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Analysis And Optimum Kinematic Design Of A Parallel Manipulator For Micro Motion Application

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ABSTRACT:

This paper presents a unique micro-motion parallel kinematic manipulator (PKM) With a three degrees of freedom (3-DOF). The 3-DOF micro-motion manipulator has three linear-motion driving units and have a passive link in the center of the structure.The purpose of this passive link is to restrain the movement of the manipulator and to improve the stiffness of the structure. As a result, the structure support 3-DOF, including one translation on the Z-axis and two rotations around the X and Y axes. In this project, the inverse kinematic, Jacobian matrix and stiffness analyses have been conducted, followed by the design optimization for structures. Finally, the FEA (Finite Element Analysis) and dynamic analysis have also been performed. There are many practical applications for micro-motion parallel manipulators. The typical applications include micro-machine assembly, biological cell operation, and micro-surgery.

KEYWORDS:-Micro MotionParallel kinematic manipulator,Prismatic - Universal – Spherical Joints, Design. etc..

I. INTRODUCTION

There is an abundance of research on the Parallel Kinematic Manipulator (PKM), most of which examines either the Micro Machine or Micro Motion Structures.Recently, there has been an increasing trend in the research of micro machines, as industries want to make current machines smaller, more energy-efficient and precise.

There are many benefits of micro machines, especially in comparison to regular machines. For instance, they are relatively small, they have a higher precision and they consume much less energy than a regular machine. These characteristics make micro machines popular in the fields of information and telecommunications, medicine, biotechnology, and the automotive industry. Specifically, micro machines are regarded as a vital component for strengthening international competition in major areas of the manufacturing industry. Applications related to these machines are expected to be in high demand by many companies in the near future.

The application of the micro machine tool, especially with its high degrees of precision and speed, provides significant benefits for the manufacturer. Specifically, it can help to increase the accuracy and precision in production, and the recent trends towards high-speed micro machining have been a very popular field of research in developing new types of parallel kinematics machines.

Three Degrees of Freedom (DOF) is the basic requirement for the parallel kinematics machines. Since most machine operations only require a maximum of 5 axes, new configurations with less than six parallel axes would be appropriate for these operations. A substantial amount of research has been conducted on the 3-DOF parallel kinematics manipulator.

The 3-DOF Micro-Motion Parallel Manipulator can be applied to precision manufacturing and assembly

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for small parts ranging in size from millimeters to micrometers. Micro Machine Tools are in demand worldwide, and their popularity will also turn Micro Motion Mechanisms into machines that can perform small motions and have very high accuracy. In the subsequent sections, parallel kinematic manipulators will be introduced, then micro motion structures will be discussed, and finally, the new design of micro motion structures will be described.

A. Parallel Robotic Machine Tool

A parallel kinematic manipulator (PKM) is a closed-loop mechanism, where a moving platform is connected to the base by at least two serial kinematic chains, or legs. The PKM has enormous potential for overcoming the disadvantages of serial robots. First, this device is more accurate, since its moving components are more strongly related and the link errors are not accumulated. Furthermore, it is much more rigid than a serial robot, as the same end-effectors are simultaneously supported by at least two kinematic chains. Lastly, it has a much lighter moving mass, as all of the actuators are mounted on the base, allowing it to function at a higher speed and with greater precision.

B.Parallel Robot Based Micro Motion System

Precise micro-motion manipulation has become increasingly important in many applications, such as small parts precision machining, chip assembly in the semiconductor industry, cell manipulation in biotechnology, and automatic surgery. The micro-motion system has been strongly recommended by researchers around the world, as it its materials are less expensive and it is more energy efficient.

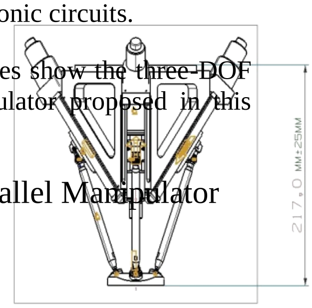
The advantages of the micro-motion parallel kinematic manipulator can be summarized in the following points

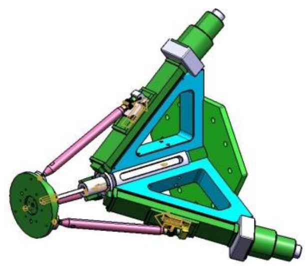
- Lower Inertia
- Improved Dynamic Behavior
- High Speed and Acceleration
- Smaller Package Size
- Greater Stiffness
- Increased Repeatability and Reliability

Some applications have special requirements, such as limited space for installation and workspace requirements that are much larger than applications with a Nano-scale structure. The newly developed designs intend to meet these two objectives, as this micro-motion manipulator has been used successfully in areas such as jewelryengraving and micro-precision machining for electronic circuits.

The illustrations below, Figures show the three-DOF micro-motion parallel manipulator proposed in this project

Micro-Motion Parallel Manipulator





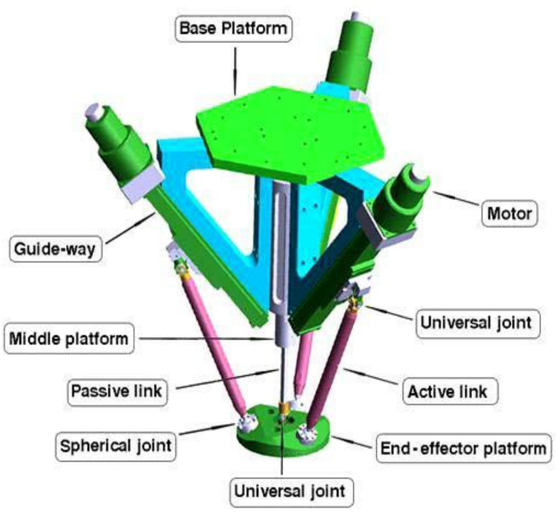
CAD ModelLine diagram

This research examines the feasibility of a novel 3-DOF parallel manipulator used for machining applications. The unique design of the manipulators aims at achieving higher stiffness and greater 3-DOF motion by eliminating all side-effect motions. This manipulator consist of three or four identical legs with active actuators, or driving motors, which accomplish their movement through the motion of precision ball screws. Each of the actuated legs is connected to the moving platform by a spherical joint, and both manipulators have one passive leg installed between the base and the moving platform. The passive linkcan only have linear motion on the middle platform, while the other end is connected to the moving platform by a universal joint, eliminating the rotation of the z-axis.

C. Description of the Micro-Motion 3-DOFParallel Manipulator

The micro-motion 3-DOF parallel kinematic manipulator proposed in this project contains three active links and have a passive link that is connected by a moving platform and a fixed base. This active links are manipulated by a high-precision ball screw that controls linear motion units and provides high speed as well as a rapid response for the moving platform.

Accordingly, Figures shows a novel parallel manipulator CAD model. The first 3-DOF parallel kinematic manipulator, known as 3-DOF PKM, is shown in Figure. This manipulator consists of four kinematic chains, including three actuatedmoving links with an identical topology, and one passive constraining link connecting the fixed base to a moving platform. The three actuated moving links are designed as PUS (Prismatic - Universal – Spherical) Joints. The passive constraining link, which connects the base centerto the platform center, consists of a prismatic joint and a universal joint attached to the moving platform. This last leg is used to constrain the motion around the z-axis rotation of the platform to only three degrees of freedom.



CAD Model with Components Description

D. Potential Applications

The newly-developed micro-motion manipulators have accomplished increasingly demanding tasks in fields where high speed and high precision are required. They can be modified for utilization as machine tool heads, and the tool heads can be attached to existing systems, such as CNC machines, robots and CMM, to expand their motion range and their dexterity.

Hence, based on the design of these structures, this 3-DOF micro-motion manipulator has been constructed with a 50 mm stroke along the z-axis and a 50° rotation on the x-axis andthe y-axis. They also have a 125mm moving platform diameter and a 250mm base platform diameter; however, these specifications can be modified according to the individual requirements.

Some potential applications include:

- Watch industry
- Assembly of micro-motors
- Assembly of micro-sensors
- Assembly of micro-technological devices
- Packaged system

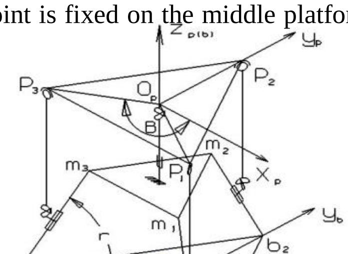
E. Kinematic Modelling of the 3-DOF Micro Motion manipulator

Unlike most existing 3-DOF parallel kinematic manipulator designs, the new design has improved the system's stiffness by using a passive leg which was connected the moving plate with a universal joint in the center of the moving platform. This design also eliminated the coupled motions at the reference point to simplify the kinematic model and the control.

As shown in the below Figure, this parallel manipulator includes a universal joint in the passive link. It is located on the moving platform rather than the base platform so that the motions along *X* and *Y* translations and *Z* rotation are eliminated.

The reference point is on the middle of the moving platform, which has uncoupled motion with *X* and *Y* rotations and *Z* translation. The proposed manipulator has threeplatforms: base platform, middle platform, and moving platform.

The base platform is fixed on the ground. The middle platform is used to support guide-way of actuated links. The moving platform is used to mount a tool. Actuated links are connected to the moving platform by a spherical joint (ball joint) at and toa slider connected to the active ball screw by a universal joint. The passive link is installed between the middle platform and the moving platform. The passive link with a prismatic joint is fixed on the middle platform at



one end, and connected to the end-effector platform by a universal joint at the other end.

Schematic Model of 3 –DOF Micro Motion Parallel Manipulator Model

F. Design Optimization

The Genetic Algorithm (GA) is an excellent method for solving both constrained and unconstrained optimization problems. This algorithm repeatedly modifies a population of individual solutions based on the principle of natural selection. In each step, the Genetic Algorithm selects random individuals from the current population as parents and uses them to produce children for the next generation. Throughout each generation, the population progresses towards an optimal solution. The Genetic Algorithm can be applied to solve a variety of optimization problems, including problems where the objective function is linear, nonlinear, continuous and Discontinuous differentiable and non-differentiable.

In this Paper, the stiffness of a parallel manipulator is expressed by a 3 × 3 matrix. In this case, the GA is applied for optimizing the global stiffness (*val*) of the micro-motion parallel manipulator. The diagonal elements of the parallel manipulator stiffness matrix represent the manipulator's pure stiffness in each direction [20] (Zhang 2000). To obtain the maximum stiffness in each direction, the following objective function, which is called the fitness function for the GA, is used.

$$Val= k_{11+} k_{22}+ k_{33}$$

where k_{ii} (i 1, 2, 3) represents the diagonal elements of the 3-DOF parallel manipulator's stiffness matrix. Subsequently, the next objective is to maximize *val* in the GA.

Parameters need to be set up before the GA is utilized. First, the fitness function, which is the function of the objective being optimized, should be created. In this case, the fitness function is represented in Eq. (5-1). In order to maximize f(x), -f(x) can be minimized.

Secondly, the number of variables should be determined. In this structure, there are three design parameters, which are considered to be the optimization variables. Specifically, they include the length of the leg "*l*", the dimension of the end-effectors "r" and the basedimension"r".

G. Simulation and Comparisons

In this,we conducted a Finite Element Analysis and a Dynamic Study. The purpose of the FEA and the Dynamic Study is to improve the design of the structures and to optimize the model sizeFinite element method (FEM) analysis plays an increasingly important role in engineering practice, as it is relatively inexpensive and efficient in comparison with physical experiments. Currently, FEM is utilized in almost all of the engineering fields, as it is a powerful tool in predicting the ultimate loads and the complex failure modes of 3-D structural members.

In this research, the purpose of FEM is to find the maximum and minimum stress points. This section examines the three-dimensional solid models, which are developed using Unigraphics NX6.

For the FEM conditions, the reasonable press force of 25N was applied to the moving platform, and the maximum stress on the components was calculated. Subsequently, the result can be exported as the stress, strain or displacement of the specific part of the structure. In order to compare the two proposed structures, the geometric size of the manipulators was made equal. From the FEM results, the maximum and minimum deformation areas were found.

H. Velocity and acceleration Analysis

The dynamics of PKMs involve the science of studying the forces required to cause motion. To accelerate a PKM from rest to a desired speed, or to decelerate it from a certain speed to rest, a complex set of forces or torques must be applied by joint actuators.

Therefore, finding the relationships between the accelerations, velocities and positions of the end-effector and the joint forces is the main task in this dynamic analysis. These relationships canbe obtained by dynamic modelling, or more specifically, by finding the dynamic equations of motion. The equations generally serve two purposes for PKMs: control and simulation. When controlling a PKM in a desired motion, the actuator torques need to be calculated using the dynamic equations of motion. On the other hand, by rearranging the dynamic equations so that the accelerations and velocities are computed as the function of the actuator forces and torques, it is possible to simulate the way in which a PKM would move under the application of actuator torques. An understanding of manipulator dynamics is important from several different perspectives. First, it is necessary to properly define the size of the actuators and the other manipulator components. Without a model of the manipulator dynamics, it is difficult to predict the actuator force requirements, and, consequently, it is challenging to properly select the actuators. Second, a dynamic model is useful for developing a control scheme. With an understanding of manipulator dynamics, it is possible to design a controller with improved performance characteristics. Moreover, some control schemes, such as the computed torque controller, rely directly on the dynamic model in order to predict the desired actuator force used in a feed-forward manner. Third, a dynamic model can be used for a computer simulation of a robotic system.

Progress till date: -

IN this, A newly developed micro-motion 3-DOF parallel manipulator which is a 3-DOF micro-motion parallel manipulator is proposed. Throughout the work, the CAD models for the design have been created, the inverse kinematics for the structure have been analyzed, and the Jacobian matrix has been derived. Additionally, stiffness models and maps were presented, the optimization of global stiffness for the PKMs were performed and the optimal design parameters have been suggested. Finally, the Finite Element Method (FEM) analysis and the dynamic analysis have been performed for the structure. The work with in the project is highlighted below.

The CAD models for the micro-motion 3-DOF parallel manipulators have been created with Unigraphics. They are designed and developed to perform the translationalong the z-axis and rotations about x and y axes. Their unique design eliminates side-effect motions, so that they only exhibit pure 3-DOF motions, and it improves the stiffness of mechanism by applying the passive link. Both inverse kinematics have been successfully examined, and the Jacobian matrix and velocity equations were fully derived.

The stiffness analysis of the proposed manipulator is done.

For the optimization of global stiffness, the optimal parameters are obtained for the 3-DOF micro-motion parallel manipulator after few generations.

FEM analysis has been used to modify the design parameters in the research. The purpose of FEM analysis is to allow a modification of the parameters and to improve structure for future applications.

Dynamics analysis is the science of studying the forces required for causing motion; it plays an important role in the trajectory generation and control of parallel robots. In the analysis of velocity and acceleration, the simulation results have been completed.

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