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TOOLPATH SIMULATION OF 3-AXIS PARALLEL MACHINE TOOL USING GEOMETRICAL MODEL

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In this paper, the study of the geometric model of a 3-axis high-speed parallel machine tool has been established, which has enabled us to find the mathematical equations that give the positions of the motors, in function of the nacelle positions (operational space). To validate this model, in a first part, we made a simulation of a simple circular and a more complex spiral toolpath with Matlab program by the application of the equations of the kinematic model studied previously. In the second part, Solidworks motion tool was used to validate our model.

Keywords: high speed machine tool, kinematic, Solidworks, Matlab, toolpath

1. Introduction

The world of the machine tool is constantly evolving to meet the market needs of these machines. The parallel structure of machine tools is one of the most used structures in the field of high-speed machining machines [1-6]. They generally comprise two platforms: one fixed and the other mobile, interconnected by joints and arms, the mobile platform being able to perform movements in its work space. These links will be spherical (ball), cylindrical (pivot) or prismatic (slides). Among these joints, there are passive and active joints [7].

The study of the geometrical model of the parallel kinematic machine tool is interested in the description of the movement of the moving parts with respect to a fixed reference, so the kinematic model describes the analytical relation between the motor positions and the position of the end effector (tool), as well as their orientation [8-9]. The geometric model can be used in the computation of the kinematic and dynamic model in several forms [10-12].

The machining toolpath calculation is an objective of some work, such as the work of [13-14]. Other studies consist in determining the trajectory of the tool to

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go from one position to another [15-18], and optimization of the trajectories of the tool [19-22].

The study of the toolpath makes it possible to optimize the machining time when moving the tool in a machining process [23-24], and proposed methods to study the machining time in high speed machining [13, 20, 23, 25].

This paper is aimed at developing a mathematical model of the machine tool with three parallel axes from a geometric model. This approach is used to generate some toolpath (simple and complex one) and to be simulated with two tools, Matlab software and Solidworks motion. 3D representation of the machine and the trajectory of the motors when machining the toolpath within the usable workspace are estimated with comparison to those obtained through Matlab and solidworks motion.

This work is organized as follows: firstly we have developed the kinematic model of a machine tool with three parallel axes, which consists of expressing the values of the articular positions (motors) as a function of the position of the cutting tool. Then, we used this kinematic model to generate a simple and complex trajectory with Matlab program, and finally, we confirmed the validation of our model with the Solidworks motion software.

2- Descriptions of the machine tool with parallel structure

The machine studied is a delta type with linear actuators. This machine tool is composed of three motorized linear actuators distributed symmetrically at 120°. The actuators function is to transfer the movement to the final effecter (cutting tool) in a workspace. Each linear actuator connected by means of two spherical joints (ball joints) with two link of the same length, and in the other side of the links there are two other ball joints for transmitting the movement to the base mobile (final effector), see figures (1, 2 and 3). The spherical joints can be replaced by universal joints.

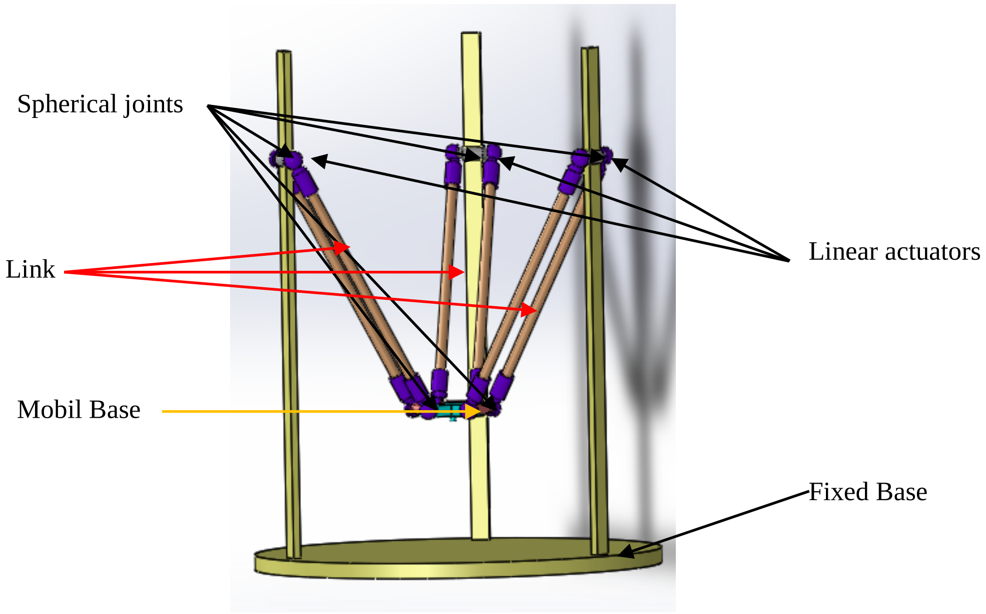


Fig. 1. CAD model of parallel machine tool

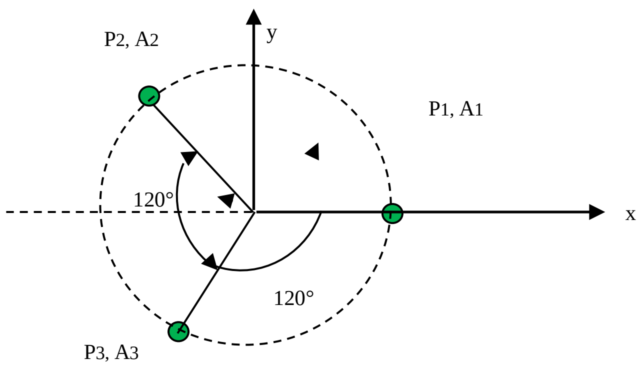


Fig. 2. Parameter setting of the base.

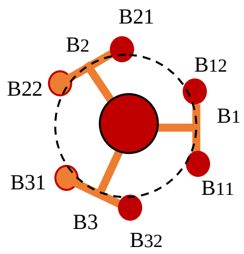


Fig. 3. Parameter setting of the nacelle

The aim of the kinematic model of the machine tool is to find the relation between the final position of the tool and the position of the joints (linear motors).

3- Modeling of the mechanism

3-1- Inverse geometric model

To find the relation between the position of the end effecter (tool) and the position of the joints, the inverse geometric model is used. It consists in finding the distances of the articulations located in the fixed platform, given the position of the final effector (tool) situated at the center of the mobile platform, see Fig. 4.

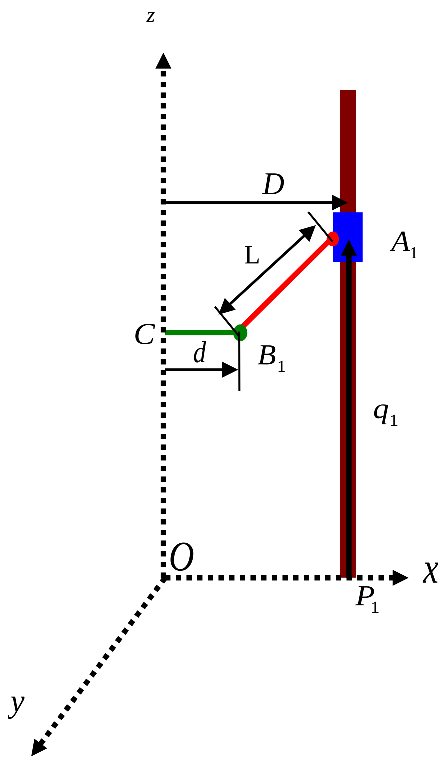


Fig. 4. Geometric Parameter

The parameters of the machine tool considered in this analysis are: the diameter of the mobile platform d = 0.15 m, the diameter of the fixed platform D = 0.70 m and the length of the link L = 1.07 m.

To perform the inverse geometrical analysis of the machine tool, it assumes a closed chain for each end of the machine tool relative to the fixed coordinates reference (OXYZ), this depending on the geometry of the machine tool shown in Figure 4.

We note that the coordinates of the points A_i in the reference frame related to the base R_b are given by :

$$A_1 = \begin{pmatrix} D \\ 0 \\ 0 \end{pmatrix} \qquad A_2 = \begin{pmatrix} -\frac{D}{2} \\ \frac{\sqrt{3}}{2}D \\ 0 \end{pmatrix} \qquad A_3 = \begin{pmatrix} -\frac{D}{2} \\ -\frac{\sqrt{3}}{2}D \\ 0 \end{pmatrix}$$

And the coordinates of the points P_i in the reference frame related to the base R_b are given by :

$$P_1 = \begin{pmatrix} D \\ 0 \\ 0 \end{pmatrix} \qquad P_2 = \begin{pmatrix} -\frac{D}{2} \\ \frac{\sqrt{3}}{2}D \\ 0 \end{pmatrix} \qquad P_3 = \begin{pmatrix} -\frac{D}{2} \\ -\frac{\sqrt{3}}{2}D \\ 0 \end{pmatrix}$$

The distance (OC) is given by the vector:

$$\overrightarrow{OC} = \overrightarrow{OP_i} + \overrightarrow{P_i A_i} + \overrightarrow{A_i B_i} + \overrightarrow{B_i C} \qquad (1)$$

With i=1, 2, 3.

By transforming the vector of equation (1) into three scalar equations, we obtain:

$$(X - x_i)^2 + (Y - y_i)^2 + (Z - z_i)^2 = q_i^2 \qquad (2)$$

So if we replace i by 1, 2, 3, we find a system of three equations:

$$\begin{cases} (z - q_1)^2 + L^2 - (d - D + x)^2 - y^2 = 0 \\ (z - q_2)^2 + L^2 - \left(\frac{1}{2}(D - d) + x\right)^2 - \left(\frac{\sqrt{3}}{2}(d - D) + y\right)^2 = 0 \\ (z - q_3)^2 + L^2 - \left(\frac{1}{2}(D - d) + x\right)^2 - \left(\frac{\sqrt{3}}{2}(D - d) + y\right)^2 = 0 \end{cases} \qquad (3)$$

The solution of the inverse kinematic model of the machine tool can be obtained by:

$$\begin{cases} q_1 = z + \sqrt{L^2 + (x - D + d)^2 - y^2} \\ q_2 = z + \sqrt{L^2 - \left(x + \frac{1}{2}(D - d)\right)^2 - \left(\frac{\sqrt{3}}{2}(d - D) + y\right)^2} \\ q_3 = z + \sqrt{L^2 - \left(x + \frac{1}{2}(D - d)\right)^2 - \left(\frac{\sqrt{3}}{2}(D - d) + y\right)^2} \end{cases} \quad (4)$$

3-2- Verification of degree of mobility of the mechanism

The criterion Chebychev - Grübler - Kutzbach determines the degree of freedom of a kinematic chain, that is to say the degree of mobility in the connections that connected between the different parts of the mechanism.

$$m = 6\left(N_p - N_i - 1\right) + \sum_{i=1}^{N_i} dof_i - m_{\text{int}}$$

m: the number of degrees of freedom of the mechanism.

N_p: the number of independent solids (built excluded).

N_i : the number of connections between the mechanism parts.

dof i: the number of degrees of freedom of the connection number *i* .

m_{int} : the number of internal mobility *m*int

In our case we have the following values: N_p=11; N_i=15

(Connections Spherical (kneecap) and 3 connections Prismatic (slide)).

So the mobility of this mechanism is:

$$dof_i = (12x\,3) + (3x\,1) = 39 \qquad m_{\text{int}} = 6$$

$$m = 6(11 - 15 - 1) + 39 - 6 \quad \Rightarrow \quad m = 3$$

4- Determination of the linear motor locations

The determination of the motors locations as a function of the tool path, is calculated with Matlab from the kinematic model of the machine tool. In what, it is possible to simulate and visualize the motors movements as a function of a path. For those two cases was investigated for example in this paper.

Case 1: circular path as shown in Fig. 5.

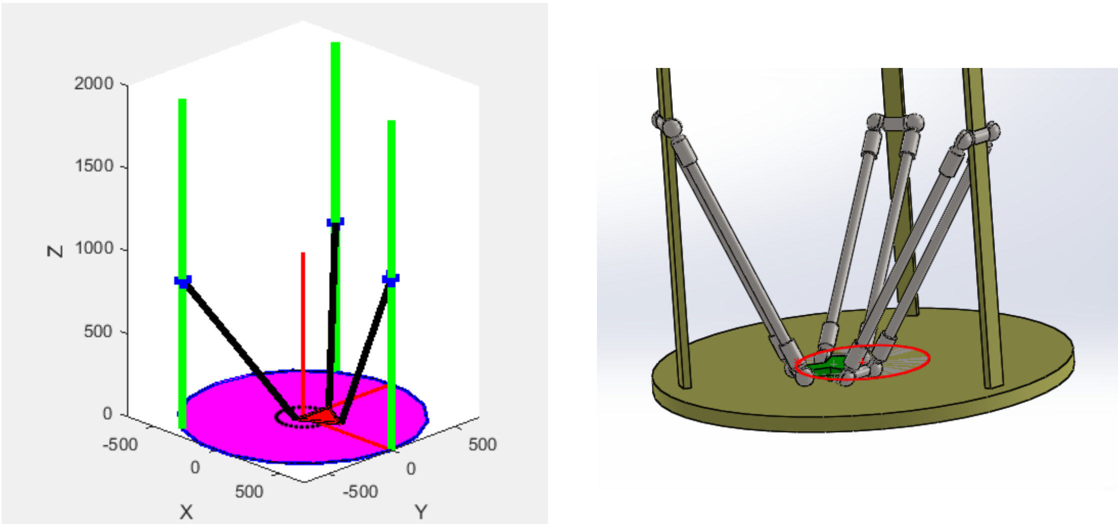


Fig. 5. Circular toolpath a) in MATLAB and b) in Solidworks

Simulation of the kinematic model with Matlab automatically converts the mathematical equation model into motor position curves based on the tool path in the machine tool workspace. For this path, the motors are moved linearly along the Z axis. The results of this simulation are shown in Figure 6.

The validation of the results of this trajectory is done with Solidworks motion software for the machine tool as shown in figure 7, the results obtained by this study is reported in figure 8.

Solidworks automatically converts the geometrical toolpath into motor position curves based on the structure of machine tool. For this path, the motors are moved linearly along the Z axis. The results of this simulation are shown in Fig. 8.

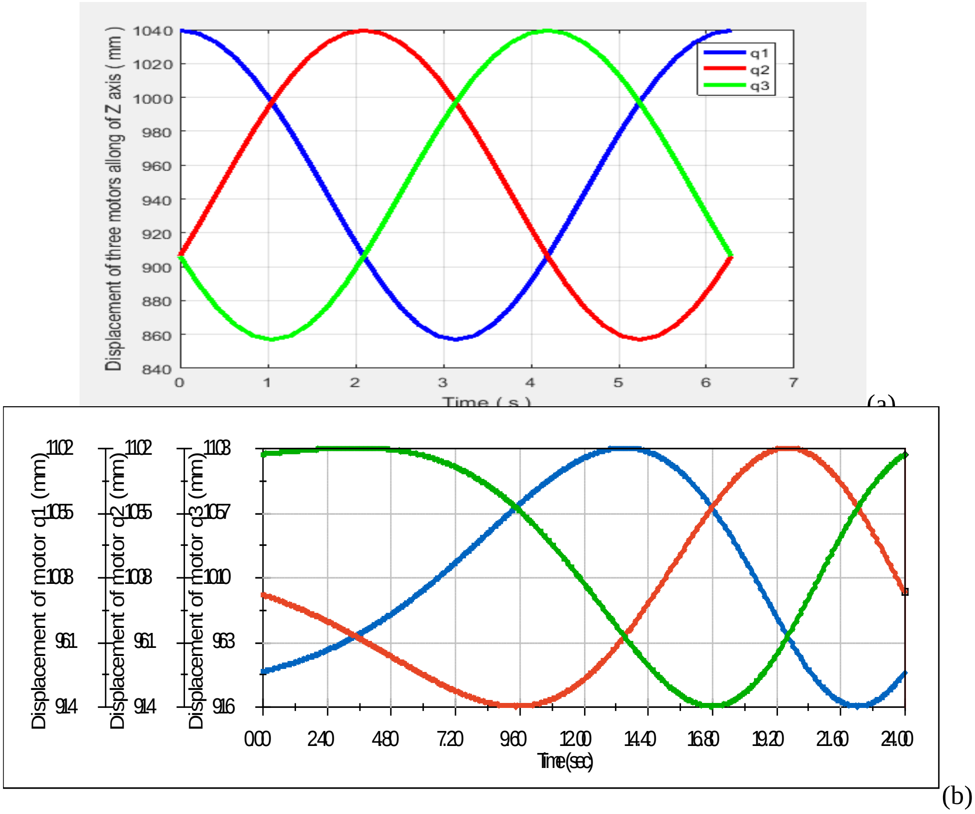


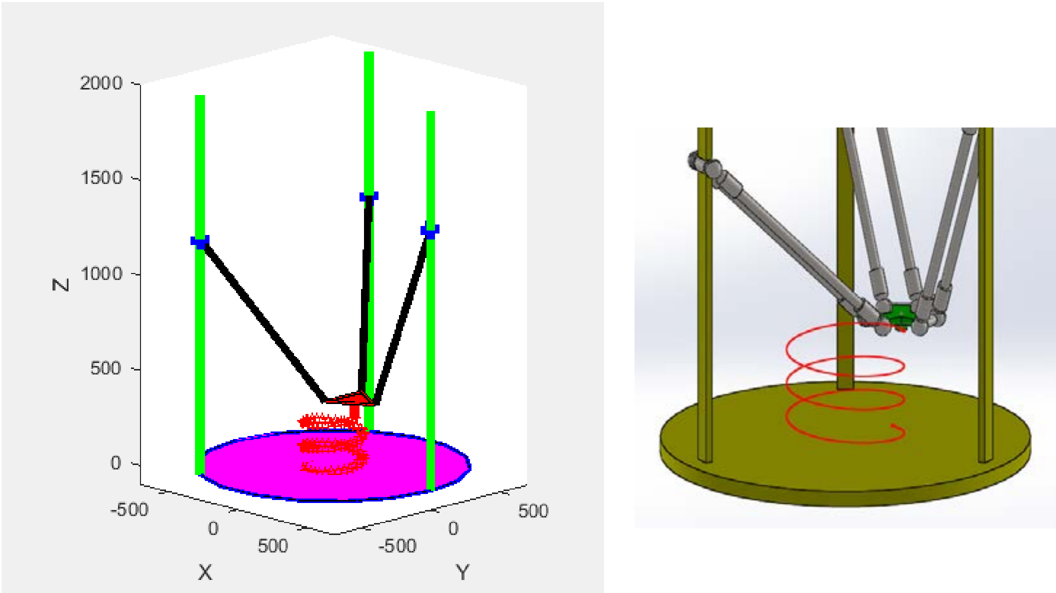
Fig. 6. Actuators displacement using a) Matlab and b) Solidworks

The previous results for the two tools used here, show that the motor displacement curves for a 300mm circular path, simulated with Matlab, are almost the same found by Solidworks. The displacement resultats is near the 190 mm in the two cases. There is a difference in the time of the study between solidworks motion and Matlab for the raison of the difference in the value of speed used here.

Case 2: spiral path as shown in Fig. 7.

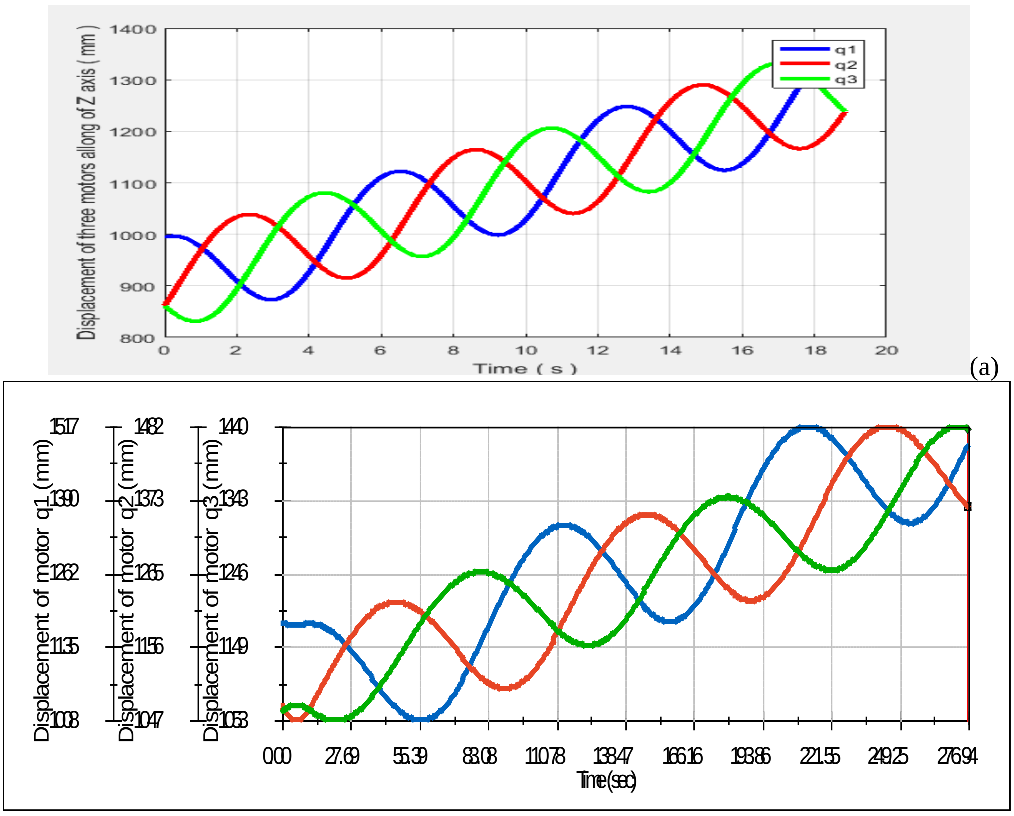
For this study, the determination of the motors positions is simulated with Matlab, we use a complex trajectory, and we let the center of the mobile platform (the tool) follow a spiral path of diameter 300 mm and a step of 20 mm as shown in figure 7. The displacement of each actuator is calculated and represented in figure 8.

The validation of the results of this trajectory is done with Matlab and Solidworks motion software for the machine tool.



(a) (b)

Fig. 7. Spiral toolpath, a) in Matlab and b) in Solidworks



(a)

(b)

Fig. 9. Actuators displacement using a) Matlab and b) Solidworks

From these results, we find that the motors displacement curves for this trajectory found with Matlab and Solidworks motion are practically the same. The displacement resultats is near the 390 mm in the two cases. There is a difference in the time of the study between solidworks motion and Matlab for the raison of the difference in the value of speed used here.

5. Conclusion

In the paper, a geometric model of a parallel kinematic machine tool was used to develop equations of motion that connect the mobile platforme to the fixed platform. The structure of the machine tool was built and the simulation was performed using Solidworks motion and Matlab software.

The Matlab program is very able to study the trajectories of the motors according to the trajectory of the cutting tool from the equations of the geometric model. Knowing the tool path, we can determinate the appropriate positions occupied by the motors to generate this trajectory. Solidworks allows to finding the positions of the motors according to the proposed trajectory by using the CAD model of the machine tool. An agreement between Matlab results and Solidworks results has certainly been obtained here, which shows that our model is valid.

We note here that Solidworks motion simulation is a power full tool to modeling these kinds of machine, because it presented with more realities the joint between solid (links) in comparison with Matlab software.

The results presented show that the kinematic model of the machine tool is a main point to make several study as example the study of the trajectories of the cutting tool, the optimization of the structure of the machine tool and the optimization of the toolpath. We can use these results in programming the machine tool.

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