Effect of Slider Spacing on Static Deformation and Spacing Selection for the Crossbeam of a Fixed Beam Gantry Machine Tool

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Abstract: A trade-off arises between static deformation and the space occupied by the moving assembly when the slider spacing of a fixed beam gantry machine tool is increased. This study compares six center-to-center slider spacings from 300 to 800 mm for a gray cast iron crossbeam and its guideway-slider assembly. The crossbeam is 3600 mm long, with an external cross-sectional envelope of 800 mm × 800 mm. Upper legend limits are extracted as peak readings from resultant-displacement contours obtained under the same nominal loading and restraint conditions. Displacement changes, incremental benefits between adjacent configurations, and the associated assembly envelope penalties are examined. For spacings of 300, 400, 500, 600, 700, and 800 mm, the peak readings are approximately 79.23, 79.23, 77.26, 75.63, 74.10, and 74.10 μm, respectively. Increasing the spacing from 300 to 700 mm reduces the reading by approximately 6.47%; increasing it further to 800 mm produces no additional improvement at the current display precision. A spacing of 700 mm is a preferred preliminary candidate for balancing a low deformation response against assembly width under the analyzed conditions. The 600 mm configuration reduces the spacing by 100 mm relative to the 700 mm configuration, at an additional peak reading of approximately 1.53 μm, and is an alternative where space constraints are more restrictive. A discrete selection method is also established to choose a smaller spacing while satisfying a displacement limit. The findings apply to the present load position, connection model, and restraints. Final selection should also consider actual travel and the machine accuracy allocation.

Keywords: fixed Beam Gantry Machine Tool; Crossbeam; Slider Spacing; Static Deformation; Finite Element Analysis

1. Introduction

The crossbeam of a fixed beam gantry machine tool supports the guideways, saddle, and spindle assembly. Its load-induced deformation is transmitted through the guidance system to the moving components and affects the relative position of the tool and workpiece. Crossbeam design must control global bending and local deformation while providing sufficient space for the moving assembly. Once the main cross-section and mounting boundaries have been established, changing the slider arrangement changes where loads enter the crossbeam and provides a direct parameter adjustment for assembly design selection.

Previous studies have examined machine tool performance in terms of structural parameters, overall loading, and joint characteristics. Lu et al. [1] used a variable-section beam model and finite element analysis to investigate crossbeam modes and the effects of structural parameters, showing that configurations in different crossbeam regions should be assessed in relation to their response characteristics. Chan et al. [2] conducted finite element analysis, structural optimization, and static stiffness experiments on a gantry machine tool, highlighting the importance of relating numerical predictions to the response of the actual structure. Hung et al. [3] incorporated guideway interface stiffness into a milling machine model and investigated dynamic responses and machining stability under different preload conditions, demonstrating the influence of guideway joints on assembly performance. These studies provide a basis for modeling and evaluating crossbeams and guidance systems.

Slider spacing and cross-sectional dimensions are design variables at different structural levels. Increasing the spacing does not directly change the beam material or the second moment of area, but changes the positions at which slider loads act and the assembly width of the moving

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components. A small spacing introduces the loads over a relatively narrow region. A large spacing requires matching components, such as the carriage plate and connectors, to occupy a greater length along the crossbeam, potentially reducing the available travel. Spacing selection should therefore establish both whether deformation is effectively reduced and whether the associated spatial penalty is justified.

This study investigates a crossbeam for a fixed beam gantry machine tool by comparing static resultant-displacement responses at six center-to-center slider spacings. Displacement changes and incremental benefits between adjacent configurations are analyzed under the same operating condition. A discrete selection method is then formulated with the moving assembly envelope width as a geometric constraint. The aim is to provide a traceable basis for spacing selection within the current design range. A single static response metric is not treated as a comprehensive assessment of machine performance.

2. Research Object and Simulation Methods

2.1 Crossbeam Structure and Spacing Configurations

Figure 1 shows the main crossbeam dimensions and slider arrangement. The crossbeam is 3600 mm long and has an external end-section envelope of 800 mm × 800 mm. Two parallel guideways are mounted on its front face, one above the other. Each guideway carries two sliders, giving four sliders in total. The longitudinal center-to-center distance between the two sliders on the same guideway is denoted by L, with corresponding arrangements on the upper and lower guideways. Thus, L denotes the slider center spacing along the crossbeam; it is neither the spacing between the upper and lower guideways nor the crossbeam support span.

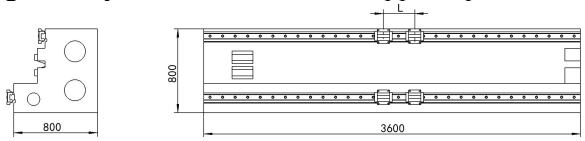
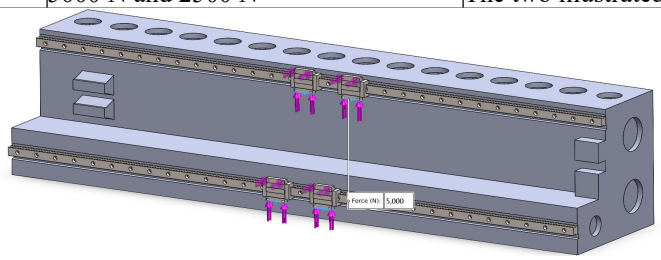


Figure 1. Main Crossbeam Dimensions and Definition of the Slider Center Spacing L

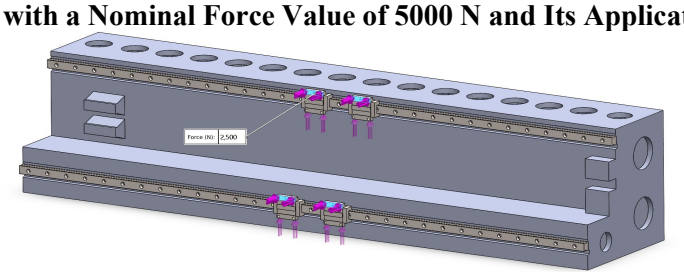
Six configurations are defined at L = 300, 400, 500, 600, 700, and 800 mm, using a 100 mm increment while retaining the same main crossbeam structure, number of sliders, and nominal loading conditions. Each configuration uses the illustrated slider arrangement near the middle of the crossbeam to compare the effect of spacing on the static response at this position.

Table 1. Geometric Parameters and Comparison Configurations

Parameter	Value or configuration	Description
Crossbeam length	3600 mm	Main beam length
Cross-sectional envelope	800 mm × 800 mm	Envelope definition shown in Figure 1
Crossbeam material	Gray cast iron	Main beam material category
Guideways and sliders	2 guideways and 4 sliders	2 sliders on each guideway
Center spacing L	300, 400, 500, 600, 700, 800 mm	Along the crossbeam length
Minimum element size	1.5 mm	Minimum size in the mesh settings
Nominal load-set values	5000 N and 2500 N	The two illustrated external load sets



(a) Load Set with a Nominal Force Value of 5000 N and Its Application Regions



(b) Load Set with a Nominal Force Value of 2500 N and Its Application Regions

Figure 2. Applied Loading

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2.2 Load Transfer and Boundary Conditions

Loads are applied to selected surfaces of the four sliders. The original setup contains two load sets with nominal force values of 5000 N and 2500 N; their application surfaces and directions are shown in Figure 2. The same load sets and direction definitions are used for all six spacing configurations to compare the structural response caused by changes in load application positions. The multiple arrows indicate loading directions over the selected regions; their number is not used to calculate the total applied force. The software distinguishes between distributing a total force over multiple selected entities and applying a force to each entity [4]. The resultant applied load should therefore be established from the load definitions and their balance with the support reactions.

Support restraints are imposed on the lower mounting regions near both ends of the crossbeam. Their positions are indicated by green symbols in the displacement contours presented below. The same support regions and restraint types are retained in all configurations to suppress overall rigid-body motion and provide consistent comparison boundaries. This study considers the static response under the present assembly restraint model. The effects of the actual columns and connection interface compliance on the overall machine response should be evaluated further in an assembly model.

2.3 Materials and Mesh Generation

The main crossbeam is made of gray cast iron. In an elastic static analysis using displacement as the response metric, Young's modulus and Poisson's ratio affect structural compliance. If gravity is included, material density also contributes to the applied loading. Material assignments and connection models should be consistent across the spacing configurations so that differences primarily reflect changes in slider arrangement.

Figure 3 shows the model mesh. The minimum element size specified in the original mesh settings is 1.5 mm. The mesh covers the crossbeam, guideways, and sliders, with a denser distribution of elements around the guideways and sliders. The minimum size describes only the local mesh control range and does not, by itself, demonstrate convergence of the displacement results. Because the differences between adjacent candidates are on the micrometer scale, spacing selection should be checked against mesh convergence of the response of interest.

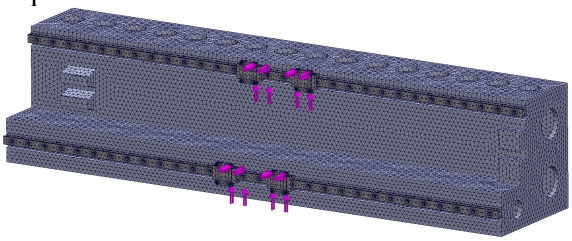

Figure 3. Mesh of the Crossbeam and Guideway-Slider Assembly

2.4 Response Metrics and Data Processing

The contour output is URES, the nodal resultant displacement [5]. In terms of the three displacement components, it is defined as

$$u_{res}=\sqrt{u_x^2+u_y^2+u_z^2} \quad (1)$$

where u_x, u_y, and u_z are the displacement components in the three coordinate directions. Resultant displacement is a nonnegative scalar and cannot be equated directly with vertical deflection or an error in a particular machining direction.

The upper legend limits of the six resultant-displacement contours are used as peak readings, denoted by u_p, and converted to μm. A peak reading equals the maximum resultant displacement within the displayed model only if the upper color-scale limit is set automatically to the actual maximum. A manually defined limit changes this correspondence [6]. Identical readings between configurations indicate that no difference is resolved at the current legend display precision; they do not establish that the underlying nodal values are exactly equal.

Taking the 300 mm configuration as the reference, the relative reduction in the peak reading, η, is defined below. The reading difference between adjacent configurations, Δu, measures the incremental benefit of increasing the spacing by 100 mm:

$$\eta(L)=\frac{u_p(300)-u_p(L)}{u_p(300)}\times 100\% \quad (2)$$

$$\Delta u_i=u_p(L_i)-u_p(L_i+100) \quad (3)$$

Both metrics are based on peak readings under the same operating condition; no unverified load-displacement stiffness values are constructed. Because the load application points and the location of the maximum may change with L, a change in the reciprocal peak reading does not directly represent a change in the beam material stiffness or cross-sectional bending

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rigidity.

3. Effect of Slider Spacing on Static Deformation

3.1 Resultant Displacement Distribution

Figure 4 presents resultant-displacement contours for three representative spacings of 300, 600, and 700 mm. In each configuration, higher resultant displacements occur near the middle of the crossbeam and in the slider load input regions, while displacements near the supports are lower. High-value regions are particularly evident around the sliders on the upper guideway, suggesting that the maximum in the present assembly model may reflect the combined compliance of the sliders, guideways, and adjacent beam body. To identify the response of the crossbeam itself, results for beam-body nodes should be extracted separately using a consistent postprocessing procedure.

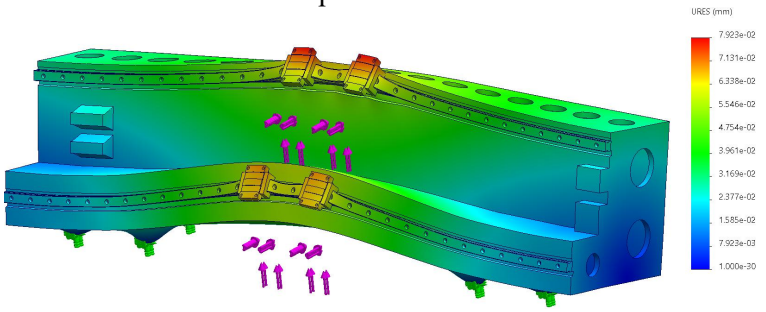

Figure 4a. Resultant Displacement Contour at L = 300 mm

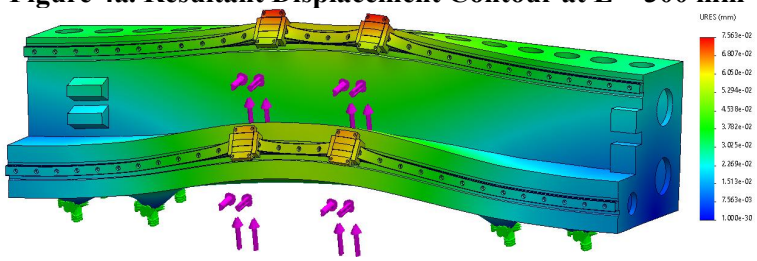

Figure 4b. Resultant Displacement Contour at L = 600 mm

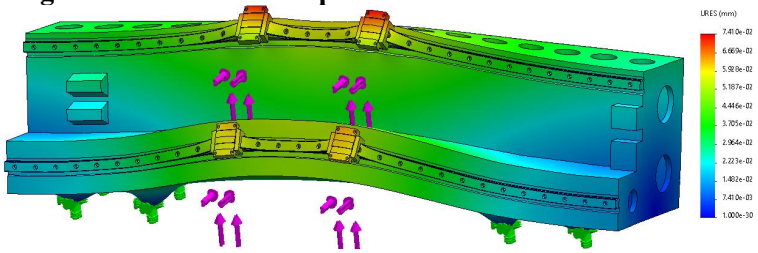

Figure 4c. Resultant Displacement Contour at L = 700 mm

Note: Figure 4 retains the original color scales. The same color on different scales does not necessarily represent the same displacement. The displayed deformed shapes should not be used to measure actual deflection from image proportions.

As the slider spacing increases, the central load input region extends along the crossbeam, changing the displacement distribution near the guideways. Each contour retains its original color scale, and quantitative comparisons are based on the readings in Table 2. The exaggerated deformed shapes help identify response locations, but cannot replace actual displacement components, changes in guideway straightness, or tool-to-workpiece errors.

3.2 Peak Readings and Incremental Benefits

Table 2. Peak Resultant-Displacement Readings and Derived Metrics for Different Slider Spacings

Spacing L (mm)	Peak reading (mm)	Peak reading (μm)	Reduction relative to 300 mm (%)	Reduction from preceding configuration (μm)
300	0.07923	79.23	0.00	—
400	0.07923	79.23	0.00	0.00
500	0.07726	77.26	2.49	1.97

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600	0.07563	75.63	4.54	1.63
700	0.07410	74.10	6.47	1.53
800	0.07410	74.10	6.47	0.00

Three response intervals can be identified. Between 300 and 400 mm, both peak readings are 79.23 μm, with no improvement resolved at the current display precision. Between 400 and 700 mm, increasing the spacing reduces the readings successively to 77.26, 75.63, and 74.10 μm. Between 700 and 800 mm, both readings are 74.10 μm, showing no additional deformation benefit from the larger spacing. The results therefore support screening of the discrete configurations, but do not justify extrapolation to uncomputed spacings.

Overall, increasing the spacing from 300 to 700 mm reduces the peak reading by 5.13 μm, or approximately 6.47%. For the adjacent increments of 400→500, 500→600, and 600→700 mm, the reductions are 1.97, 1.63, and 1.53 μm, respectively. Thus, the benefit per additional 100 mm decreases across these three intervals. No further benefit is displayed from 700 to 800 mm, so the need for a larger spacing should be assessed using the original results at higher precision.

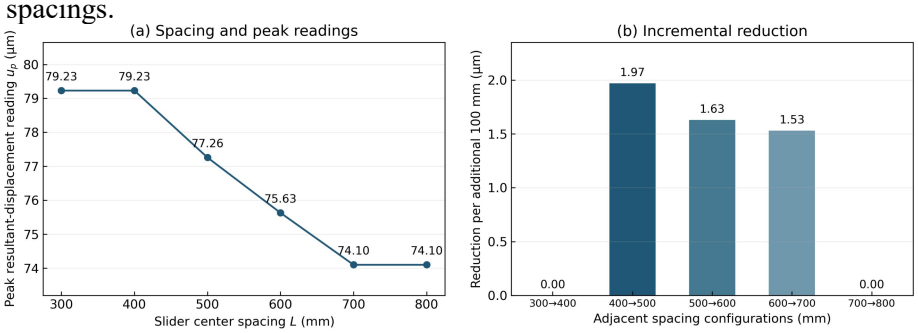

Figure 5. Peak Resultant-Displacement Readings Versus Slider Spacing and Incremental Benefits Between Adjacent Configurations

3.3 Mechanical Interpretation of the Deformation Changes

With the main material and cross-section unchanged, changing the slider spacing primarily changes the longitudinal positions at which external loads enter the crossbeam and their relationship to the local structure. A larger spacing spreads the load input regions and affects the superposition of beam bending, local guideway deformation, and deformation around the connections. Since the number of sliders does not increase, a lower displacement cannot simply be attributed to an increase in total contact area. Nor does it indicate a change in the Young's modulus or second moment of area of the gray cast iron crossbeam.

The high-value regions around the load input components also suggest that local assembly compliance may contribute substantially to the peak metric. Beyond a certain spacing, further changes in load position may have less influence on the current maximum. This explanation still requires verification using component-specific displacements of the beam and sliders, contact reactions, and directional displacement components. The existing contours support a description of the response trend, but cannot quantitatively separate the contributions of global bending, local deformation, and joint compliance.

4. Spacing Selection under Deformation and Travel Constraints

4.1 Geometric Relationship between Spacing and Envelope Width

Increasing slider spacing generally requires corresponding dimensions in the carriage plate, mounting plate, or connectors. To describe the spatial penalty, let b be the longitudinal length of an individual slider, and let m be the mounting allowance on each side beyond the outermost sliders. When these components determine the moving envelope, and b and m remain unchanged with L, the envelope width B satisfies the relationship illustrated in Figure 6:

$$B(L)=L+b+2m \quad (4)$$

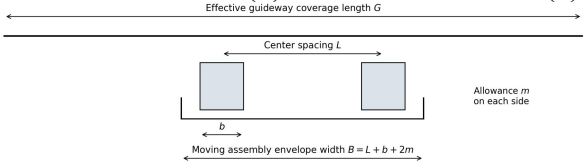

Figure 6. Geometric Relationship Between Slider Center Spacing and the Moving Assembly Envelope Width

Let G denote the effective guideway coverage length after accounting for guideway ends, travel limits, and interference requirements. Under the conditions of Equation (4), the available geometric travel is

$$S(L)=G-B(L) \quad (5)$$

The difference in travel between two spacing configurations is therefore

$$S(L_1)-S(L_2)=L_2-L_1 \quad (6)$$

Equation (6) states only that reducing the spacing can produce an equal gain in geometric travel when the component under consideration determines the envelope width and all other conditions remain unchanged. If the spindle head, guards, cable carrier, or other components govern the moving envelope, the actual travel benefit must be established by an assembly interference check. The 3600 mm crossbeam length cannot be substituted directly for G, and no absolute travel value can be established from it without checking the assembly.

4.2 Screening of Discrete Configurations

When both spacing and peak reading are treated as quantities to be minimized, configurations that offer no advantage in either metric can first be excluded. At the current readings, the 400 mm configuration has a larger spacing than the 300 mm configuration with the same peak reading. The same relationship holds between the 800 and 700 mm configurations. Neither larger-spacing configuration is preferred on these two metrics alone. The 300, 500, 600, and 700 mm configurations require further selection according to the allowable displacement and space constraints.

Table 3. Comparison of Deformation Response and Dimensional Penalties for the Spacing Configurations

Spacing L (mm)	Peak reading (μm)	Spacing reduction relative to 800 mm (mm)	Reading increase relative to 700 mm (μm)	Selection implication
300	79.23	500	5.13	Most compact configuration analyzed
400	79.23	400	5.13	No advantage over 300 mm at the current readings
500	77.26	300	3.16	Alternative if a larger displacement is acceptable
600	75.63	200	1.53	Alternative under tighter space constraints
700	74.10	100	0.00	Candidate where a low deformation response is prioritized
800	74.10	0	0.00	No advantage over 700 mm at the current readings

The 700 and 800 mm configurations share the same low peak reading at the current display precision. Since the 700 mm configuration has a spacing smaller by 100 mm, it is a preferred preliminary candidate where a low deformation response is required. Relative to 700 mm, the 600 mm configuration reduces the spacing by another 100 mm while increasing the peak reading by 1.53 μm, or approximately 2.06%. This comparison directly quantifies the displacement penalty of a more compact arrangement and helps determine whether an additional 100 mm of assembly width is necessary.

Accordingly, the 700 mm configuration should be checked first when a larger moving assembly envelope is acceptable and the aim is to obtain a low peak response within the present sample. The 600 mm configuration warrants further validation under tighter space constraints if an additional peak response of approximately 1.53 μm is acceptable. Spacings of 500 mm or less should not be rejected solely because their relative displacements are larger; their suitability still depends on the deformation limit allocated to this structure in the overall machine design.

4.3 Selection Based on an Allowable Displacement

To avoid assigning arbitrary weights when actual cost and travel requirements are unknown, a constrained selection approach is used: among the analyzed configurations, select the smallest spacing satisfying the allowable peak reading u_a and required travel S_{req}. Let the discrete spacing set D contain the six configurations of 300, 400, 500, 600, 700, and 800 mm. The selection criterion is

$$L^*= min \{ L \in D : u_p(L) \le u_a, S(L) \ge S_{req} \} \quad (7)$$

If only the displacement constraint is initially considered, Table 4 gives the discrete selection intervals based on the current readings. Here, u_a is a selection parameter for the present model and metric definition, and should be established from the actual accuracy allocation. It is neither a universal machine tool tolerance nor equivalent to overall positioning accuracy or tool-tip error.

In practice, u_a should first be established from the accuracy budget. A spacing candidate can

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then be selected from Table 4, followed by checks of the assembly envelope and available travel. If a smaller spacing satisfies all constraints, the assembly need not be enlarged further to meet the same displacement requirement. If none of the configurations satisfies both displacement and travel constraints, the local crossbeam structure, joint configuration, or other design variables should be modified. Because adjacent configurations differ only slightly, selection near a threshold should include a margin appropriate to numerical and manufacturing uncertainties.

Table 4. Discrete Selection Intervals Considering Only the Displacement Constraint

Allowable peak reading u_a (μm)	Smallest spacing satisfying the displacement constraint (mm)
$u_a < 74.10$	None of the six configurations satisfies the constraint
$74.10 \le u_a < 75.63$	700
$75.63 \le u_a < 77.26$	600
$77.26 \le u_a < 79.23$	500
$u_a \ge 79.23$	300

5. Scope of Applicability and Validation Requirements

The spacing conclusions apply to the illustrated load position and support arrangement. As the saddle moves along the crossbeam, the positions of the loads relative to the supports and local structure change, and the ranking of configurations may also change. Candidates identified under the present central loading condition should therefore be checked near both ends and at other representative working positions, together with loads in different feed directions, spindle extension, and actual gravity conditions.

The peak resultant displacement is an overall response metric for the assembly model. A formal design assessment should additionally extract displacement components for the beam body, guideway mounting surfaces, and moving assembly, and, where necessary, evaluate moving assembly orientation and tool-to-workpiece errors. For the gray cast iron beam, displacement comparisons do not replace the corresponding stress and strength checks. Guideway load ratings, contact distributions, and preload compatibility also require separate verification.

The 600 and 700 mm candidates differ by only 1.53 μm. Exporting the original maximum values, checking mesh convergence, and assessing joint sensitivity therefore directly affect the conclusion. Both candidates should be evaluated using consistent high-precision output and mesh control, with comparisons of beam-body displacement, slider displacement, and support reactions. Static load tests should also be conducted when a prototype or component becomes available. Final spacing selection should be based on these comparisons only when the difference between candidates exceeds the acceptable numerical uncertainty and the actual travel requirement is satisfied.

6. Conclusions

(1) Under the same nominal loading, supports, and assembly model, the peak readings from the resultant-displacement contours are approximately 79.23, 79.23, 77.26, 75.63, 74.10, and 74.10 μm at slider center spacings of 300, 400, 500, 600, 700, and 800 mm, respectively. Increasing the spacing from 300 to 700 mm reduces the reading by approximately 5.13 μm, corresponding to a relative reduction of approximately 6.47%.

(2) From 400 to 700 mm, the reductions in the reading for each additional 100 mm are 1.97, 1.63, and 1.53 μm, respectively. Between 700 and 800 mm, no additional reduction is resolved at the current display precision. A spacing of 700 mm is therefore a preferred preliminary candidate for combining a low deformation response with a smaller assembly width under the present operating condition. This preference is limited to the discrete configurations analyzed.

(3) Compared with the 700 mm configuration, the 600 mm configuration reduces the spacing by 100 mm and increases the peak reading by approximately 1.53 μm, or approximately 2.06%. It is an alternative where space constraints are more restrictive. If the slider-related components determine the moving envelope and other dimensions remain unchanged, reducing the spacing can produce an equal gain in geometric travel. Actual machine travel must still be checked against interference and travel limits.

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