in Figure 6. The vibration can be divided into natural vibration and cultural vibration. The PSD of natural vibration is approximately proportional to $1/f^4$ and the cultural vibration mainly concentrated within 50 Hz. As for the support, the Eigen-frequency should also be as high as possible to avoid the peaks in the PSD. The RMS of the ground vibration is 27.1 nm in the horizontal direction and 29.8 nm in the vertical direction.

**Finite element analysis and optimization.** According to the design requirements and the fixed condition of the platform, the initial model of the support is shown in Figure 7(a). It simply consists of a base connected to the platform, a pillar, and a structure for fixing the probe. Finite element analysis was performed on Invar 36 and SUS 304 supports which are fixed on the platform through ANSYS. In the ANSYS model, the boundary condition is set as that the platform is fixed on the ground and the support is bonded on the platform. Mesh setting is a trade-off between computation time and element quality. Too high element quality...
often results in a significant increase in computation time. Usually, an average element quality above 0.7 is a usable mesh and the meshes are shown in Figure 9. For two supports with the same structure and different materials, the horizontal modes are shown in Figure 9(a) and (b), and the horizontal Eigen-frequencies of the simulation are respectively $f_{\text{Invar 36}} = 191.4\text{Hz}$ and $f_{\text{304}} = 228.2\text{Hz}$.

Considering the magnetic effect of Invar 36, a hybrid support combining Invar alloy and carbon fiber/epoxy was proposed, as it is shown in Figure 7(b). The boundary conditions and mesh settings are the same as the other two supports. Invar 36 and carbon fiber/epoxy are bonded together. The length of Invar 36L is optimized through finite element analysis to obtain a higher Eigen-frequency. The relationship between L and the horizontal Eigen-frequency is shown in Figure 8. Both the Eigen-frequency and the thermal expansion are considered and L is set to be 230 mm. As shown in Figure 9, the horizontal Eigen-frequency of the hybrid support is 609.0 Hz.

**Test**

Test on Eigen-frequency (vibration mode), vibration response and dynamic stiffness are performed on the three supports to verify the mechanical stability.

**Experimental instruments and experimental method**

The instruments used in the experiment include a data collector and three types of sensors. The three types of sensors are shown in Figure 9. Piezoelectric acceleration sensor in Figure 10(a) has a sensitivity of $10\text{mV} \cdot \text{s}^2/\text{m}$, a range of $\pm 500 \text{m/s}^2$ and a frequency range of 0.5–7000 Hz. It can measure acceleration in three directions perpendicular to surfaces. The hammer in Figure 10(b) has a sensitivity of $0.94 \text{mV/N}$ and a range of 5000 N. When hitting an object with it, the force signal will be obtained. Piezoelectric speed sensor and integrator are shown in Figure 10(c). The black cube is a piezoelectric speed sensor with a sensitivity of $20\text{mV} \cdot \text{s}/\text{mm}$, a range of 0.125 m/s and a frequency range of 1–100 Hz. The gray box is an integrator and...
integrates the velocity signal obtained by the piezoelectric speed sensor into the displacement signal.

Three supports with the structure shown in Figure 7(a) and (b) are fixed on the bench of HALF magnet support platform, as it is shown in Figure 11(a) to (c).

Tests on vibration mode, contact stiffness and vibration response are conducted on the three supports. Fix two piezoelectric acceleration sensors on the red points in Figure 7 and hit the free end with the hammer. Vibration mode is measured through the frequency response of the acceleration signal to the force signal. Fix the piezoelectric speed sensor and piezoelectric acceleration sensors on the blue points and red points. Tapping on the free end, the acceleration signal and the displacement signal obtained by integrating the velocity signal are measured and contact stiffness is calculated by equation (13).

$$m \ddot{z} = K_z \cdot z$$ (13)

Fix the piezoelectric speed sensors on the blue points in Figure 7 and on the ground. After integration by the integrator, the displacement signals of the platform surface and the top of the bracket will be obtained.

**Test on vibration mode**

Figure 12 shows frequency response and coherence of the acceleration signal to the force signal at measurement points of the three supports. Each figure contains eight curves: vertical and horizontal frequency response and coherence curves of two points. The coherence of the frequency response (red lines) is approximately 1, which proves that the response curve is less affected by external interference and the result is reliable. The peak frequency of the frequency response curves (blue lines) represents the Eigen-frequency in the direction. The experimental results show that the hybrid support has a higher horizontal Eigen-frequency than the other two supports and the SUS 304 support has a higher horizontal Eigen-frequency than the Invar 36 support. The Eigen-frequencies of the three supports are listed in Table 3.

**Figure 10.** Experiment instruments used in this article: (a) piezoelectric acceleration sensor, (b) hammer, and (c) piezoelectric speed sensor and integrator.

**Figure 11.** Supports for BPM displacement measurement system: (a) SUS 304 support, (b) Invar 36 support, and (c) hybrid support.
**Test on contact stiffness**

The errors between the experimental Eigen-frequencies and the simulation results are shown in Table 3. The errors are mainly due to the defect of the connection between the supports and platform. The difference between the undesirable connections and the ideal boundary conditions in ANSYS leads to the errors.28 After measurement, we obtained the contact stiffness of between the three supports and the platform, as shown in Table 3. Substituting the normal contact stiffness into the ANSYS, a more accurate Eigen-frequency will be obtained, as shown in Figure 13.

We can see that for each support, the corrected simulation horizontal frequency is slightly smaller than the experimental result. This is mainly because the piezoelectric speed sensor in Figure 10(c) is fixed at the top of the support when measuring the contact stiffness, which reduces the Eigen-frequency of the support.

**Test on vibration response**

HALF requires beam orbit stability to be less than 200 nm in vertical and 500 nm in horizontal. After calculation, it is found that the stability of the supports should be less than 36.88 nm in vertical and 45.85 nm in horizontal.

Figures 14 and 15 shows the vibration PSD and transfer functions of three supports in the vertical and horizontal directions. Figure 14(a) to (c) are the horizontal vibration PSD of the top of the hybrid support, the SUS 304 support, Invar 36 support, and the ground, respectively. Figure 14(d) is the ratio of the vibration amplitude of the top of the support to the amplitude of the ground at different frequencies. The Invar 36 support (the orange curve) has a larger amplification of the ground vibration at 20 Hz, and the amplification of the ground vibration at 60–100 Hz is also larger than the other two supports. The amplification of the ground vibration by the hybrid support (the green curve) is slightly smaller than that of the SUS 304 support. The horizontal rms vibration amplitudes of the three supports are shown in Table 4. The horizontal vibration amplitude of Invar 36 support is much larger than the other two supports and the horizontal vibration amplitude of the hybrid support is slightly smaller than that of the SUS 304 support, which is consistent with the relationship shown in the vibration PSD in Figure 14.

Furthermore, Figure 15(a) to (c) are the vertical vibration PSD of the top of the hybrid support, the SUS 304 support, Invar 36 support, and the ground, respectively. Figure 15(d) is the ratio of the vibration amplitude of the top of the support to the amplitude of the ground at different frequencies. At the peak point around 20 Hz, the hybrid support has less amplification of the vertical ground vibration than the other two supports.
supports. In general, the responses of the three supports in the vertical direction to ground vibration are similar. The vertical rms vibration amplitudes of the three supports are also identical.

**Discussion**

The horizontal Eigen-frequencies of the three supports are 208.0 Hz for SUS 304 support, 174.8 Hz for Invar 36 support, and 579.1 Hz for hybrid support. With the correction of contact stiffness, the simulation results fit well with the experiment results. The horizontal Eigen-frequencies of the three supports are higher than the main energy range of the ground vibration and avoid the peak frequency of the ground vibration. The hybrid support has smaller vibration amplitude and amplification factor in both horizontal and vertical direction. The vibration amplitude of the hybrid support is 42.6 nm in horizontal and 29.9 nm in vertical, which meets the HALF’s stability requirements of 45.85 nm in horizontal and 36.88 nm in vertical. Better stability will be obtained on HALF treated foundation.

**Figure 12.** The frequency response and coherence of the three supports: the blue lines represent the frequency response acceleration signal to force signal, and the red lines represent the coherence function curve of the two signals: (a) the support with SUS 304, (b) the support with Invar 36, and (c) the hybrid support with Invar 36 and carbon fiber.

**Figure 13.** Corrected FEA modal simulation of the three supports: (a) SUS 304 support, (b) Invar 36 support, and (c) hybrid support.
Figure 14. Horizontal vibration PSD and horizontal transfer function: (a) horizontal vibration PSD of the SUS 304 support and the ground, (b) horizontal vibration PSD of the Invar 36 support and the ground, (c) horizontal vibration PSD of the hybrid support and the ground, and (d) The ratio of the horizontal vibration amplitude of the three supports relative to the ground.

Figure 15. Vertical vibration PSD and vertical transfer function: (a) vertical vibration PSD of the SUS 304 support and the ground, (b) vertical vibration PSD of the Invar 36 support and the ground, (c) vertical vibration PSD of the hybrid support and the ground, and (d) The ratio of the vertical vibration amplitude of the three supports relative to the ground.
In conclusion, we study on the support for BPM displacement measurement system of the fourth-generation diffraction-limited storage ring. By means of FEA, the effect of Invar 36 on the magnetic field and the difficulty in carbon fiber processing are avoided and the low thermal expansion of Invar 36 and carbon fiber/epoxy are fully taken advantage of. And theoretical calculations and experiments prove that the hybrid support has higher thermal and mechanical stability and can meet the requirements of HALF.

Conclusion

In this article, a model of the support for BPM displacement measurement system is established and the factors affecting the stability of the support are analyzed. Through simulation and experiment, the commonly used support materials in synchrotron accelerator are studied from the perspective of thermal stability and mechanical stability. A hybrid support with Invar 36 and carbon fiber/epoxy was proposed and designed. Experimental results indicate that the support can meet the requirement of HALF. Compared with the other two supports, it has higher thermal and mechanical stability. In addition, this article also provides feasible suggestions and references for the design and material selection of supports in the fourth-generation accelerator.

Declaration of conflicting interests

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Table 4. Vibration amplitude of the three supports.

|                  | Horizontal (nm) | Vertical (nm) |
|------------------|-----------------|---------------|
| Ground           | 27.1            | 29.8          |
| Invar 36 and carbon fiber | 42.6            | 29.9          |
| 304              | 44.6            | 29.9          |
| Invar 36         | 55.2            | 30.1          |

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