Jurnal Kejuruteraan 38(5) 2026: 2469-2481
https://doi.org/10.17576/jkukm-2026-38(5)-29

Linear Programming Approach for Feasible Workpiece Mounting Regions to Maximize Workspace Utilization in Spindle-Tilted Five-Axis CNC Milling Machines

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Received 8 August 2025, Received in revised form 16 March 2026
Accepted 16 April 2026, Available online 30 August 2026

ABSTRACT

Maximum utilization of the workspace of five-axis CNC machines is a difficult task. Maximum utilization means machining a larger part on a smaller CNC machine by using optimized setup parameters of the workpiece on the machine table. Determination of these setup parameters is a core problem of this research. Currently, these setup parameters are selected randomly and simulation is done for the verification of the complete machining without overtravel of the machine translational axes. A spindle-tilting/rotating five-axis CNC milling machine is chosen for its superior ability to machine larger parts. In this research, a method is developed for determining the feasible regions on the table, where part can be mounted. These feasible regions will give the guarantee of complete machining of a bigger part without over travel of machine translational axes. By bounding the translational axis movements determined by the postprocessing equations with the limits set by the manufacturer, a linear programming model can be developed and solved for the feasible regions for mounting the workpiece on the table. Validation of the valid setup parameters determined by the proposed method is done in virtual machining environment. Through this method, it is easy to determine whether all machining features can be completed in one setup or if multiple setups are required. It also identifies the minimum number of setups, significantly reducing the workpiece setup time.

Keywords: Spindle-tilted/rotating 5-axis CNC Machine; feasible setup parameters; linear programming

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INTRODUCTION

Five-axis CNC milling is widely used in industries for the manufacturing of aerospace, automotive, and other complex parts. Due to its maximum flexibility (tool interaction with the workpiece at any orientation in space) with the minimum requirement of freedom (Five-axis freedom), it is difficult to determine the workspace (where cutter and work piece can meet) of the five-axis machine tools. Furthermore, different configurations of five axis-machine tool form different geometrical regions at which cutter and work piece can meet. These regions depend on the overall cutting system length in which cutter length is selected by the user and machine tools translational and rotational limits set by the manufacturer. Minimum cutter length based on collision free tool path can be selected by using algorithm presented by Ahmed et al. (2017). Part setup parameters i.e. the position of the workpiece relative to the table coordinate system also influence the utilization of the workspace on five- axis machine tools. This research presents a method developed for the determination of the setup parameters for utilizing maximum workspace of the spindle tilting/rotating five-axis machine tool. Application of this method is more effective on a spindle tilting/rotating five-axis machine tool configuration, as it allows for the machining of larger and heavier parts due to the rotational axes being located on the head rather than the table.

To address the issue of maximum utilization of the five-axis machine tool, a comprehensive literature review was conducted, which is primarily categorized into three.

1. Tool path generation without collision.
2. Interpolation techniques i.e. how movement of the axes can be controlled between two cutter locations in a tool path.
3. Post processing issues i.e. generation of G-codes.

As this study is focuses on post-processing, a comprehensive review of the relevant literature was conducted. Generally, five-axis machining tool path is generated in the part coordinate system regardless of the choice of five-axes machine tool configuration. This tool-path is then converted into the motions of the specific machine tool's translational and rotational axes. This conversion process is called post- processing. Since five-axis machines are available in different configurations, a generic approach is required for the development of post-processors. She et al. (2007) designed a generic five axis machine tools post-processor applicable to the different configurations of the 5- axis machine tools.

Bohez et al. (2002) designed a kinematic chain of the five-axis machine tools along with the advantages and disadvantages of different configurations of five-axis machine. Some useful definitions of space efficiency, workspace utilization factor, and the orientation space index are also presented.

Jung et al. (2002) developed an efficient post-processor by reducing the phase reverse processes for the table tilted/rotated five-axis machine tools. Optimization of the setup parameters to reduce the kinematic error is presented by Anotaipaiboon, W. et al., (2006). Lin, Z., et al. (2014) evaluated non-linear error caused by the rotary motion of the five-axis machine tools. They used RTCP (Rotational tool center point) function and optimized the setup parameters for the reduction of non-linear error. Munlin et al. (2004) developed a post-processing technique for the reduction in kinematic errors by optimizing the rotation of the table. An offline methodology is presented by Doung et al. (2019) for improving the post-processing and contouring of tool path and mitigate the errors during the five-axis machining. Chen et al. (2016) developed a new mathematical model to determine the feasible space for setting up parts on a table. But the method developed is applicable to the tilted-spindle, table-rotating five-axis milling machine.

Setup parameters have also influenced the energy consumption of the machine during machining. Several researchers have highlighted the importance of setup parameters in the energy consumed during machining. Pessoles, X., et al. (2013) developed a model for the setup parameters which minimized the distance traveled by the translational axes while machining the part. By minimizing the distance traveled, machining time is reduced and hence energy saved. Xu, K., et al. (2017) also optimized the setup parameters to reduce the machining time and improve energy efficiency of sculptured surface machining. Wei, C., et al. (2020) developed a generic algorithm to optimize workpiece setup across various 5-axis machines configuration, thereby reducing machining time. Zhao et al. (2023) uses NURBS surface principle for the development of an algorithm for the global collision detection of cutter axis vector. Chu, M., et al. (2023) presented an intuitive framework which provides the practical guidance for the development of CNC postprocessors for all configurations of 5-axis CNC machines. Liu, X., et al. (2024) presented a method for optimizing setup parameters by establishing an analytical stiffness model for the five-axis machining space. The developed method shows significant improvement in machining quality of the workpiece surface. Literature review reveals that optimization of setup parameter has been primarily focused on enhancing machining accuracy, reduce energy consumption through shortest tool path and minimizing kinematic error. However, optimization of setup parameters to minimum the number of setups, thereby improving the utilization of the five-axis machine- has been completely ignored by researchers.

Machining oversized parts is a challenge for machinists. Some features may be machined by putting the part at certain location and other features may require other setup parameters for completing the machining of the designed part without over travel of translational axes of the five-axis machine tools. This iterative process can be accomplished by using CAD/CAM software such as Vericut and CATIA. These softwares perform simulation and detect collision (over travel of machine translational axes). To avoid this collision, other setup parameters are tested. It is necessary to find the feasible setup parameters to avoid an iterative selection process. The main objective of this research is "To develop an algorithm for determining the minimum number of setup parameters required to machine a large part, thereby improving the utilization of the five-axis machine".

METHODOLOGY

Different combinations of five-axis machine tools are presented by different researchers. Typically, five-axis machine tools are classified based on rotation axis. According to this, five-axis machine tools are classified into three (a) One rotary axis belongs to the table and other is carried by the spindle. (b) Both rotary axes belong to the table (c) Both rotary axes belong to the spindle. Type (c) configuration machines are suitable for machining the large and heavy parts due to three non-rotational axes attachment with the table. The methodology for determining the setup parameters to improve five-axis machine utilization is presented in Figure 1. Initially, tool path strategy is selected by the machinist and tool path is generated in the part coordinate system along with the following assumptions.

1. Collision and singularity avoidance is checked during the tool path generation by using different machining strategies in the workpiece coordinate system.
2. No effect on the cutter location due to the stiffness of the tool that can cause deflection in the tool during the actual machining.

Generated tool path contains series of cutter locations i.e. CL-points [Cl_x Cl_y Cl_z] and tool orientations i.e. Tool vectors[I_x I_y I_z]. To take the full advantage of the presented algorithm, type (c) five-axis CNC milling machine is selected. Since both rotational axes belong to the spindle, these machines are suitable for machining larger and heavier parts. These larger parts can be machined with the help of different setup parameters. These different and minimum setup parameters can be found with help of the presented algorithm as shown inside the rectangular dashed-line region in Figure 1. In the following sections, the kinematic chain and post- processing equations are developed for the given machine tool configuration. Then, linear inequalities are developed based on the machine tool travel limits set by the manufacturer. In the last two sections, machining example and discussions are presented which show the effectiveness of the presented algorithm. This example shows that a larger part can be completely machined in a minimum number of setups.

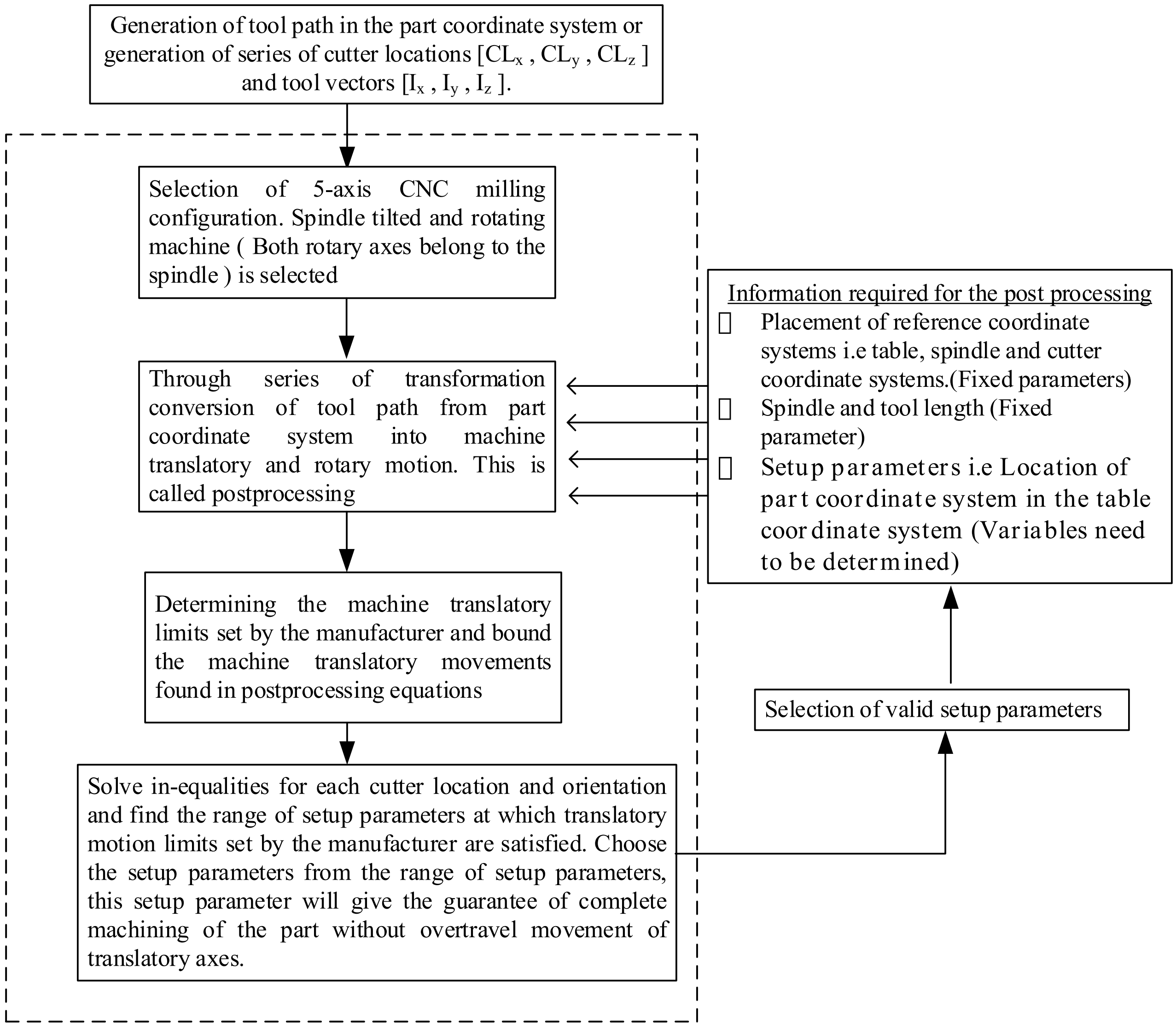


FIGURE 1. Flow chart of the methodology for the proposed algorithm

DEVELOPMENT OF THE KINEMATIC CHAIN AND POST PROCESSING EQUATIONS

Type (c) configuration machine is taken from "Fryer 5x series" with specification of 5x-120 as shown in Table 1.

TABLE 1. Geometrical specification of Fryer 5x-120

Parameter	Specification
Travel Range	(X/Y/Z): (120", 50",40")
Rotation Range	(Θ/α): (±105° - 120° / 220°-240°)
Table Size	40" x 126" or 40 x 165 in.

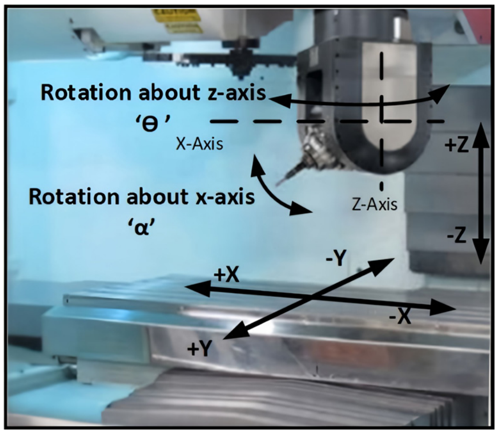


FIGURE 2. Five-axis machine tool configuration

Reference coordinate systems are introduced to develop post-processing equations. These reference coordinate systems are shown in Figure 3. Following right-handed coordinate systems are the reference coordinate systems.

0_w= Origin of the work piece coordinate system.

0_t= Origin of the table coordinate system.

0_p= Origin of the coordinate system attached at the pivot point. Both machine tool rotations are also about the axes of this coordinate system.

0_c= Origin of the tool tip (cutter) coordinate system or cutter location.

On this machine, x- and y-travel belong to the table while z- travel belongs to the spindle. Both machine tool rotations also belong to the spindle. These two rotations are R (α, x) i.e. "α" is the rotation angle about x-axis and R (Θ, z) i.e. "Θ" is the rotation angle about z-axis are shown in Figure 2.

The main objective of this work is to determine the valid setup parameters. To illustrate these, Figure 4 displays an isometric view of the machine and the designed part, clearly showing the setup parameters.

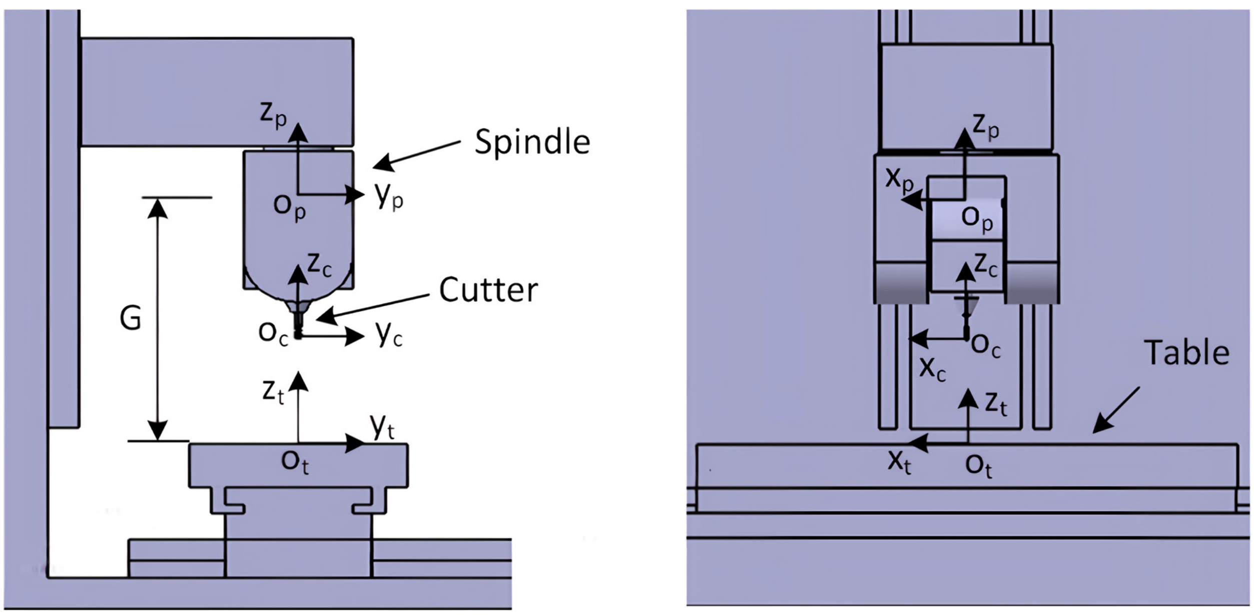


FIGURE 3. Front and side view of the machine tool indicating the reference coordinate systems

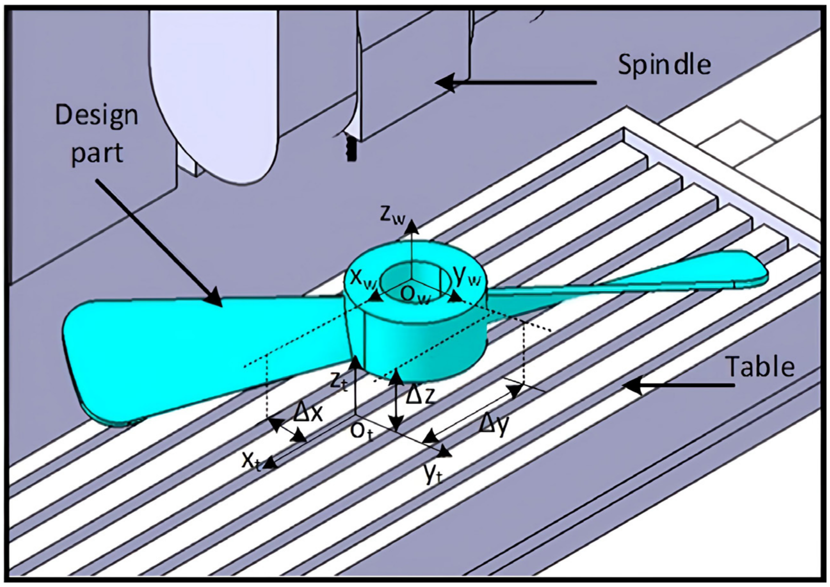


FIGURE 4. Relationship between the part coordinate system and table coordinate system through the setup parameters

The parameter 'G' is introduced. It is the vertical distance between the table coordinate system and the pivot point relative to the machining zero position. This parameter is used to transform a point from the table coordinate system to the pivot point coordinate system. The parameter 'L' is the overall cutting system length which includes the cutter length, the shank length, and the spindle length. This length is used for the transformation of a point from the pivot point coordinate system to the cutter coordinate system. Series of transformations are required to transform the cutter location in the part coordinate system to the tool tip coordinate system. These transformations include three translation matrices and two rotation matrices. Let $P_w = [Cl_x \quad Cl_y \quad Cl_z \quad 1]^T$ be a point in the workpiece coordinate system. This point can be transformed into tool tip coordinate system through the series of transformation matrices. This series of transformations are shown along with the reference coordinate systems in Figure 5.

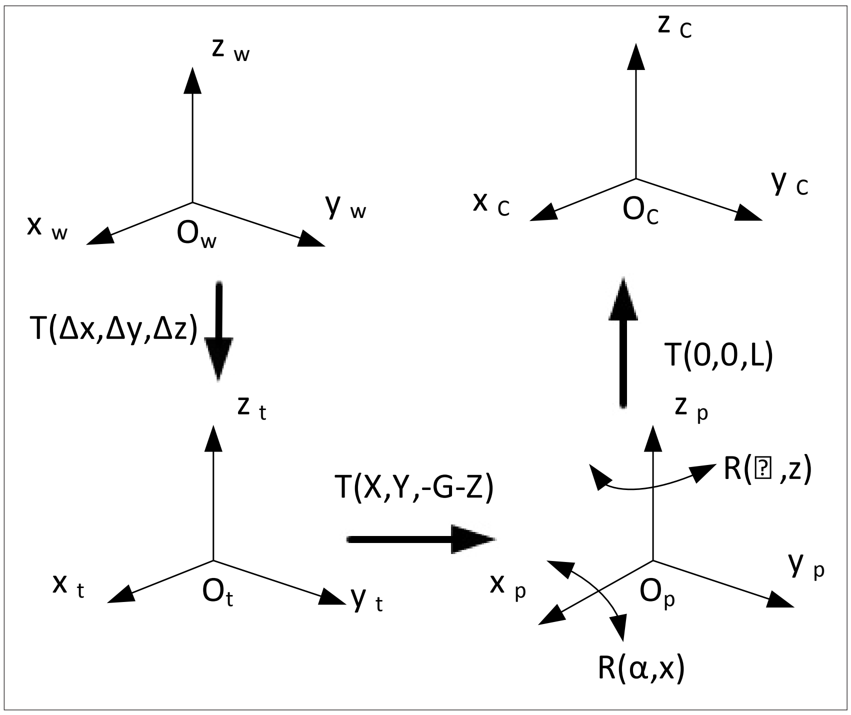


FIGURE 5. Series of transformation from work piece to cutter coordinate system

$$P_c = T(0 \quad 0 \quad L).R(\alpha, x).R(\theta, z).T(X \quad Y \quad -G-Z).T(\Delta x \quad \Delta y \quad \Delta z).P_w$$

$$\begin{bmatrix}0\\0\\0\\1\end{bmatrix} = \begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&L\\0&0&0&1\end{bmatrix}.\begin{bmatrix}1&0&0&0\\0&cos(\alpha)&sin(\alpha)&0\\0&-sin(\alpha)&cos(\alpha)&0\\0&0&0&1\end{bmatrix}.\begin{bmatrix}cos(\theta)&sin(\theta)&0&0\\-sin(\theta)&cos(\theta)&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}.$$
$$\begin{bmatrix}1&0&0&X\\0&1&0&Y\\0&0&1&-G-Z\\0&0&0&1\end{bmatrix}.\begin{bmatrix}1&0&0&\Delta x\\0&1&0&\Delta y\\0&0&1&\Delta z\\0&0&0&1\end{bmatrix}.\begin{bmatrix}Cl_x\\Cl_y\\Cl_z\\1\end{bmatrix}$$

After solving above equation (See Appendix A), machine translation movements are found as under

$$X = -Cl_x - \Delta x - L.sin(\alpha).sin(\theta) \tag{1}$$

$$Y = L.cos(\theta).sin(\alpha) - \Delta y - Cl_y \tag{2}$$

$$Z = Cl_z - G + \Delta z + L.cos(\alpha) \tag{3}$$

Machine rotations are only the function of tool vector $[I_x \quad I_y \quad I_z \quad I]^T$ and can be found from the following equations

By solving above equation for the given tool vector, machine rotations can be found as

$$\alpha = cos^{-1}(I_z) \tag{4}$$

and

$$\theta = \begin{cases} -tan^{-1}(\frac{I_x}{I_y}) & If\ I_y < 0, \\ -tan^{-1}(\frac{I_x}{I_y}) - \pi & If\ I_y \geq 0 \text{ and } I_x \leq 0, \\ 0 & If\ I_y = 0 \text{ and } I_x = 0, \\ -tan^{-1}(\frac{I_x}{I_y}) + \pi & \text{otherwise,} \end{cases} \tag{5}$$

DEVELOPMENT OF INEQUALITIES

Manufacturer-set limits for translatory axis movement can be found in the pivot coordinate system when the cutter axis is vertically aligned with the center of the table. The orthographic views of the machine which show the minimum and maximum limits of the translatory axes are shown in Figure 6. These limits can be used for the development of linear inequalities. The objective of this work is to determine the range of setup parameters that guarantees the complete machining of all design features. Furthermore, much bigger part having different machining features can be machined with the minimum number of setups.

To find out the feasible range of setup parameters, it is necessary to bound translational movement of the translational axes of the machine found from equations (1) to (3) with the maximum and minimum travel limits shown in Figure 6. Mathematically,

$$X_{min} \leq X_i \leq X_{max} \tag{6}$$

$$Y_{min} \leq Y_i \leq Y_{max} \tag{7}$$

$$Z_{min} \leq Z_i \leq Z_{max} \tag{8}$$

Where i= 1, 2, 3, …………, n (Number of cutter location points in the given tool path)

By substituting the machine translational movements of each cutter location from equations (1) to (3) in inequalities from (6) to (8), we get

$$X_{min} \leq -Cl_{xi} - \Delta x_i - L.sin(\alpha_i).sin(\theta_i) \leq X_{max} \quad (9)$$

$$Y_{min} \leq L.cos(\theta_i).sin(\alpha_i) - \Delta y_i - Cl_{yi} \leq Y_{max} \quad (10)$$

$$Z_{min} \leq Cl_{zi} - G + \Delta z_i + L.cos(\alpha_i) \leq Z_{max} \quad (11)$$

By solving inequalities from (9) to (11) for the setup parameters, we get

$$X_{min} + Cl_{xi} + L.sin(\alpha_i).sin(\theta_i) \leq -\Delta x_i \leq X_{max} + Cl_{xi} + L.sin(\alpha_i).sin(\theta_i) \quad (12)$$
$$Y_{min} - L.cos(\theta_i).sin(\alpha_i) + Cl_{yi} \leq -\Delta y_i \leq Y_{max} - L.cos(\theta_i).sin(\alpha_i) + Cl_{yi} \quad (13)$$
$$Z_{min} - Cl_{zi} + G - L.cos(\alpha_i) \leq \Delta z_i \leq Z_{max} - Cl_{zi} + G - L.cos(\alpha_i) \quad (14)$$

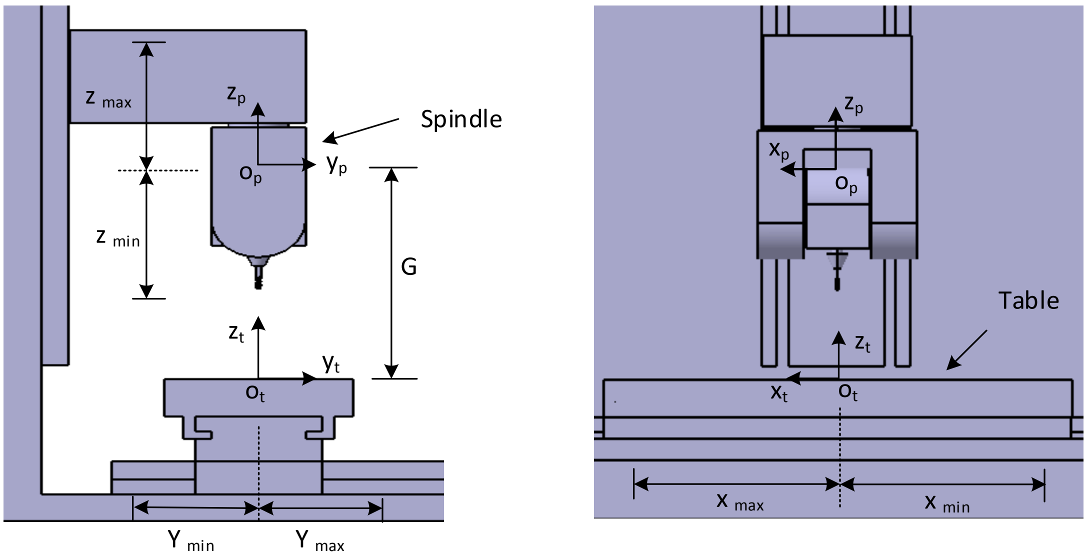


FIGURE 6. Machine translational limits in the pivot coordinate system

For each cutter location, a range of setup parameters can be determined. For complete machining of the given feature of the design part, it is necessary that the above inequalities must be satisfied. To satisfy the inequalities from (12) to (14), maximum and minimum conditions are introduced, and final range of the setup parameters can be determined as follows

$$Max[X_{min} + Cl_{xi} + L.sin(\alpha_i).sin(\theta_i)] \leq -\Delta x \leq Min[X_{max} + Cl_{xi} + L.sin(\alpha_i).sin(\theta_i)] \quad (15)$$
$$Max[Y_{min} - L.cos(\theta_i).sin(\alpha_i) + Cl_{yi}] \leq -\Delta y \leq Min[Y_{max} - L.cos(\theta_i).sin(\alpha_i) + Cl_{yi}] \quad (16)$$
$$Max[Z_{min} - Cl_{zi} + G - L.cos(\alpha_i)] \leq \Delta z \leq Min[Z_{max} - Cl_{zi} + G - L.cos(\alpha_i)] \quad (17)$$

The setup parameters range from (15) to (17) will generate a feasible space of a cubical volume on the table. If the machining part is mounted in such a way that the part coordinate system is located within the cubical volume, then it will give the guarantee of complete machining of the given feature of the design part without collision or crossing the limits of machine translational axes.

MACHINING EXAMPLE AND SIMULATION VERIFICATION

A design part with rough stock, as shown in Figure 7, is considered for machining. A much bigger part is selected to check the effectiveness of this method. This design includes various machining features.

Different machining strategies can be adopted for different features of a designed part. For instance, an initial roughing operation is performed to the achieve maximum material removing rate. This is followed by four top inclined facing operations and bottom pocketing, along with four inside inclined facing operations. An isoperimetric machining strategy is adopted for finishing the end curved edge of the design part. Finally, four bottom through holes and one top hole are drilled. Since the feasible range of setup parameters is not only dependent on the machining strategy but also depends on the cutter length as well as the maximum and minimum travel limits set by the manufacturer. Maximum and minimum travel limits set by the manufacturer in the pivot point coordinate system are given in Table 2. All machining operations along with the cutter length required and the plot of their determined feasible ranges are given in Table 3.

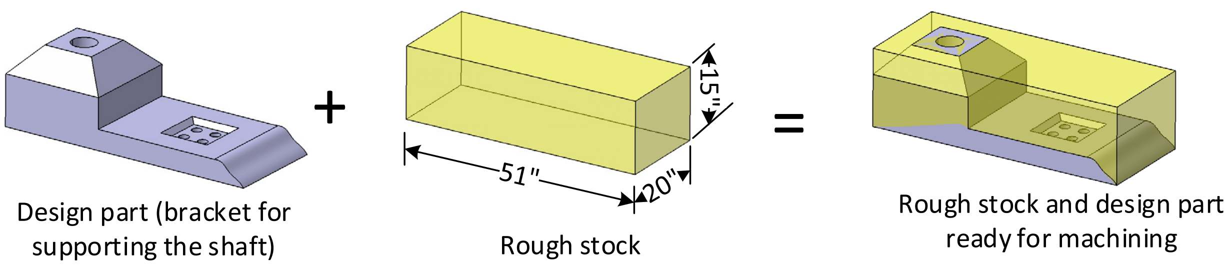
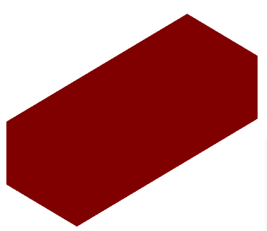
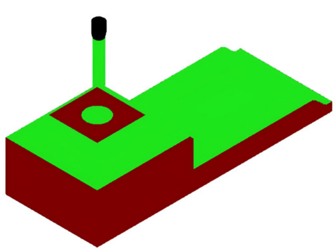
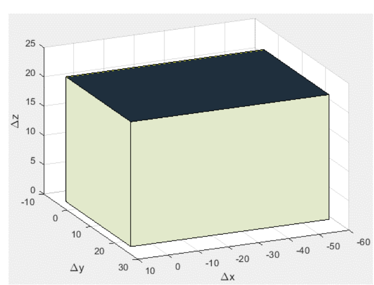


FIGURE 7. Design part with rough stock ready for machining

TABLE 2. Maximum and minimum travel limits in inches, set by the manufacturer in the pivot point coordinate system

X_{min}	X_{max}	Y_{min}	Y_{max}	Z_{min}	Z_{max}
-60	60	-25	25	-40	0

TABLE 3. All machine operations along with the cutter length required and the plot of their determined feasible ranges in inches

MACHINING FEATURE	WORKPIECE MOUNTING REGION
ROUGH STOCK 	Machining has not yet started. No feasible region
ROUGHING (Tool Length=12”) 	Numerical limits: $7.5190 \geq \Delta x \geq -58.1086$; $23.8532 \geq \Delta y \geq -3.7690$;$21.5630 \geq \Delta z \geq 0.2565$ Plot 

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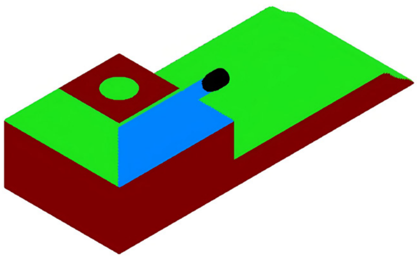
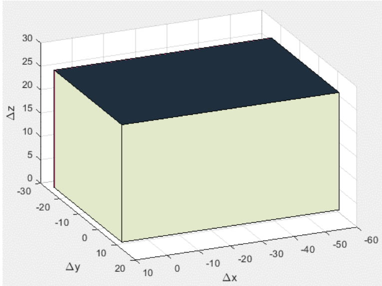
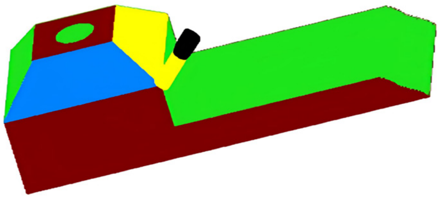
INCLINED FACING 1 (Tool Length=7.874”)



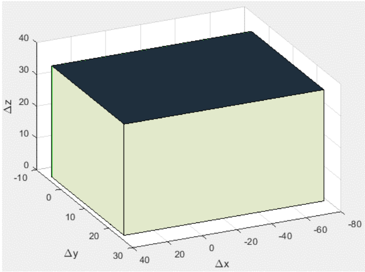
Numerical limits:
$8.6410 \geq \Delta x \geq -60$; $10.5656 \geq \Delta y \geq -25$; $25.6890 \geq \Delta z \geq 0.5934$
Plot



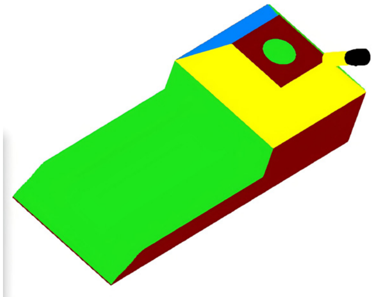
INCLINED FACING 2 (Tool Length=7.874”)



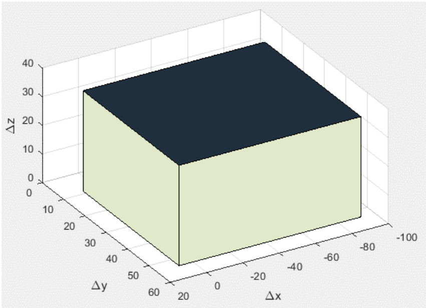
Numerical limits:
$38.0476 \geq \Delta x \geq -76.9246$; $25 \geq \Delta y \geq -5$; $35.5934 \geq \Delta z \geq 0.5934$
Plot



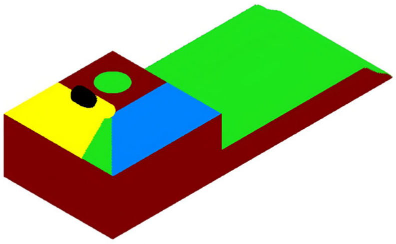
INCLINED FACING 3 (Tool Length=7.874”)



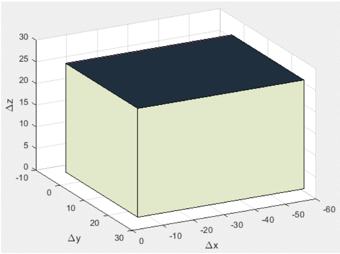
Numerical limits:
$8.6410 \geq \Delta x \geq -91.3590$; $54.4066 \geq \Delta y \geq 9.4344$; $35.5934 \geq \Delta z \geq 0.5934$
Plot



INCLINED FACING 4 (Tool Length=7.874”)



Numerical limits:
$-5.7934 \geq \Delta x \geq -60$; $25 \geq \Delta y \geq -5$; $25.6890 \geq \Delta z \geq 0.5934$
Plot



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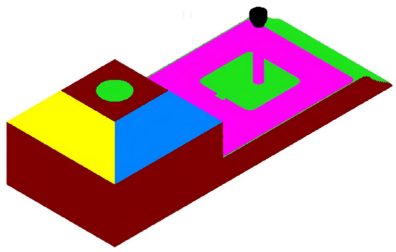
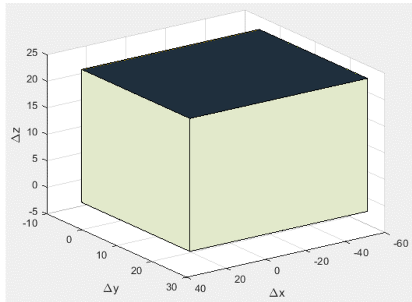
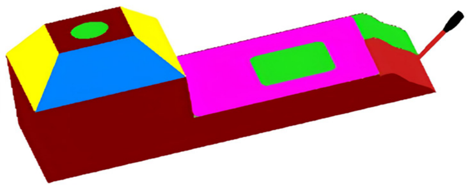
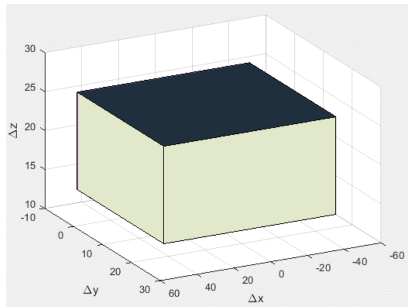
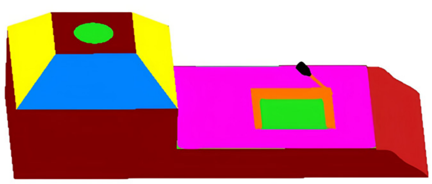
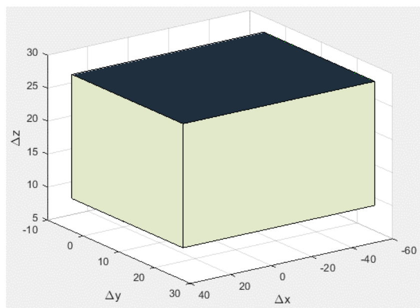
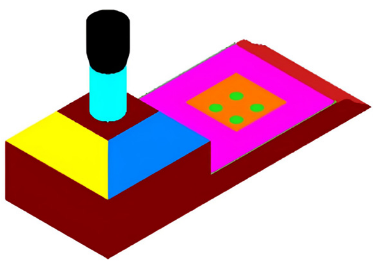
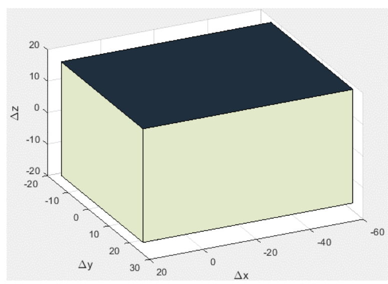
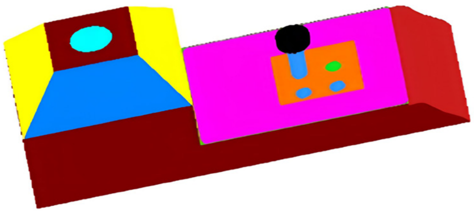
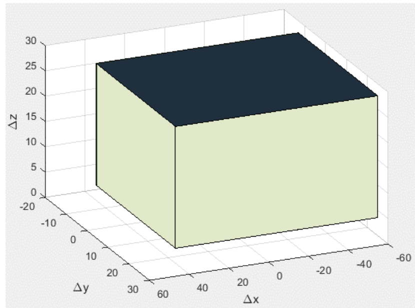
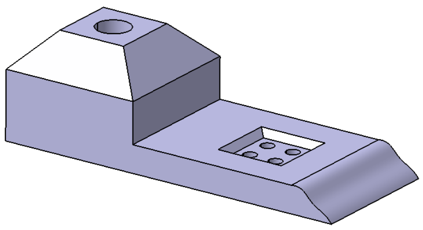
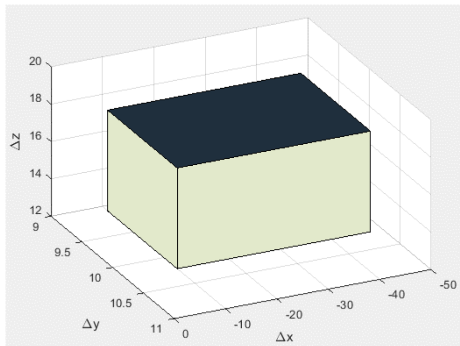
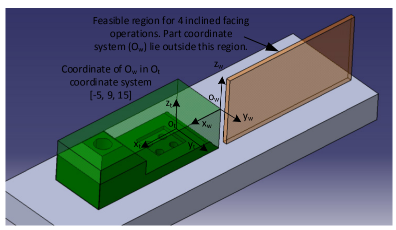
FACING OF BOTTOM POCKET (Tool Length=11”) 	Numerical limits: $29.5910 \geq \Delta x \geq -60$; $25 \geq \Delta y \geq -5.9500$; $22.5630 \geq \Delta z \geq -2.5000$ Plot 
ISO PARAMETRIC MACHINING (Tool Length=11”) 	Numerical limits:$50.213 \geq \Delta x \geq -43.410$; $25 \geq \Delta y \geq -5$; $25.689 \geq \Delta z \geq 13.1718$ Plot 
INCLINED SIDE FACING OF BOTTOM POCKET (Tool Length=7.874”) 	Numerical limits: $34.7652 \geq \Delta x \geq -60$; $25 \geq \Delta y \geq -6.0966$; $27.6570 \geq \Delta z \geq 8.8458$ Plot 
TOP HOLE DRILLING (Tool Length=5.906”) 	Numerical limits: $18.6410 \geq \Delta x \geq -60$; $25 \geq \Delta y \geq -15$; $18.5630 \geq \Delta z \geq -17.5000$ Plot 

continue...

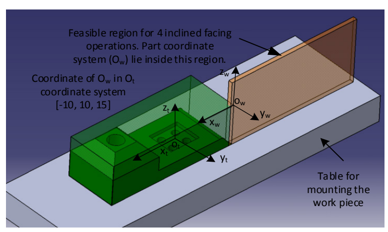
...cont.

THROUGH HOLE DRILLING (4 holes) (Tool Length=5.906”) 	Numerical limits: 41.6410 ≥ Δx ≥ -60; 25 ≥ Δy ≥ -13; 27.6570 ≥ Δz ≥ 3.5940 Plot 
FINAL DESIGN PART AFTER MACHINING 	Numerical limits: -5.7934 ≥ Δx ≥ -43.4106; 10.565 ≥ Δy ≥ 9.4344; 18.5630 ≥ Δz ≥ 13.1718 Plot 

It can be seen in the above example, only one setup of the rough stock is required to complete the machining of the whole part. In the above table for final design part after machining, numerical limits of the setup parameters are (-5.7934 ≥ Δx ≥ -43.4106), (10.565 ≥ Δy ≥ 9.4344) and (18.5630 ≥ Δz ≥ 13.1718). The y-axis constraint is less than 1inch, preventing easy determination by using any machining software. Generally, more than one setup is used to complete the machining of this part. However, developed algorithms enable finding a smaller range of Δy. Using only one setup for a part can significantly decrease the setup time of the rough stock. After finding the feasible setup parameters, it is necessary to set up the part within the feasible region and verify the complete machining of the designed part. Usually, simulation is done before the actual machining to avoid global collision i.e. collision of spindle with the design part during the machining. This collision can be avoided through adjustment in the cutting tool length and shank design. The primary focus of this research is the mitigation of over travel of translational axes, accomplished through simulation to verify axis limitation. For the simulation purpose two scenarios are taken for the combined inclined facing (4-sided inclined facing). In one scenario, the part coordinate system lies inside the feasible region, and in the other, it lies outside. Both setups are shown in Figure 8. Similarly, two scenarios of iso-parametric machining operation are also taken for simulation verification. These two scenario setups are shown in Figure 9.

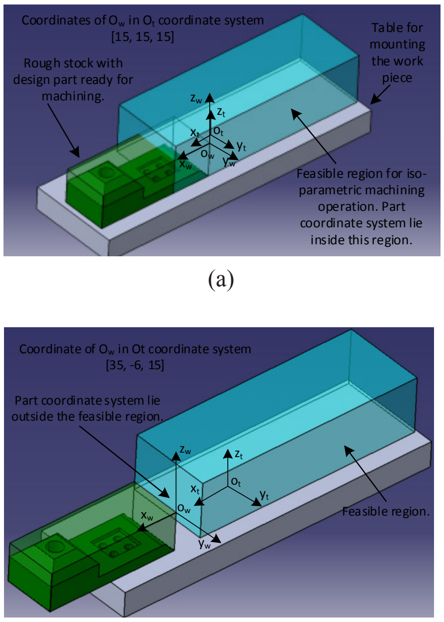


(a)



(b)

FIGURE8 (a) Arrangement of a rough stock where part coordinate system lies inside the feasible setup region and complete facing machining operation is possible. (b) Arrangement of rough stock where work piece coordinate system lies outside the feasible setup region and complete facing machining operation is not possible.



(a)

(b)

FIGURE 9 (a) Arrangement of a rough stock where part coordinate system lies inside the feasible setup region and complete iso-parametric machining operation is possible. (b) Arrangement of rough stock where work piece coordinate system lies outside the feasible setup region and complete iso-parametric machining operation is not possible.

For four inclined side-facing operations, the simulation in the virtual environment is completed without over-travel when part coordinate system lies inside the feasible region, as shown in Figure 8 (a). However, when the part coordinate system lies outside the feasible region, as shown in Figure 8 (b), complete machining of the four inclined facing is not possible. Out of 252 CL points, 48 are unreachable. Similarly, for iso-parametric operation, the simulation in the virtual environment is completed without over-travel when part coordinate system lies inside the feasible region, as shown in Figure 9 (a). However, for the setup shown in figure 9 (b), out of 1137 CL points, 114 are unreachable.

DISCUSSION AND CONCLUSION

This research develops a linear programming model to determine the feasible space on the table for mounting the workpiece. Mounting the workpiece within this feasible space on the table guarantees complete machining of the design part without exceeding the translational axis limits. This approach is applied on the spindle tilted and rotating five-axis machine, which has the capability of machining a much bigger part. Simulation results show that for the complete machining of a bigger part, there is very small mounting limits along the y-direction. And it is difficult to find out this space by using hit and trial method. Usually, machining of this part is done by using two setups, but it is possible to do the machining of this part in a single setup. Furthermore, this small mounting limits along y-direction is due to the smaller y-axis translational limits set by the manufacturer. Above discussion shows that this algorithm is useful for finding the minimum number of setups required for the complete machining of the larger part and hence increases the utilization of type (C) five-axis machine.

ACKNOWLEDGEMENT

None.

DECLARATION OF COMPETING INTEREST

None.

REFERENCES

Ahmed, A. & Chen, Z. C. 2017. A comprehensive approach to determining minimum cutter lengths for five-axis milling. *International Journal of Advanced Manufacturing Technology* 90: 1235–1252.

Anotaipaiboon, W. et al. 2006. Optimal setup for five-axis machining. *International Journal of Machine Tools and Manufacture* 46: 964–977.

Bohez, E. L. J. 2002. Five axis milling machine tool kinematic chain design and analysis. *International Journal of Machine Tools & Manufacture* 42: 505–520.

Chen, Z. C. & Ahmed, A. 2016. A precise approach for the determination of the setup parameters to utilize maximum workspace of five-axis CNC machine tools. *International Journal of Advanced Manufacturing Technology* 85: 2297–2310.

Chu, A. M. et al. 2023. A framework for practically effective creation of postprocessors for 5-axis CNC machines with all possible configurations and working mechanisms. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*. https://doi.org/10.1177/09544054231179314

Duong, T., Rodriguez-Ayerbe, P. & Lavernhe, S. 2019. Contour error pre-compensation for five-axis high speed machining: Offline gain adjustment approach. *International Journal of Advanced Manufacturing Technology* 100: 3113–3125.

Jung, Y. H., Lee, D. W., Kim, J. S. & Mok, H. S. 2002. NC postprocessor for 5-axis milling machine of table rotating/tilting type. *Journal of Materials Processing Technology* 130: 641–646.

Lin, Z., Fu, J., Shen, H. & Gan, W. 2014. On the workpiece setup optimization for five-axis machining with RTCP function. *International Journal of Advanced Manufacturing Technology* 74: 187–197.

Liu, X. et al. 2024. A workpiece setup optimization method for 5-axis machining with motion coherence and stiffness enhancement. *Precision Engineering* 88: 867–883.

Munlin, M. et al. 2004. Optimization of rotations of a five-axis milling machine near stationary points. *Computer-Aided Design* 36: 1117–1128.

Pessoles, X., Landon, Y., Segonds, S. & Rubio, W. 2013. Optimization of workpiece setup for continuous five-axis milling: Application to a five-axis BC type machining center. *International Journal of Advanced Manufacturing Technology* 65: 67–79.

She, C. & Chang, C. 2007. Design of a generic five-axis postprocessor based on generalized kinematics model of machine tool. *International Journal of Machine Tools and Manufacture* 47: 535–547.

Wei, C. & Lee, W. 2020. Optimization of the setup position of a workpiece for five-axis machining to reduce machining time. *Advances in Mechanical Engineering* 12(12): 1–13.

Xu, K. & Tang, K. 2017. Optimal workpiece setup for time-efficient and energy saving five-axis machining of freeform surfaces. *Journal of Manufacturing Science and Engineering* 139(5): 051003–051018.

Zhao, P. et al. 2023. Research on tool axis vector optimization when face milling complex surfaces. *International Journal of Advanced Manufacturing Technology* 128: 5081–5099.