Development of a 2-Dof Parallel Kinematics Machine for Macro Scale Products

Nor Liyana Maskuri, Muhamad Husaini Abu Bakar and Ahmad Razlee Ab Kadir

Abstract This paper presents a new computer numerical control (CNC). The revolution of a parallel kinematics machine (PKM) is reducing many problems in the manufacturing process from a theoretical and practical point of view. The experimental setup was developed to optimize the kinematics design of a 2 Degree of Freedom (2 DoF) planar parallel manipulator. The excellent workspace design without link collision is presented in this paper. It was observed that increasing the precision in the PKM modeling, reduces the drawback of the existing product. The result is obtained from the various experiment which were plotted graphically and discussed in this paper.

Keywords Computer numerical control (CNC) · Parallel kinematics machine (PKM) · 2 degree of freedom (2 DoF)

1 Introduction

Nowadays, computer numerical control (CNC) machines are widely used in the manufacturing industry. Many industries use CNC machines for production, but they face difficulties in the machining process, i.e., complex shapes design, and various sizes in production [1]. Parallel kinematics machines offer various potential benefits for machine tools, but they also cause many disadvantages in the design process and radical efforts for precise control and calibration [2]. Parallel kinematics

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offer, for example, higher stiffness and at the same time higher acceleration performance than serial structures (serial manipulator) [3, 4]. Other features and concepts are based on the structure selected, the configuration selected for the central point of the device and the position with the interior of the workspace.

The problem arises when the limit workspace of the parallel kinematics machine is decreased because of the link collision problem. A huge machine requires a large space which is not suitable for the macro size fabrication and may cause some waste. In this paper, the focus has been chosen to take the links as the main purpose of the project to avoid the links collision with the wider reach in the workspace section.

2 Literature Review

2.1 Computer Numerical Control

Computer numerical control is the machine tools automation that is operated by precisely programmed commands encoded on a storage medium as a device to control manually, wheels, levers or mechanically automated by cams alone.

2.2 Parallel Kinematics Machine

The parallel kinematics machine is a revolution of a machine tool which was firstly shown at the 1994 in Chicago. There is a reliable and complex link among the type of parameters and its performance. It is difficult to choose the geometrical parameters in such a way as to optimize the performance. The configuration of parallel kinematics is more complicated due to the high sensitivity to variations of the design parameters [5]. This is the reason why the design process is an essential key to the overall performance of a parallel kinematics machines. Figures 1 and 2 show the concept of parallel kinematic machine.

2.3 Benefits of Parallel Kinematics Machines

High dynamical performance is achieved due to the low moving masses. Due to the closed kinematics, the movements of parallel kinematics machines are vibration free for which the accuracy is improved [6]. This can recover the drawback of the application of series manipulators. Furthermore, the modular concept allows the cost-effective production of the mechanical parts.

Fig. 1 Bipod parallel kinematics mechanism

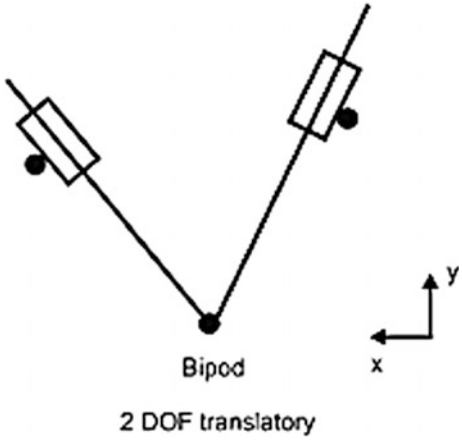
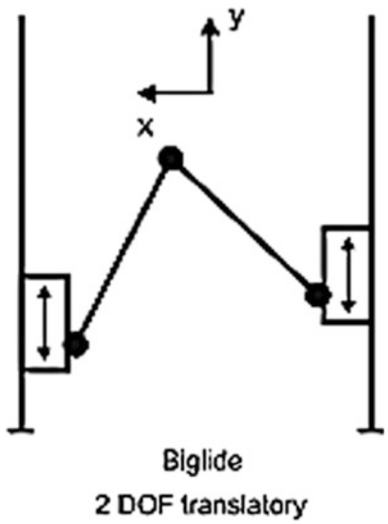


Fig. 2 Biglide parallel kinematics mechanism



2.4 Design and Simulation Analysis

SOLIDWORKS Simulation provides core simulation tools to test the designs and to make the decisions to improve quality. The full integration creates a short learning curve and eliminates the redundant tasks required with traditional analysis tools. Component materials, connections, and relationships defined during design development are fully understood for simulation.

2.4.1 Motion Analysis

This task includes to perform physics-based kinematic and dynamic analysis, using existing SOLIDWORKS software together with motion features to calculate the exact motion behavior. Furthermore, it allows to determine part and assembly displacements, velocities, and accelerations. Also, SOLIDWORKS Motion Study Analysis show the results as an animation or a graph. Selecting a point on the design allows the creation of a trace path that can be used in subsequent design processes.

3 Methodology

This part describes in detail the entire methodology on the two-degree-of-freedom parallel kinematics machine for macro scale product. The computer aided design (CAD) model of parallel kinematics machine is drawn in the SOLIDWORKS software and optimizes the workspace, kinematics chain (leg), prismatic (P) rotating (R), motion, and force transmission [7]. The model of parallel kinematics machine file was transferred to the simulation SOLIDWORKS software to synthesize the parallel kinematics machine model in detail by a simulation method. Then, based on the simulation method by the SOLIDWORKS software can be characterized the behavior of parallel kinematics machine. In this chapter describes the procedures to investigate the performance of parallel kinematics machine.

For the experimental setup, the analysis has been divided into three sections which are CAD model analysis, mathematical model analysis, and performance

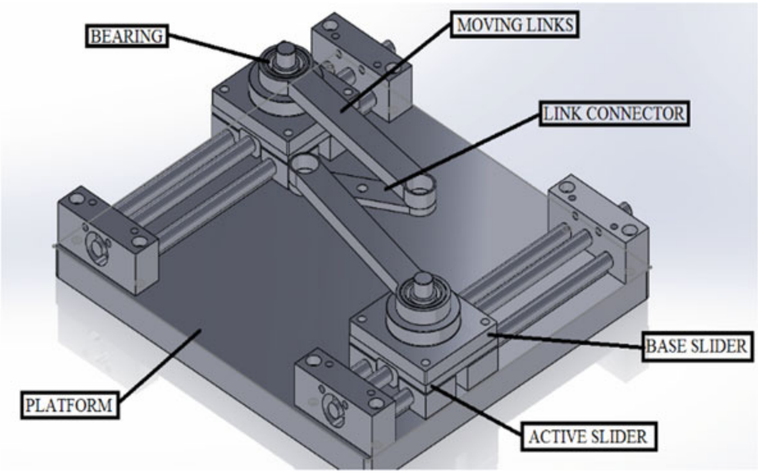


Fig. 3 Parallel kinematics machine in SOLIDWORKS

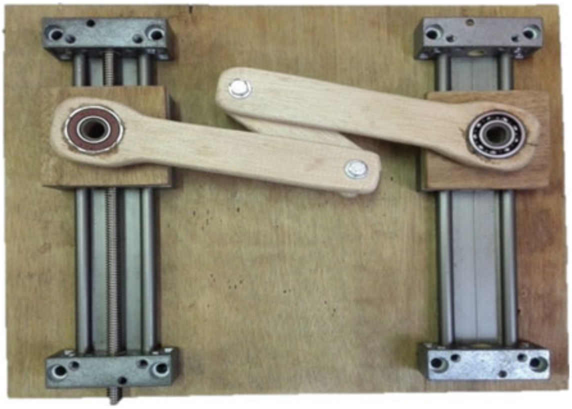


Fig. 4 Parallel kinematics machine prototype

analysis. The analysis has been done three times for every section. For the CAD model analysis and performance analysis, the point is gained from the SOLIDWORKS measurement in Fig. 3, and the actual size parallel kinematics prototype model in Fig. 4.

The mathematical model analysis has been done for the three types of the equations. The equation are the inverse solution of the kinematics, the direct kinematics of the manipulator and the singularity analysis. Figure 5 shows the assumed kinematics point for mathematical model.

Inverse Solution of Kinematics

$$y_1 = y + \sqrt{l_1^2 - (x - r + R)^2}$$

$$y_2 = y + \sqrt{l_1^2 - (x + r - R)^2}$$

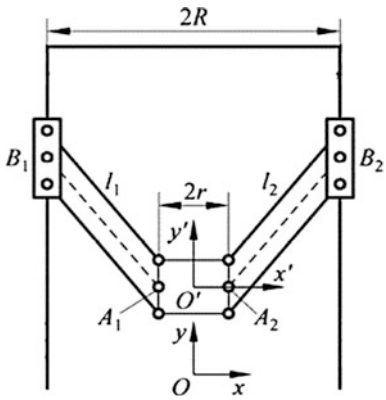


Fig. 5 Parallel kinematics structural model

Direct Kinematics of the Manipulator

$$y = \frac{-(2af - 2y_1) \pm \sqrt{f^2 + 4(a^2+1)(l_1^2 - y_1^2 - f^2)}}{2a^2+1}$$

Singularity Analysis

$$\dot{y}_1 = \dot{y} - \frac{x - r + R}{\sqrt{l_1^2 - (x - r + R)^2}}\dot{x}$$

$$\dot{y}_2 = \dot{y} - \frac{x - r + R}{\sqrt{l_1^2 - (x + r - R)^2}}\dot{x}$$

4 Result and Discussion

The mechanism of the parallel kinematics machine is composed of a moving platform, effective slider, kinematics chain or links, and the center connector. Two parallelogram chains were used to make the structure symmetric and to increase the stiffness. The kinematics is analyzed to get an optimum kinematics design. The analysis has been divided into three sections which are the CAD model analysis, the mathematical model analysis, and the performance analysis. The analysis has been done three times for every section. For the CAD model analysis, the point is gained from the SOLIDWORKS measurement and the actual size parallel kinematics prototype model. The percentage error graph is presented in Figs. 6, 7, 8 and 9. The sliders motion is increased for every 15 mm for the single arm meanwhile another arm is fixed, and the data are collected, and the average of the percentage error is released. The experimental setup for this section to get data is fixing the left arm and let the right arm to move 15 mm above and so on. Then, the points are taken for three times and the percentage error is found. From the data of the percentage error, the average point is gained.

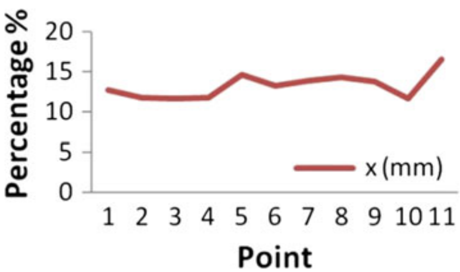


Fig. 6 Graph of the x-axis at right arm

Fig. 7 Graph of the y-axis at right arm

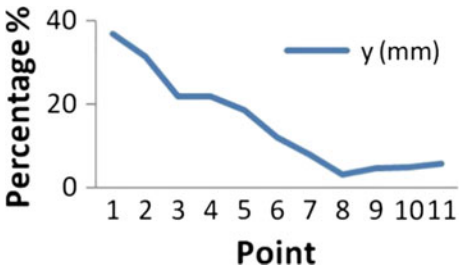


Fig. 8 Graph of the x-axis at left arm

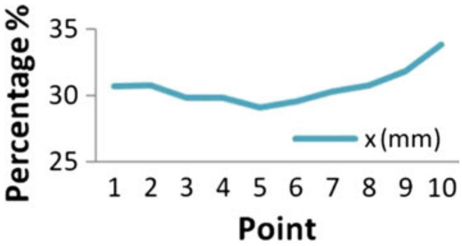
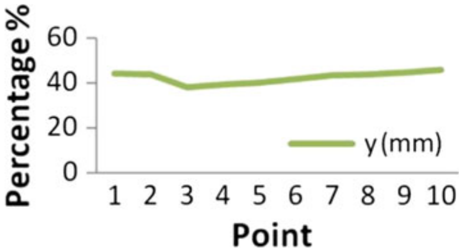


Fig. 9 Graph of the y-axis at left arm



$$x_t = \frac{x_{sw} - x_{ac}}{x_{ac}} \times 100$$

The graph in Fig. 6 shows that the result gained from the occurring percentage error occurs. For the x-axis at point 1 to point 4, the percentage is maintained but increases at point 5, the point is constant again and drops at point 10 but increases again at point 11. Meanwhile, for the y-axis in Fig. 7, the graph is a decreased from point 1 until point 3 but is constant in point 3 to point 4. Then, for the point 5 to point 8 the graph is decreasing but instantly increases at point 11. The error may cause the rotation by the bearing which is rough, and friction occurs.

The experimental setup for this section to get data is fixing the right arm and let the left arm to move 15 mm above and so on. Then, the points are taken for three times and the percentage error is found. From the data of the percentage error, the average point is gained. The graph in Figs. 9 and 10 show that the result gained from the percentage error occurs in point of the x-axis. For both of these graph, the point is in the average rate and stable. However, the error still occurs due to the

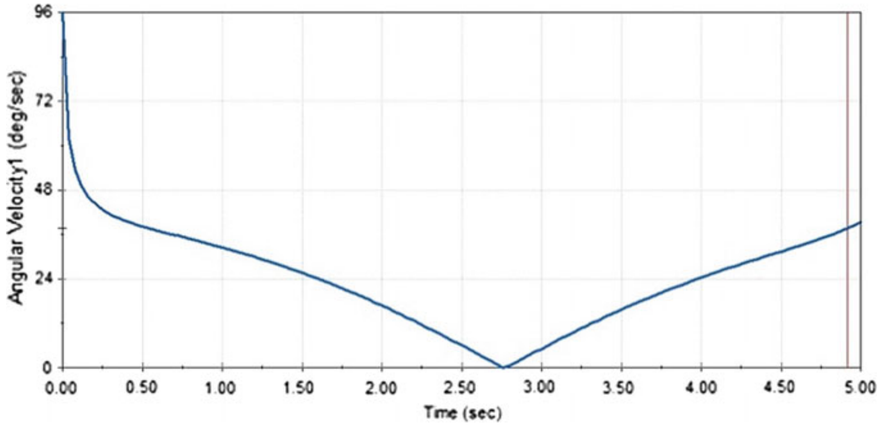


Fig. 10 Graph of the angular velocity

manufacturing error and enlargement of the actual size. The actual arm size is on the larger size because of the material is wood, and the drawback of wood is that may crack if the size is too thin.

The SOLIDWORKS motion analysis has been done, and these three graphs are released. The first one is the angular velocity graph. The angular velocity of a rotating body is defined as the rate of change of the angular displacement and is a vector quantity for more precisely specifies the angular speed or rotational speed of the links and the axis about which the object is rotating. In Fig. 10, the higher point is decreased due to the movement of both links downward and the point increased due to both links moving upwards.

The angular displacement of a body is the angle in radians is degrees and revolutions through which a point or line has been rotated in a specified sense about

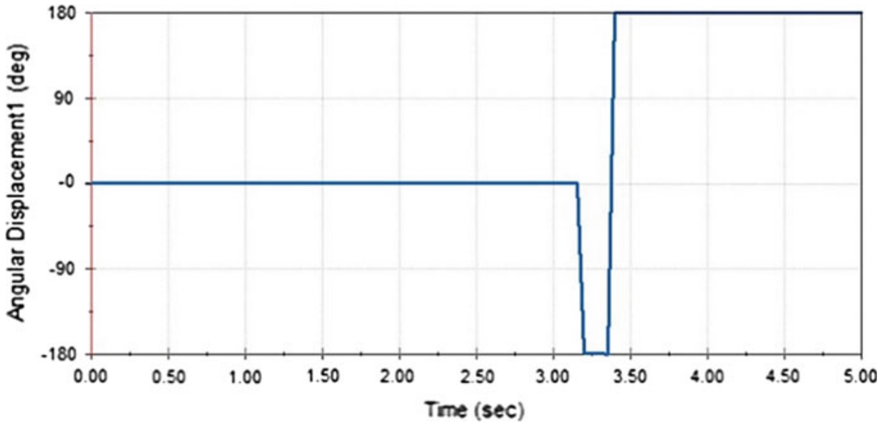


Fig. 11 Graph of angular displacement

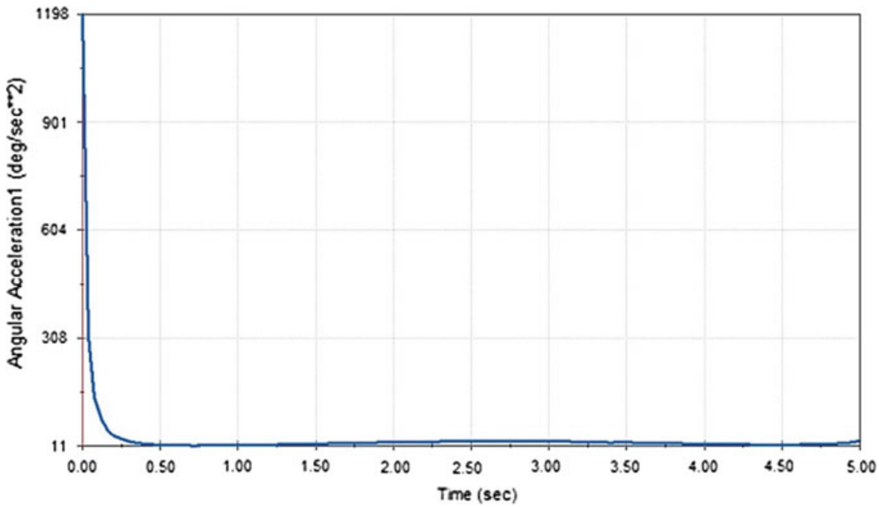


Fig. 12 Graph of angular acceleration

a specified axis. This situation can be described as an object rotates about its axis, the motion cannot merely be analyzed as a particle since in circular signal it undergoes a changing velocity and acceleration at any time (*t*). When dealing with the variation of an object, it becomes simpler to consider the body itself as rigid. In Fig. 11, the displacement motion is constantly stuck in the 0° position, and the line is decreased and increased back due to the movement of link, which change the motion position.

The angular acceleration is the amount of the conversion of angular velocity. In SI units, it is measured in radians per second squared (rad/s^2). The graph shown in Fig. 12 is about the point at the line graph which starts high and drops sharply and constant at the single point. This situation occurs due to the high acceleration when the motion starts, and the line graph was dropped and maintained caused by the angular acceleration is maintained to the single point. In the other hand, the third experiment is the mathematical model. In this section, the data collected from the actual fabrication size and the drawing size from the SOLIDWORKS to find the error. The result is valid, and the error percentage is small. For the mathematical model, the error between the actual size and the SOLIDWORKS size is only 2.364% for y_1 and 0.839% for y_2.

5 Conclusion

The focus of this project was to develop the parallel kinematics machine with 2-DOF for macro scale products. About the research objectives, this project was successfully conducted where all objectives were achieved. The motivation is to avoid the link collision, maximize the use of workspace in the compact size machine and performance evaluation of the parallel kinematic machine.

The analysis has been divided into three sections which are the mathematical model analysis, CAD model analysis, and performance analysis. The analysis has been done three times for every section. For the CAD model analysis, the point is gained from the SOLIDWORKS measurement and the actual size of the parallel kinematics prototype model.

The analysis done in SOLIDWORKS is to determine the maximum distance point with the new concept of parallel kinematics machine. These values are then used to calculate and differentiate with the prototype model data. With all of the data from the simulation and CAD model design, the parallel kinematics machine has been done as the most practical to use with the compact and simple device. The purpose of carrying out the design of the parallel kinematics machine prototype is to compare the data.

Moreover, the distance between two links is determined by optimum design, so the link collision problem has been avoided. Parallel kinematics machine performance has been evaluated by the comparison of CAD model and the actual fabrication. For the mathematical model, the error between actual size and SOLIDWORKS design size is only 2.364% for y_1 and 0.839% for y_2.

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