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Comparative evaluation of milling machine tooling fixtures using finite geometry and finite element methods

Stephen Takim*, Ayantunji S.A

Department of Mechanical Engineering, University of Cross River State (UNICROSS), Nigeria

ARTICLE INFO	ABSTRACT
<i>Article history:</i> Received 15 August 2026 Received in revised form 19 September 2026 Accepted 09 October 2026 Keywords: Fixture design, Finite element analysis, Finite geometry, Kinematic stability index, Milling machine, Tooling fixture *Corresponding author Email address: xamskye@gmail.com DOI: 10.55670/fpjl.fdtai.2.2.4	Fixture layout directly affects workpiece stability during milling, but checking several possible locator arrangements with finite element analysis can be time-consuming, especially at the initial design stage. This study examines a milling machine angle plate fixture using a two-stage Finite Geometry (FG) and Finite Element Analysis (FEA) procedure based on the 3–2–1 locating principle. Three locator configurations were developed from the fixture geometry and first assessed using finite geometry. The Effective Support Area and Kinematic Stability Index (KSI) were used to assess the geometric stability of each arrangement, with MATLAB used to carry out the required geometric calculations. The KSI values obtained for Configurations 1, 2, and 3 were 0.01214, 0.01033, and 0.00772, respectively. Configuration 3 was consequently selected for structural assessment. The selected configuration was then analyzed in ANSYS Mechanical under a 10 kN distributed machining load. A maximum von Mises stress of 48.322 MPa and a maximum deformation of 0.015394 mm were obtained. The results show that the geometric assessment provided a means of screening the three locator arrangements before the more detailed finite element analysis was carried out. The study therefore demonstrates the use of FG as a preliminary assessment stage, followed by FEA for structural verification of the selected fixture configuration.

1. Introduction

A machining fixture holds the workpiece in a known position during machining. The arrangement of the locating and clamping elements determines how the workpiece is restrained and how it responds to the forces generated during machining. Previous studies have shown that changes in fixture-element positions can affect workpiece deformation and, in turn, machining accuracy [1-3]. The fixture layout therefore becomes important when more than one locator arrangement is possible. When several locator arrangements are possible, deciding which one to use is not always straightforward. Two layouts may satisfy the same basic locating requirements but behave differently under machining loads. In practice, fixture development often involves repeated changes to locator and clamp positions before a suitable arrangement is found. Computational methods allow comparison of these alternatives before committing to a final layout. Researchers have used finite element methods to examine fixture-workpiece behavior and the effects of locating and clamping positions [2-5]. Other studies have combined finite element analysis with response surface methods and evolutionary algorithms to further improve fixture layouts [6].

Researchers have also used numerical methods to compare and optimize fixture layouts. Qazani et al. [7] investigated fixture-locating layouts for end milling and examined how fixture-element positions affected workpiece deformation. Ramesh et al. [8] combined finite element data with artificial neural networks, particle swarm optimization, and evolutionary techniques to identify suitable fixture layouts. Liu and Sun [9] used a genetic algorithm with finite element analysis for fixture-layout optimization, while Liu et al. [10] developed an evolutionary method to optimize the clamp and support-head arrangement of a thin-walled workpiece. These studies show the value of computational methods in reducing trial and error during fixture development. At the same time, using several optimization techniques can make the evaluation process more complex, especially when many possible layouts must be considered.

Finite element analysis helps examine how a fixture-workpiece system responds to specified machining and clamping loads. For example, Subramanian et al. [11] used ANSYS to evaluate fixture layouts and predict elastic deformation under machining and clamping forces. Feng et al. [12] examined the contact behavior between the workpiece and fixture, showing the importance of appropriate contact modeling in fixture analysis. Li et al. [13] also reported that clamping force during machining depends on the interaction among workpiece geometry, clamping conditions, and cutting forces. More recent studies have considered the dynamic behavior of fixture-workpiece systems and combined finite element modeling with optimization techniques [14,15]. While these approaches provide detailed structural information, applying them to many alternative layouts can increase the computational effort required during the early stages of fixture design.

This has led to greater use of methods that can reduce the number of candidate configurations before detailed structural analysis. Recent studies have examined computer-aided fixture design, heuristic optimization, particle swarm optimization, and other computational approaches for this purpose [16-18]. Liu et al. [16] reviewed fixture-layout optimization and identified problem formulation, deformation modeling, and optimization as key stages of the process. They also noted that mechanism-based models can provide accurate results but may require considerable computation for large layout problems. Liu et al. [17] used an improved particle swarm optimization method to determine suitable layouts for large thin-walled parts, while Feng et al. [18] investigated fixture-point arrangements for reducing machining deformation. Other studies have examined reduced-support layouts and finite-element-based optimization to improve machining stability [19,20]. Related mechanical design studies have also applied analytical methods, CAD modeling, and performance assessment in the development of engineered systems. Nwadinobi et al. [21] combined kinematic analysis and CAD modeling to develop a six-degree-of-freedom robotic arm, while Takim et al. [22] applied mechanical design and performance evaluation to develop a motorized palm fruit stripper. These studies further demonstrate the use of analytical and design-based approaches in developing and assessing mechanical systems.

Previous studies have applied finite element analysis and optimization methods to investigate fixture layouts, particularly their effects on workpiece deformation and stability [2-5]. These methods provide useful information about the structural behavior of fixture-workpiece systems, but evaluating several possible locator arrangements through detailed numerical analysis can increase the computational effort required during fixture design [6-10]. In this study, Finite Geometry (FG) is first used to examine the proposed locator arrangements before FEA is carried out on the selected configuration. The Effective Support Area and Kinematic Stability Index (KSI) serve as geometric measures to compare the arrangements and determine which configuration should proceed with structural analysis. This creates a two-stage procedure in which the geometric characteristics of the fixture are assessed before the more detailed FEA. This work integrates geometric assessment and structural analysis into a single procedure for the milling fixture considered. Instead of performing FEA on all proposed configurations, the geometric results first select one arrangement for further analysis. The procedure is demonstrated using three locator configurations based on the 3–2–1 locating principle. In this workflow, FG serves as the initial screening stage, while FEA subsequently evaluates the structural response of the selected configuration. This arrangement allows the initial comparison to be completed before carrying out the more detailed structural analysis. In this work, we examine three configurations based on the 3–2–1 locating principle, using the KSI value to select the configuration for FEA. This study examines an angle plate milling machine tooling fixture using Finite Geometry (FG) and Finite Element Analysis (FEA). The specific objectives of the study were to:

- Develop and assess alternative locator configurations based on the 3–2–1 locating principle using finite geometry principles.
- Determine the most stable configuration using the Kinematic Stability Index (KSI).
- Validate the selected configuration through finite element analysis under machining loads.

The study uses FG to compare the three locator configurations at the preliminary stage and FEA to assess the structural response of the selected configuration.

2. Materials and methods

2.1 Development of the fixture model

A commercially available angle plate fixture was used for the comparison of the Finite Geometry (FG) and Finite Element Analysis (FEA) approaches. The three-dimensional Computer-Aided Design (CAD) model was obtained from the open-source “Angle Plate Fixture” model created by Mohamed Hussin Motwea [23], and published on GrabCAD in March 2025. The model was imported into ANSYS SpaceClaim and prepared for the subsequent FG and FEA work. The same fixture model was maintained for both analyses so that the locator configurations could be compared using the same geometry. Figure 1 shows the three-dimensional fixture model together with its main dimensions and orthographic views. The drawing indicates the principal dimensions of the fixture, including the overall length and width of the base, plate thickness, lug geometry, slot dimensions, and other relevant geometric features used to define the fixture model.

2.2 Finite geometry evaluation procedure

Three locator configurations were developed based on the 3–2–1 locating principle to investigate how changes in primary locator positions affect the fixture's geometric stability. The overall fixture geometry was kept unchanged, while the positions of the primary locator points were varied for each configuration. Configuration 1 was used as the initial arrangement. In Configuration 2, two primary locators were shifted closer to the fixture's center, while the third locator remained in its original position. In Configuration 3, one primary locator was moved to a different position toward the opposite side of the fixture, with the other two retaining positions used in Configuration 1. The three arrangements therefore provided different distributions of the primary support points while maintaining the same 3–2–1 locating principle. Their geometric characteristics were evaluated using the Effective Support Area (Ae), the distance between the machining force and the support centroid, and the Kinematic Stability Index (KSI). These parameters were used to assess the support region size and its position

relative to the applied machining force. The KSI served as the primary basis for comparing the configurations, where a lower value indicated more favorable geometric stability within this study's formulation. The coordinates for the three configurations are given in [Tables 1-3](#).

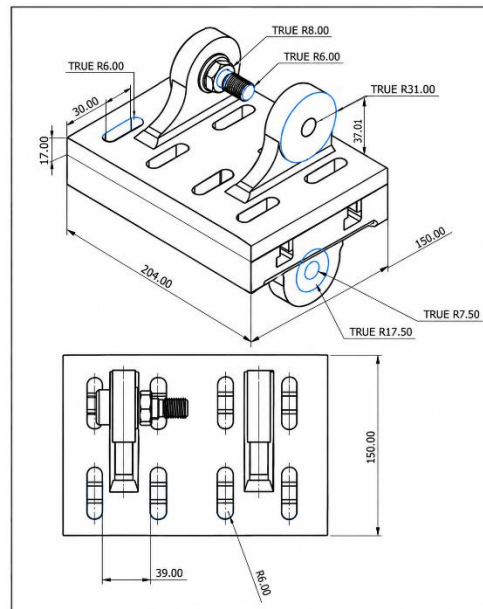


Figure 1. Geometric architecture and principal dimensions of the selected milling machine tooling fixture

Table 1. Configuration 1 - Recorded Locator Coordinates

Point	X (mm)	Y (mm)	Z (mm)
P1	0	85	96
P2	0	-85	96
P3	-34	-51	13.5

Table 2. Configuration 2 - Recorded Locator Coordinates

Point	X (mm)	Y (mm)	Z (mm)
P1	0	42	92
P2	0	-42	92
P3	-34	-51	13.5

Table 3. Configuration 3 - Recorded Locator Coordinates

Point	X (mm)	Y (mm)	Z (mm)
P1	-102	0	82.5
P2	0	85	96
P3	0	-85	96

The three configurations differ only in the positions of the primary locator points; the overall fixture geometry remains unchanged. In Configuration 1, P1 and P2 are located at $Y = \pm 85$ mm and $Z = 96$ mm, while P3 is at $(-34, -51, 13.5)$ mm. For Configuration 2, P1 and P2 are moved toward the central region of the fixture to $Y = \pm 42$ mm and $Z = 92$ mm, with P3 remaining at the same position. Configuration 3 uses a different arrangement, with P1 at $(-102, 0, 82.5)$ mm and P2 and P3 taking the positions previously occupied by P1 and P2 in Configuration 1. These changes provide three different locator distributions for comparing the Effective Support Area and Kinematic Stability Index.

2.3 Theoretical Analysis

The 3–2–1 locating principle was used to define the basic support arrangement of the workpiece. Three primary locators establish the main support plane, two secondary locators restrict movement in the next direction, and one tertiary locator provides the final positional constraint. For the present analysis, the primary locator positions were used to form the support region whose relationship with the machining force was then examined. The positions of the three primary locators were expressed using a three-dimensional Cartesian coordinate system. This representation allows us to describe the location of each support point and use the same coordinates in subsequent geometric calculations [2,5].

$$P_i = (x_i, y_i, z_i) \quad (1)$$

where:

P_i = coordinate position of the i^{th} locator point;

x_i , y_i , and z_i are the locator coordinates along the x-, y-, and z-axes, respectively.

The centroid of the triangular region formed by the three primary locator points was calculated from their Cartesian coordinates as:

$$C \left(\frac{x_1+x_2+x_3}{3}, \frac{y_1+y_2+y_3}{3}, \frac{z_1+z_2+z_3}{3} \right) \quad (2)$$

where:

C = centroid of the support triangle;

x_c , y_c , and z_c are the centroid coordinates.

The point at which the machining force was applied was also defined in the same coordinate system as:

$$F = (x_f, y_f, z_f)$$

where:

F denotes the machining force coordinates.

The distance between the force application point and the centroid of the support triangle was then obtained using the Euclidean distance between the two coordinate positions:

$$d = \sqrt{(x_f - x_c)^2 + (y_f - y_c)^2 + (z_f - z_c)^2} \quad (3)$$

where:

d = force-to-centroid distance;

(x_f, y_f, z_f) = machining force coordinates;

(x_c, y_c, z_c) = centroid coordinates.

The area of the support triangle alone does not fully describe the geometric condition of a locator arrangement because the positions of the support points relative to the machining force also matter. For this reason, an Effective Support Area (A_e) was determined for each configuration from its geometric characteristics using MATLAB-based finite geometry analysis.

The Kinematic Stability Index (KSI) was then used to combine the force-to-centroid distance with the Effective Support Area. The formulation used in this study is given as:

$$KSI = \frac{1+d}{A_e} \quad (4)$$

where:

KSI = Kinematic Stability Index;

d = force-to-centroid distance (mm);

A_e = Effective Support Area (mm²).

In this work, KSI is used as a comparative measure for the three proposed locator arrangements. It provides a common numerical basis for comparing their geometric stability and is not presented as a universal stability criterion for machining fixtures. The three configurations were compared using three geometric indicators: Effective Support Area (A_e), force-to-centroid distance (d), and Kinematic Stability Index (KSI). A_e describes the effective support provided by the locator arrangement, while d represents the distance between the machining force location and the centroid of the support region. KSI combines these quantities into a single value for comparison. In the present formulation, a lower KSI value corresponds to a more favorable geometric stability condition.

2.4 MATLAB-based determination of geometric stability parameters

The locator coordinates for the three configurations were entered into MATLAB as Cartesian coordinate data. MATLAB was used to define the support triangle from the three primary locator points and to determine the centroid and other geometric quantities required for the

comparison. The Effective Support Area (A_e) was obtained from the finite geometry calculations as the geometric measure used to compare the support provided by each locator arrangement (Table 4). The machining force location was then defined in the same global coordinate system, and its distance from the support centroid was calculated using the Euclidean distance. These geometric quantities were used to obtain the Kinematic Stability Index (KSI) for each configuration. The same calculation procedure was applied to all three configurations (Table 5).

Table 4. Effective support area obtained from finite geometry evaluation

Configurations	Effective Support Area, A_e (mm ²)
Configuration 1	9308.14
Configuration 2	10219.75
Configuration 3	12011.66

Table 5. Computed KSI values for the three configurations

Configuration	KSI Value
Configuration 1	0.01214
Configuration 2	0.01033
Configuration 3	0.00772

The KSI values indicate that the three locator arrangements have different geometric stability characteristics. Configuration 1 recorded a KSI of 0.01214, followed by Configuration 2 with 0.01033, while Configuration 3 produced the lowest value of 0.00772. Because the KSI relates the force-to-centroid distance to the Effective Support Area, the lower value obtained for Configuration 3 suggests a more favorable relationship between the applied machining force and the support region. This observation agrees with the other geometric results, as Configuration 3 provided the largest Effective Support Area of 12011.66 mm² and the smallest force-to-centroid distance of 172.93 mm. The KSI values were therefore used to compare the three locator arrangements before proceeding to the structural analysis. Configuration 3 was chosen for FEA because it produced the lowest KSI value and showed the most favorable geometric characteristics among the configurations examined. In this study, the KSI was not treated as a complete measure of fixture performance, but as a consistent parameter for screening and comparing the proposed arrangements. Based on this geometric assessment, Configuration 3 was carried forward to the FEA stage to evaluate its structural response under the specified machining load.

2.5 Finite element analysis procedure

Structural Steel was assigned to the fixture model using the material data available in ANSYS Engineering Data. The material properties used in the analysis were a density of 7850 kg/m³, Young's modulus of 200 GPa, Poisson's ratio of 0.30, yield strength of 250 MPa, and ultimate tensile strength of 460 MPa. These values were retained for the finite element analysis and are listed in Table 6.

Table 6. Material properties of structural steel used in the analysis

Property	Value	Unit
Density	7850	kg/m ³
Young's Modulus	200	GPa
Poisson's Ratio	0.3	—
Yield Strength	250	MPa
Ultimate Tensile Strength	460	MPa

The fixture model was meshed using a global body size, with additional local refinement applied around the upper lug holes and the lug root fillets. These regions were refined because they are close to the applied loading and are relevant to the stress response of the fixture. The resulting mesh is shown in Figure 2. A mesh refinement check was carried out by varying the local mesh size while keeping the body sizing at 8 mm. The resulting maximum von Mises stresses were compared to determine whether further refinement produced a meaningful change in the result. The mesh sizes and corresponding stress values are presented in Table 7.

2.6 Boundary conditions and loading conditions

Fixed supports were applied at the lower lug holes to represent the mounting points of the fixture. The support locations used in the ANSYS model are shown in Figure 3.

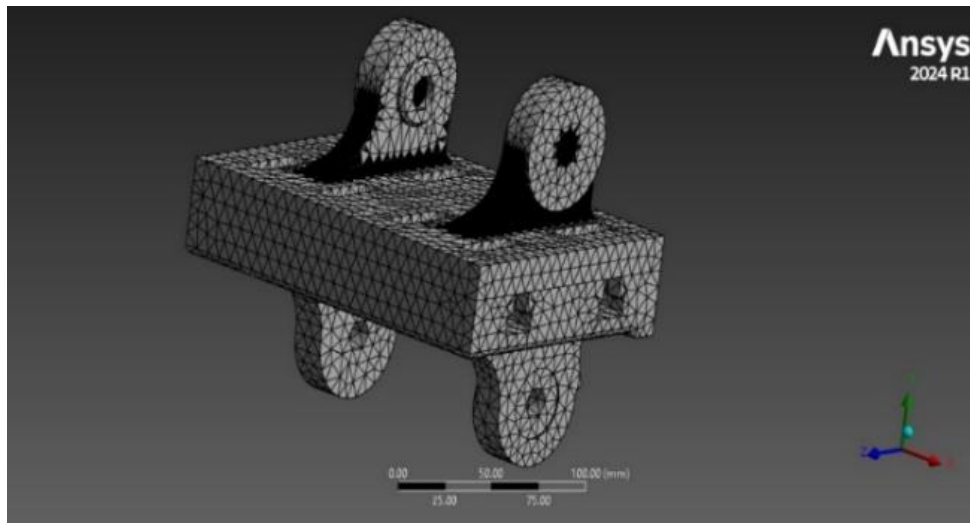


Figure 2. Discretized finite element mesh with local refinement

Table 7. Mesh convergence results

Body Sizing (mm)	Local Sizing (mm)	Maximum von Mises Stress (MPa)
8	2.0	48.297
8	1.5	48.305
8	1.0	48.322

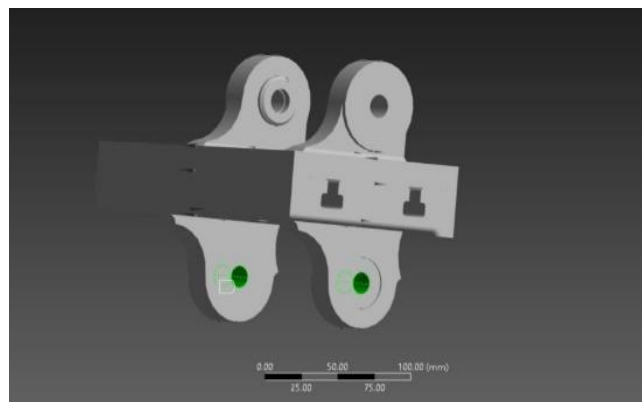


Figure 3. Fixed support boundary conditions applied at the lower lug holes

The free-body diagram in [Figure 4](#) shows the loading arrangement considered for the fixture. The total machining load was taken as 10 kN and represented by two equal 5 kN forces acting downward at the upper lug locations. The lower lug locations provide the supporting reactions required to restrain the fixture. The diagram is used to show the force and support arrangement before its implementation in the ANSYS model. For the ANSYS analysis, the 10 kN vertical machining load was applied at the two upper lug holes as two equal 5000 N forces. The resulting load distribution used in the numerical model is shown in [Figure 5](#).

The FEA was carried out as a static structural analysis, with the fixture material represented using the Structural Steel properties defined in ANSYS Engineering Data. The lower lug holes were treated as fixed support locations, while the machining load was represented by two equal vertical forces of 5000 N applied at the upper lug holes. The analysis was therefore based on the specified loading and support conditions, and the resulting deformation and von Mises stress were used to evaluate the structural response of the selected configuration.

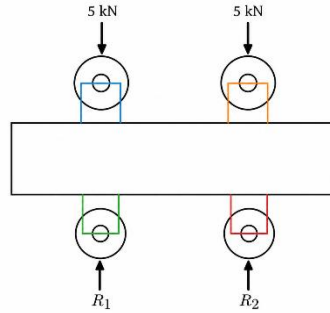


Figure 4. Free-body diagram of the milling fixture showing the two 5 kN applied forces and the support reactions at the lower lug locations

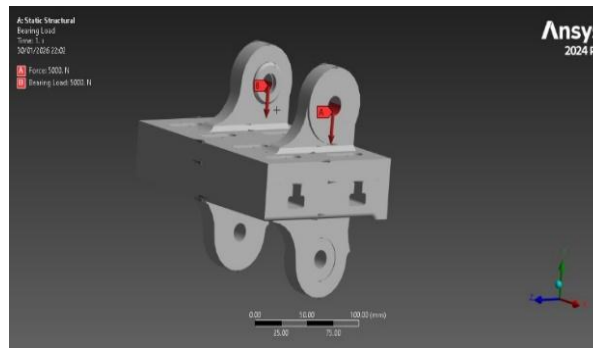


Figure 5. Distributed 10 kN machining load applied at the upper lug holes

2.7 Comparative evaluation procedure

The three locator configurations were compared using the geometric results from FG, while the selected configuration was assessed structurally using FEA. For the FG assessment, the Effective Support Area (A_e), force-to-centroid distance (d), and Kinematic Stability Index (KSI) were used as the main comparison measures. The KSI was calculated as:

$$KSI = \frac{1+d}{A_e} \quad (5)$$

where d is the distance between the machining force application point and the support centroid, and A_e is the Effective Support Area. Lower KSI values were interpreted as indicating more favorable geometric stability. For the FEA assessment, maximum deformation and maximum von Mises stress under the 10 kN machining load were used to describe the structural response. The selected configuration was therefore considered using both its geometric results from FG and its deformation and stress results from FEA.

The FG and FEA results were considered together to provide the overall assessment of the selected fixture configuration.

3. Results and discussion

3.1 Finite geometry analysis of locator configurations

Finite Geometry (FG) analysis was used to compare the three locator configurations developed from the 3–2–1 locating arrangement. The analysis considered the support region formed by the three primary locators and its position relative to the machining force. Table 8 summarizes the resulting geometric quantities and stability parameters for the three configurations. Configuration 3 gave the largest Effective Support Area, 12011.66 mm², compared with 10219.75 mm² for Configuration 2 and 9308.14 mm² for Configuration 1. The three support arrangements are shown in Figures 6–8. The difference in Effective Support Area provides one of the geometric measures used to distinguish the locator arrangements before the FEA stage.

Table 8. Summary of finite geometry metrics

Configuration	Triangle Area (mm ²)	Effective Support Area (mm ²)	Centroid Coordinates (mm)	Distance (Force → Centroid) (mm)
Configuration 1	7584.7	9308.14	(−11.33, −17.00, 68.5)	190.58
Configuration 2	3,593.3	10219.75	(−11.33, −17.00, 65.83)	188.12
Configuration 3	8,743.5	12011.66	(−34.00, 0.00, 91.50)	172.93

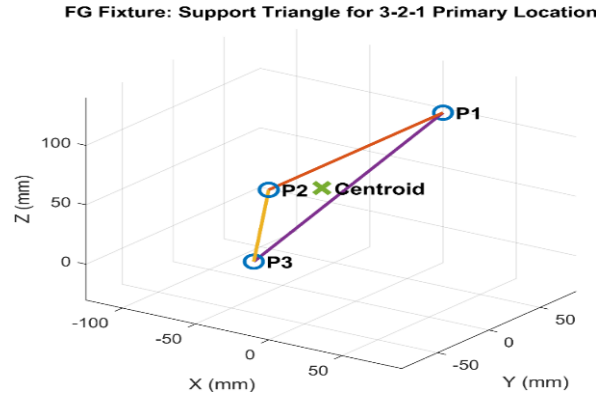


Figure 6. MATLAB 3D visualization of the measured locator coordinates (P1, P2, and P3) forming the primary support triangle

Figure 7 shows the three primary locator points used to define the support triangle. The plotted points form the triangular support region used in subsequent geometric calculations, and the centroid derived from these points was used to calculate the force-to-centroid distance. Configuration 2, including the machining force application point. Figure 7 and Figure 8 show the support regions for Configurations 2 and 3 together with the machining force location. Configuration 3 has a larger Effective Support Area and a shorter force-to-centroid distance than Configuration 2. These geometric differences are reflected in the KSI values reported in the next section, where Configuration 3 gives the lowest value among the three arrangements.

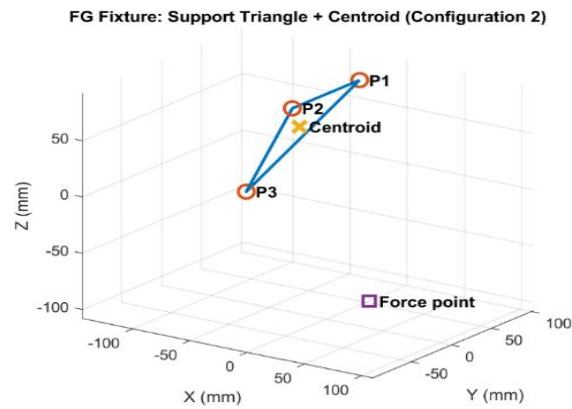


Figure 7. Geometric support area for Configuration 2, including the machining force application point

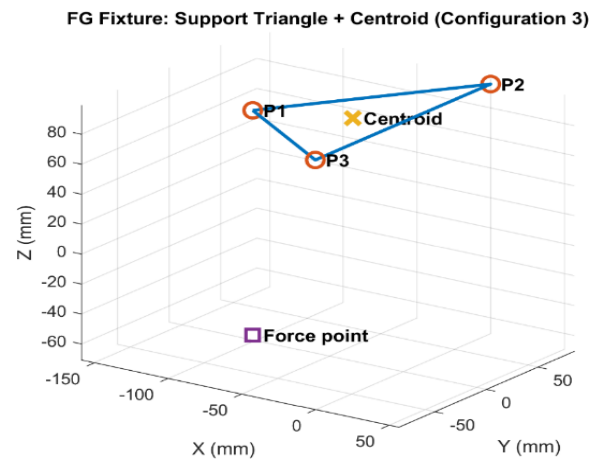


Figure 8. Geometric support area for Configuration 3 including the machining force application point

3.2 Analysis of kinematic stability index results

The Kinematic Stability Index (KSI) was used to compare the geometric stability of the three locator configurations. The Effective Support Area, support centroid coordinates, and KSI values obtained for each configuration are presented in Table 9. The KSI values decreased from 0.01214 for Configuration 1 to 0.01033 for Configuration 2 and 0.00772 for Configuration 3. Within the formulation used in this study, the lower value obtained for Configuration 3 reflects the combined effect of its Effective Support Area and the distance between the machining force location and the support centroid. Based on the KSI comparison, Configuration 3 was selected for the subsequent FEA, while Configuration 1 recorded the highest KSI value among the three arrangements. The results show that changing the locator positions affected the geometric parameters used in the stability assessment. The KSI calculation therefore provided the screening step used to select the configuration for structural analysis.

Table 9. Finite geometry results for all locator configurations

Configuration	Effective Support Area (mm ²)	Centroid Coordinates (mm)	KSI Value	Geometric Stability Ranking
Configuration 1	9308.14	(-11.33, -17.00, 68.5)	0.01214	Least Stable
Configuration 2	10219.75	(-11.33, -17.00, 65.83)	0.01033	Moderately Stable
Configuration 3	12011.66	(-34.00, 0.00, 91.50)	0.00772	Most Stable

3.3 Finite element analysis results

The configuration selected from the FG assessment was evaluated using FEA under a total machining load of 10 kN, applied as two equal 5000 N vertical forces at the upper lug holes. Table 10 summarizes the resulting maximum deformation and von Mises stress. The results indicate that the fixture experienced a maximum deformation of 0.015394 mm and a maximum equivalent von Mises stress of 48.322 MPa.

Table 10. Finite element results for selected configuration

Parameter	Result
Applied Load	10 kN Total
Load Type	Two equal 5000 N vertical downward forces at the upper lug holes
Maximum Deformation (mm)	0.015394 mm
Maximum von Mises Stress (MPa)	48.322 MPa
Structural Integrity	Maintained
Structural response	Acceptable
Critical stress location	Lug region / base

3.4 Total deformation

Figure 9 shows the total deformation obtained from the analysis. The maximum deformation of 0.015394 mm occurs near the applied machining load, while the constrained regions show little displacement. The deformation is concentrated around the loaded part of the fixture rather than the fixed support locations.

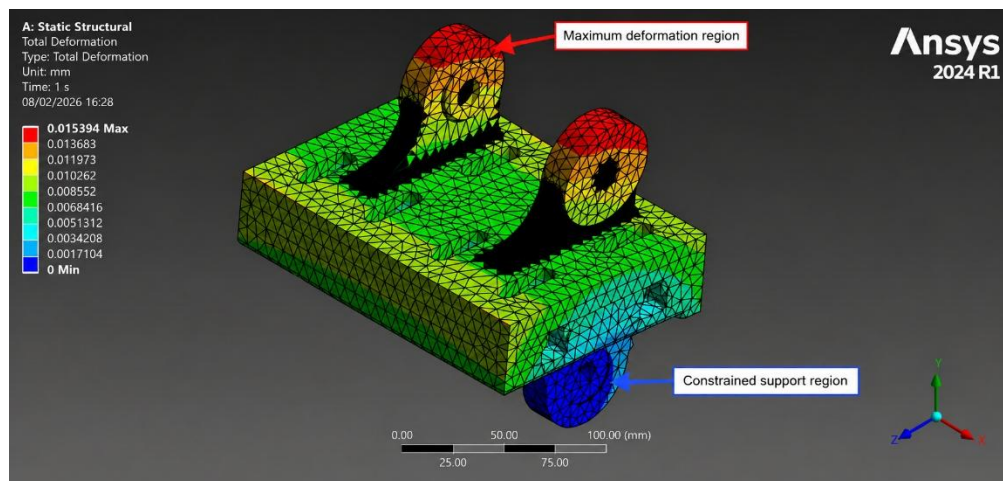


Figure 9. Total deformation contour of the angle plate fixture showing the maximum deformation region and constrained support regions

3.5 Stress distribution

Figure 10 shows the von Mises stress distribution obtained from the analysis. Higher stress regions occur around the lug area and the fixture base, where the structure transfers the applied load. The maximum von Mises stress was 48.322 MPa, which is below the 250 MPa yield strength used for the Structural Steel material in the analysis. The FEA results provide the structural response of the configuration selected from the finite geometry comparison.

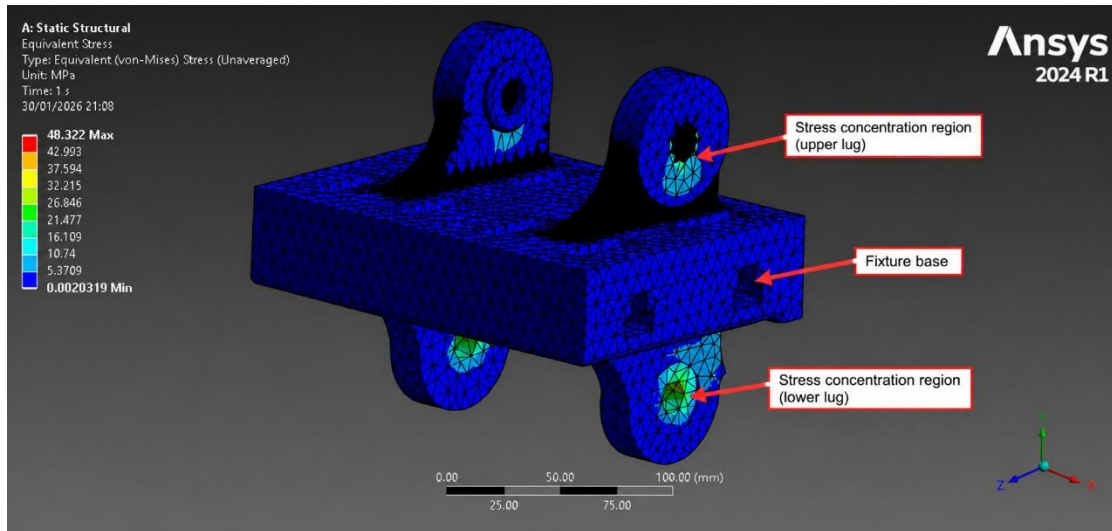


Figure 10. Von Mises stress distribution of the angle plate fixture showing the critical stress region around the lug and the fixture base

3.6 Comparative evaluation of finite geometry and finite element analysis

The FG and FEA results were considered together to show how the two stages contributed to the fixture assessment. FG was used to compare the three locator configurations, while FEA was applied to the configuration selected from that comparison. The main results from both stages are summarized in Table 11. The two methods were used at different stages of the analysis. FG was applied to all three configurations using the Effective Support Area, centroid location, force-to-centroid distance, and KSI. Configuration 3 gave the lowest KSI value, 0.00772, and was selected for the FEA stage. FEA was then used to determine the deformation and von Mises stress of this configuration under the 10 kN distributed machining load. A further comparison of the actual parameters and results obtained from the Finite Geometry and Finite Element Analysis stages is presented in Table 12. The FG results provided the basis for selecting Configuration 3 from the three locator arrangements. The selected configuration was then subjected to the 10 kN machining load in the FEA model. The analysis gave a maximum deformation of 0.015394 mm and a maximum von Mises stress of 48.322 MPa. These values describe the structural response of the configuration selected from the geometric assessment.

Table 11. Comparison of finite geometry and finite element analysis

Aspect	Finite Geometry	Finite Element Analysis
Primary assessment	Geometric and kinematic stability	Structural response
Configurations evaluated	3 locator configurations	1 selected configuration
Principal parameters	Effective Support Area (A_e) = 9308.14, 10219.75, and 12011.66 mm ² ; KSI = 0.01214, 0.01033, and 0.00772 for Configurations 1, 2, and 3, respectively	Maximum deformation = 0.015394 mm; maximum von Mises stress = 48.322 MPa
Machining force representation	Force application point and its geometric relationship with the support centroid	10 kN total machining load applied as two equal 5000 N vertical forces
Configuration selected	Configuration 3, KSI = 0.00772	Configuration 3 validated
Role in the study	Preliminary comparison and selection	Structural validation

3.7 Proposed hybrid FG–FEA framework

The results in this study support using FG and FEA at different stages of fixture assessment. FG was used first to compare the three locator configurations, after which FEA was applied to the selected configuration to examine its structural response. Table 13 summarizes the geometric and structural results obtained at each stage. In this study, we applied the FG–FEA sequence by first comparing the three locator configurations using the Effective Support Area and Kinematic Stability Index. Configuration 3 had the lowest KSI value (0.00772) and was selected for the FEA stage. The selected configuration was analyzed under a total machining load of 10 kN applied as two equal 5000 N

vertical forces, giving a maximum deformation of 0.015394 mm and a maximum von Mises stress of 48.322 MPa. The results provide a two-stage assessment: FG for the initial geometric comparison and FEA to examine the structural response of the selected arrangement.

Table 12. Comparative assessment of FG and FEA parameters used in the present study

Criterion	Finite Geometry (FG)	Finite Element Analysis (FEA)
Number of configurations assessed	3	1 selected configuration
Effective Support Area (Ae)	9308.14, 10219.75, and 12011.66 mm ²	Not evaluated
Kinematic Stability Index (KSI)	0.01214, 0.01033, and 0.00772	Not evaluated
Best/selected configuration	Configuration 3	Configuration 3
Applied machining load	Force location used for geometric assessment	10 kN total machining load
Maximum deformation	Not evaluated	0.015394 mm
Maximum von Mises stress	Not evaluated	48.322 MPa
Primary purpose	Geometric screening and configuration selection	Structural validation of the selected configuration

Table 13. Recommended hybrid FG–FEA workflow based on the present study

Design Stage	Recommended Method	Study Results Used	Purpose
Concept Design	Finite Geometry	Three locator configurations developed based on the 3–2–1 locating principle	Generate alternative locator layouts for geometric assessment
Configuration Optimization	Finite Geometry	Ae: 9308.14, 10219.75, and 12011.66 mm ² ; KSI: 0.01214, 0.01033, and 0.00772 for Configurations 1, 2, and 3, respectively	Compare the configurations; Configuration 3 selected based on the lowest KSI of 0.00772
Final Validation	Finite Element Analysis	Selected Configuration 3 subjected to a total 10 kN machining load applied as two equal 5000 N vertical forces; maximum deformation = 0.015394 mm; maximum von Mises stress = 48.322 MPa	Verify the structural response of the configuration selected through FG
Design Approval	FG + FEA	Configuration 3: KSI = 0.00772, Ae = 12011.66 mm ² , maximum deformation = 0.015394 mm, maximum von Mises stress = 48.322 MPa	Establish the final configuration by combining geometric stability assessment with structural validation

4. Conclusion

This study evaluated three locator configurations for an angle plate milling fixture using Finite Geometry (FG) followed by Finite Element Analysis (FEA). The FG stage compared the configurations using the Effective Support Area and Kinematic Stability Index (KSI), while the FEA stage examined the structural response of the selected configuration under the applied machining load. The three configurations produced different geometric results. Configuration 3 had the largest Effective Support Area of 12011.66 mm² and the lowest KSI value of 0.00772, and was therefore selected for the structural analysis. Under the 10 kN machining load, the FEA produced a maximum deformation of 0.015394 mm and a maximum von Mises stress of 48.322 MPa. The calculated stress was below the 250 MPa yield strength used for the Structural Steel material in the model. The results show how FG and FEA can be used at different stages of fixture assessment. FG provided an initial comparison of the locator arrangements and helped select Configuration 3, while FEA then examined its structural response under the specified loading condition. The study therefore provides a two-stage approach for comparing locator layouts and assessing the selected configuration. A limitation of the study is that the results were obtained numerically and were not compared with experimental measurements. Experimental testing would provide an additional basis for assessing the numerical results. The workflow used in this study can also be applied to other fixture arrangements and machining conditions. The finite geometry analysis can first be used to compare different locator positions based on how they relate to the applied machining force. The arrangement that provides the preferred geometric condition can then be used in FEA to examine its structural behavior under the required loading and support conditions. In the present work, the analysis was limited to an angle plate milling fixture and the specified machining load. However, the same approach can be used for other fixture layouts and loading conditions by defining the appropriate locator positions, fixture geometry, material properties, and machining loads.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically regarding authorship (avoidance of guest authorship), dual submission, figure manipulation, competing interests, and compliance with research ethics policies. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Data availability statement

The manuscript contains all the data. However, additional data are available upon request from the corresponding author.

Conflict of interest

The authors declare no potential conflict of interest.

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