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Micro/Macro Approach for Dexterity Enhancement of PKM's

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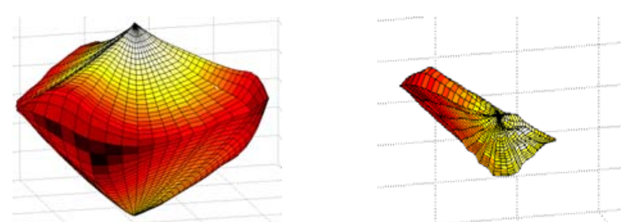
Abstract: *The Stewart-Gough, extendable strut type parallel kinematic mechanism (PKM) tends to lack sufficient dexterity over any sizeable workspace volume. This is particularly true for applications such as robotic deburring and machining. This paper describes the concept of micro/macro system integration of a PKM and a two-degree of freedom micro-manipulator. The particular application focus is on automated deburring and finishing systems.*

1 Introduction

Roots of development of parallel structures can be found in the late 1800's when the first theoretical article on parallel structures was published by Maxwell in 1890. In 1965, Stewart developed a 6-degree of freedom parallel structure for use as a flight stimulator called the 'Stewart platform'. Since this time parallel kinematics is seen as a promising research area, with a wide range of applications. A recent survey shows PKM's used in robotics, measuring machines, machine tools, positioning devices, and other special applications related to production. Equipped with today's fast computing devices, implementation of advanced controllers is also being achieved on PKM's (Tönshoff, 1998).

However, at the onset of parallel kinematic mechanisms used as machine tools, great claims were made regarding their dexterity, stiffness and range of motion. Many of these claims were an over statement of the PKM designs capabilities (Fassi and Wiens, 2000). Inspite of recent developments, PKM's have some inherent drawbacks like low work volume to size ratio, limited dexterity and shrinking of work volume with tilt in platform angles, see Figure 1. Furthermore, PKMs generally do not have ability for continuous rotation about its platform's vertical axis. These limitations become a particular problem for applications such as finishing and deburring which require controlled forces normal to an edge or surface contour. A limited number of PKM's have been developed for such applications, e.g. 3 dof Tricept PKM with deburring head attached and shoe deburring PKM (Molinari-Tosatti, et al., 2000). To overcome these drawbacks, the University of Florida System Automation and Mobility in Manufacturing (SAMM) Laboratory has designed a 2-degree of freedom micro-manipulator system operating under hybrid controller. This paper presents the 2-degree of freedom micro-manipulator as a subsystem of a micro/macro parallel kinematic mechanism as a new approach for increasing the dexterity of PKM's therefore, providing a vectorized rotational dexterity for finishing complex shapes and contours, see Figure 2.

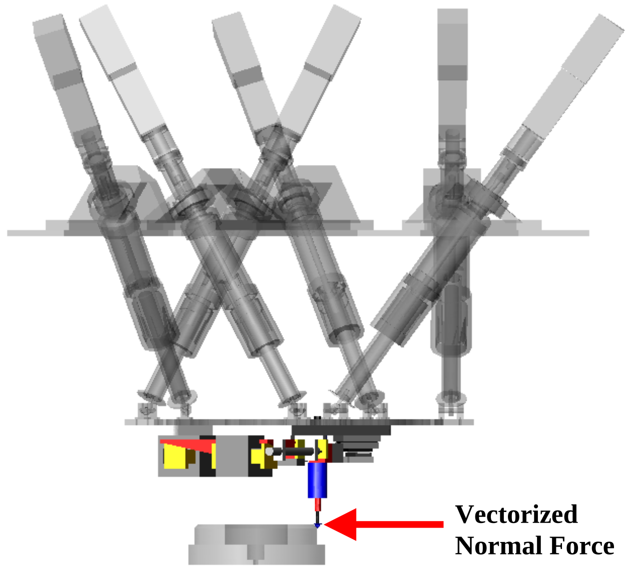


Horizontal Platform   Platform Tilted 15 degrees

Figure 1. Workspace Reduction with Dexterity

2 Background

Deburring operations are expensive and increase the cost of manufacturing. Burrs are sharp and relatively small projections that form along the edges on the work piece that is machined or stamped. In most cases, these burrs must be removed for improved product/system performance, safety, cost, ease of assembly, elimination of stress risers, proper tolerancing, appearance, etc.



(a) Side View

(b) Final Assembly

Figure 2. UF-SAMM Laboratory Micro/Macro Automated PKM Finishing System

In manual deburring a person moves a deburring knife/file or a high-speed cutting tool along the desired edges of the work piece, maintaining a constant normal force on the tool. This process is time consuming and involves risk of part rejection, especially in cases of complex and thin walled sections. Due to repetitive task injuries and the hostile environment associated with manual deburring, corporations also suffer from large turnover rates. This has promoted the increased interest in automatic deburring and chamfering machines, as seen during the past decade.

Existing robots/machine tools typically operate as positioning devices, moving a cutter through a programmed trajectory. They generally lack the ability to control proper direction and force with respect to burr variation. Attaching an active micro-manipulator as end-effector tooling has been found to be effective in providing existing systems controlled compliance in the direction of burr variation. However for varying contours, the positioning device has to change its orientation continuously to maintain the constant normal force along the desired trajectory. This can result in long cycle time and tedious CNC/robot programming. The SAMM Laboratory's macro/micro system eliminates the orientation issues through controlled vectorized chamfering and deburring forces. In addition, this system uses event-driven control yielding tighter toleranced edges and surfaces and a reduction in the need for multiple passes for finishing.

3 New Micro/Macro PKM Design

The SAMM Laboratory PKM is divided into two-sub systems: Nominal Positioning Device (PKM) and Force Control Device (Two DOF).

3.1 PKM

The PKM of the SAMM Laboratory is a modular machine that can be easily assembled and dismantled. It is capable of producing sufficient forces needed for moving the finishing component while performing chamfering and deburring operations (refer to Figures 2 and 3). Design criteria for the PKM were it should be small to medium-size, maintain structural rigidity, and produce enough force to carry out finishing operation. The SAMM Laboratory's PKM adheres to a special 6-6 layout patented by Griffis and Duffy (1989). To accommodate cost restrictions, the PKM was designed using as many off the shelf components as possible. This PKM has limited rotation about its platform's vertical axes, and at a cost in workspace volume.

The main components of the PKM are a base, moving platform and six struts. Each strut consists of a telescopic cylinder. To adjust the length of the struts, one cylinder slides inside the other and this is achieved and controlled using a servomotor and ball screw arrangement. Selection, arrangement and alignment of the base and moving platform joints connecting the struts was made so that the maximum range of motion within the joints is achieved, full range of actuated motion is not restricted due to a joint limit, and each joint has sufficient static and dynamic load capacity. Six degrees of freedom of the moving platform is achieved through each of the six struts having a six degree of freedom kinematic chain of a spherical, prismatic and Hooke joint pair. A ball spline is used to form the prismatic pair. The base platform joints are hollowed spherical bearings, through which passes the ball screw/motor shaft. The joints connecting the struts to the moving platform are designed to serve two purposes. First is to allow angular motion while transmitting the linear strut forces and motion to platform and second is to provide a means to perform minor adjustments to the moving platform upon PKM setup. To accommodate both these features, simple rod ends are used.

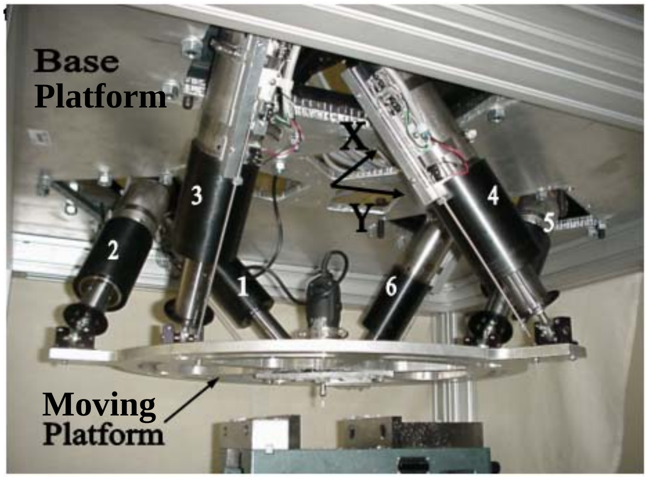


Figure 3. UF-SAMM Parallel Kinematic Mechanism

3.2 Two Degree of Freedom

The two degree of freedom micro-manipulator is designed to be attached to the moving platform of the PKM forming an automated finishing system (refer to Figures 2 and 4). It controls both normal force so as to maintain constant chamfer depth and controls tangential position of spindle along the feed direction. Due to its compliance in two directions, the application of this micro-manipulator is very effective for chamfering and deburring of parts with geometries in which the edge contours vary two dimensionally in the plane of movement of positioning device. That is providing a vectorized normal force vector. Machines equipped with this micro-manipulator do not have to change its orientation (e.g., minimizes robotic wrist/platform rotation) to maintain desired normal force. Hence, greatly saves cycle time and eliminates tedious programming. (Wiens, Musuner and Walker, 1997)

The main components of this manipulator are two VCA's (Voice Coil Actuator), two LVDT's, two single axis force tranducers, and spindle mounting bracket. The two VCA's are aligned along x and y directions at 90 degrees to each other. The spindle mounting bracket is attached to VCA-X and VCA-Y through a ball spline, ball nut and a force transducer. The assembly is done in such a way that movement of the VCA-X does not reflect the applied VCA-X force on VCA-Y and vise versa. Two cross-slides are provided to prevent moments on the force transducers. The VCA assembly base can be mounted on PKM or a stationary frame.

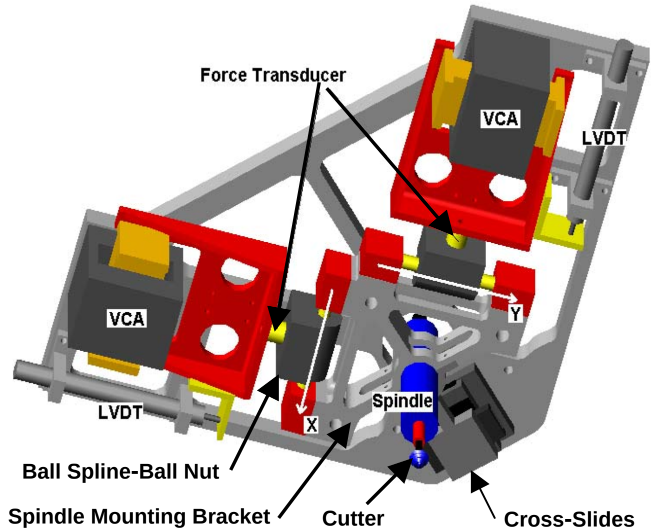


Figure 4. UF-SAMM Micro-Manipulator

3.3 Macro/Micro Assembly

The assembly of the macro/micro components allow for an easy deburring operation. The micro-manipulator has a high-speed spindle mounted at the center of its platform. Depending on the force experienced by the spindle, the controller reacts in real-time to maintain a desired normal force. If no burrs are experienced, then this force is constant. Figure 2 shows a 3-D model of the assembled machine with the cutter in contact with a sample part.

The micro-manipulator assembly is located so that the spindle is also at the center of the platform of the PKM. The PKM provides the motion along the edges of the part where the chamfering and deburring operation is required, see Figure 2. The PKM's motion does not need to take into account the presence and or shape of a burr in the plane of motion because those are already dealt with in real-time by the micro-manipulator controller. So theoretically any shape or contour within the range of the PKM can be submitted to a deburring operation by simply deriving the proper nominal (ideal) path for the PKM.

3.4 Control System

Around-the-arm force control is a method that is based on using the macro-manipulator (here PKM) for nominal positioning and motion only and a micro-manipulator for higher bandwidth force control. This method decouples the micro-manipulator's controller from the macro-manipulator's controller. The hybrid position/force control micro-manipulator can be either mounted to a stationary base or on the macro-manipulator. The micro-manipulator performs as an auxiliary tool that adds additional axes of motion to the system. Along these axes of motion, the required compliance for automated finishing tasks is provided.

There are two methods used to implement around-the-arm force control: passive and active. Passive force control is an open loop control system with no mechanism to adjust for force errors. The advantages of this micro-manipulator system are its simplicity and the cost. Closing the force loop, the active around-the-arm control maintains a constant normal force inspite of burr variations. Typically these micro-manipulators have been instrumented to sense the position, enabling these constant force devices to automatically determine the tool wear, part misalignment, and sudden process changes due to the presence of burrs.

The UF-SAMM PKM uses the active around-the-arm control approach. The PKM's controller is the National Institute of Standards and Technology Enhanced Motion Controller modified to accommodate six axis non-orthogonal systems, and running under Real-time Linux. The micro-manipulator is an event-driven hybrid position/force controller. This controller uses a process based logic module to instantaneously modify the constant force reference value (F_n) in accordance to sensed burr variations. Thus yielding a higher precision edge and a reduction in the need for multiple deburring passes.

In the design of the event-driven hybrid controller, the VCA-X and VCA-Y are orthogonal to each other but are in general not aligned with the normal and tangent directions relative to the cutter's trajectory along the part's edge. The PKM provides the nominal motion of the cutter such that the VCA-X and VCA-Y frame is in a parallel plane to the normal and tangent frame of the part's edge. Ideally, the origins of these two frames will coincide. Referring to Figure 5, the micro-manipulator's controller takes measured LVDT signals in X and Y directions and force transducer signals and converts them to normal and tangent components relative to the part's edge (directions as defined by the ideal part contour and process plan). The converted signals are then fed into corresponding comparator and controller (position and force) followed by another transformation back to the VCA axes directions. The signals from both the position and force controller are then combined generating the appropriate VCA-X and VCA-Y input commands. The hybrid position/force controller is designed in such way that tangential position is controlled to keep spindle at center of VCA stroke while at the same time maintaining the normal force required to maintain the desired chamfer depth. This controller also uses the position feedback to detect the presence of burrs and part misalignment. If a burr is detected, the process plan's normal force is adjusted using a process based "Logic Module". Without this module the finished edge would be a replica of the original surface prior to the deburring and chamfering operations, i.e., have the same waviness of the original edge. If the burrs are small than the edge would be within tolerance with the use of the appropriate normal force. More aggressive action is required if this is not the case, e.g. the 'logic module' is needed.

3.5 Results

Figures shows simulation results achieved on hole processing. The VCA rotates the force vector electronically to follow the normal to the work piece edge and thus maintain the constant desired chamfer depth. Experimental results are very close to theoretical values, see Figures 6 and 7. Figures 6 shows the experimental result of the force vectorisation done by the micromanipulator. In this particular case the movement along the edges was simulated using a 2dof machine (U500). Figure 7 shows the same force vectorisation done by the micro/macro manipulator final assembly. One of the reasons for noise in the simulation results may be friction in ball screw, ball nut and counter balance slides.

4 Conclusions

In conclusion, the integration of the two devices into one macro/micro machine takes advantage of the two manipulators while canceling their drawbacks. For example the small movements in 2-D by the 2 degree of freedom micro-manipulator are compensated by an ability of the PKM to follow 3-D nominal paths through out its work volume; and the relative low precision of the PKM is compensated by the ability of the micro-manipulator to apply greater precision with its hybrid position/force control. Combining these 2 manipulators and the process based, event-driven controller results in a new machine that is superb for low cost and high precision deburring operations.

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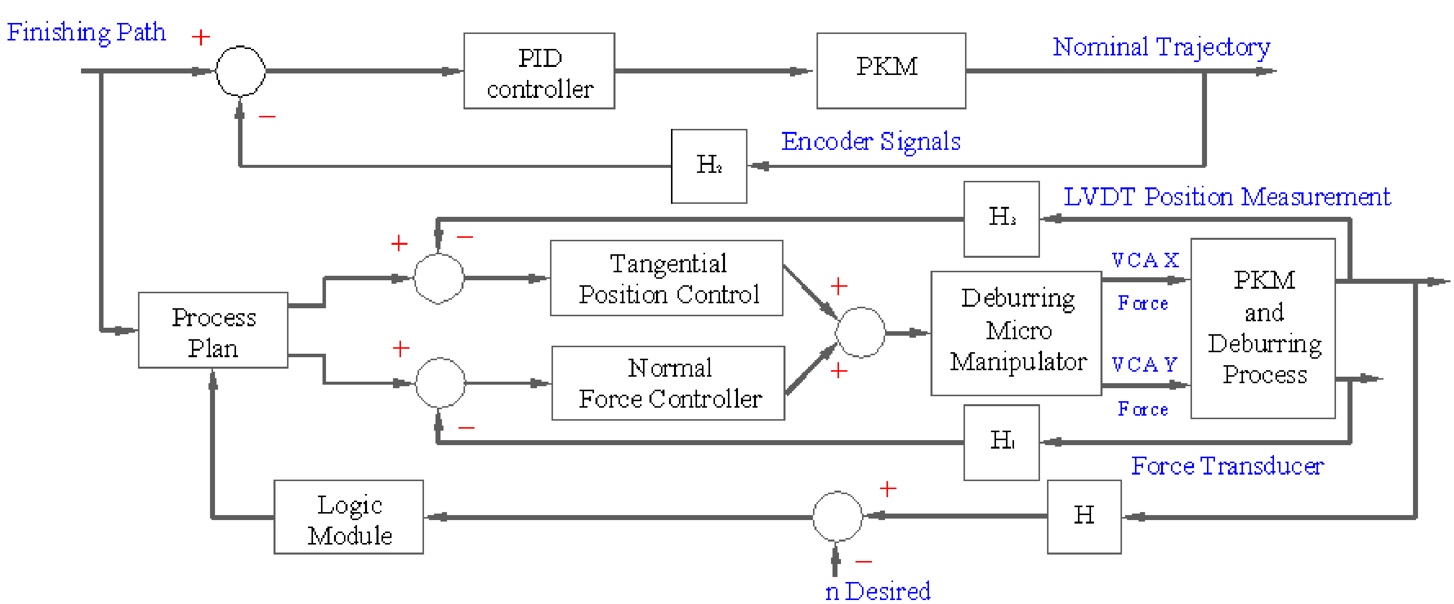

Figure 5. Controller for the Macro/Micro Automated PKM Finishing System

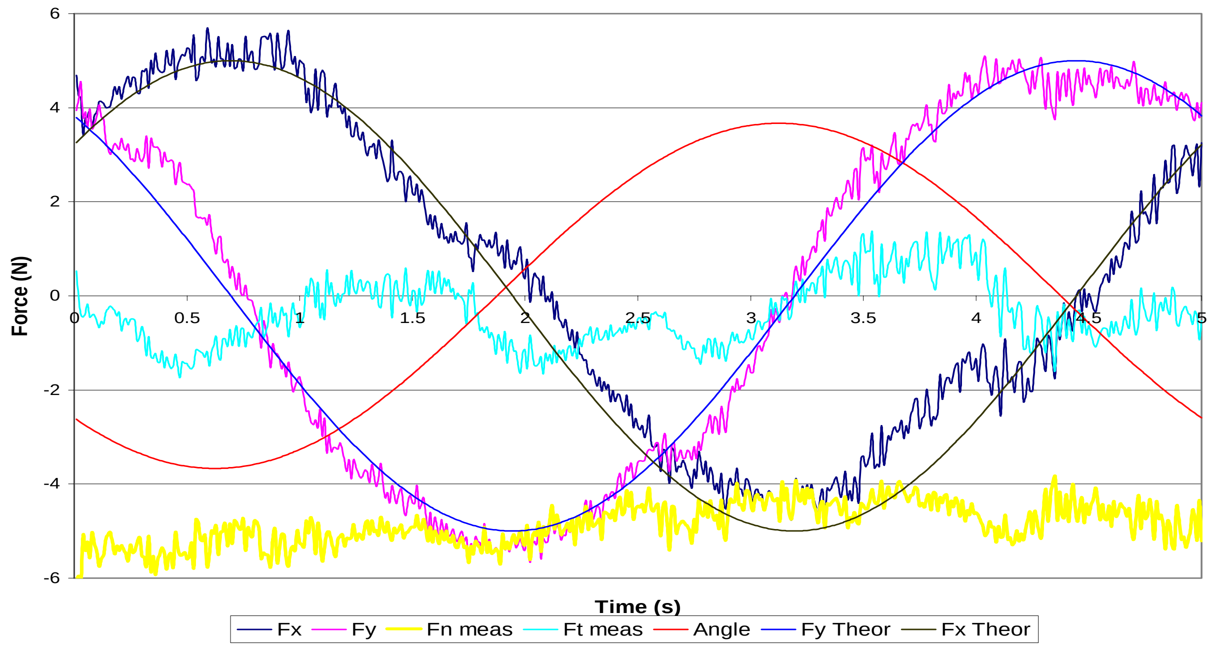

Figure 6, Experimental Results on U500.

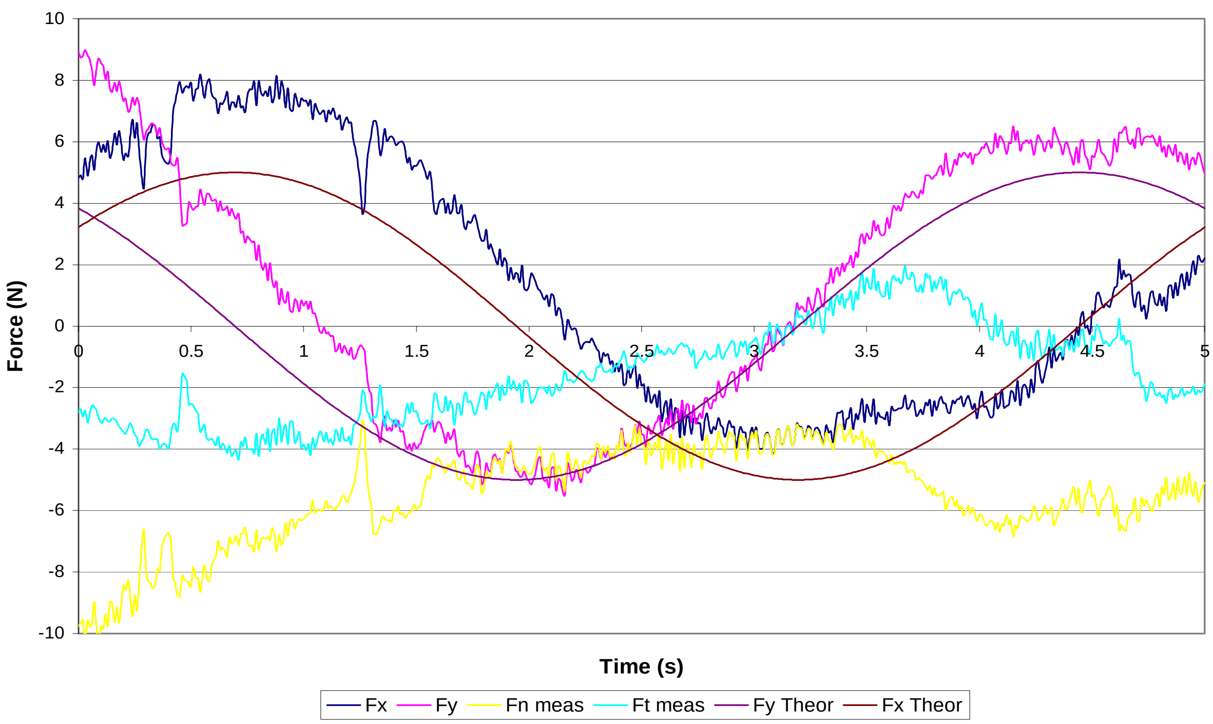

Figure 7, Experimental Results on PKM.