# Design of a Novel Parallel Reconfigurable Machine Tool

D. Modungwa[1*], N.S Tlale[1], and C.M. Kumile[2]

[1]Department of Material Science and Manufacturing
Council for Scientific and Industrial Research
Pretoria, 0001, South Africa

[2]Department of Mechanical Engineering
Tshwane University of Technology
Pretoria, 0001, South Africa

***Abstract***

*The manufacturing of moulds and dies is achieved through expensive and complicated manufacturing processes. There is a need in the mould and die tool industry for technologically advanced systems/machinery that will be able to facilitate re-conditioning of moulds and dies at moderate costs and within short period of time.*

*The re-conditioning process requires highly dextrous equipment, with high stiffness. Each worn out mould or die has different defects, which requires different mechanical processing and positioning of the reconditioning tools. Conventional machine tools and serial manipulators have been found incapable of meeting the demands for high mechanical dexterity adaptation as well as high stiffness necessary for mould and die re-conditioning.*

*This paper presents, the design of parallel reconfigurable machine tool (PRMT) based on both application and philosophy of re-configurability. The structure is influenced by 1) specifications for the repair and re-conditioning of moulds and dies, and 2) the manufacturing processes involved.*

## 1. Introduction

Serial manipulators have been used extensively in applications ranging from assembly of vehicles to milling applications. However, these manipulators vibrate under high pay-load (low dynamic stiffness) and loose accuracy depending on their posture. As such, they cannot be used in applications that require high stiffness and high accuracy, such as manufacturing and re-conditioning of moulds and die tools.

Research in parallel manipulators has shown results of high stiffness and accuracy characteristics which are not dependant on the pose of the manipulator. It is envisaged that parallel manipulators can provide the necessary stiffness and accuracy to enable them to be utilized in the reconditioning of moulds and dies. Hence, parallel manipulators will be designed to be used as reconfigurable machine tools in this regard.

Since these parallel kinematic machines (PKMs), both as manipulators or PRMTs exhibit these necessary characteristics, it is thus imperative to undertake research and development thereof. Reconfigurable machine tools (RMTs) have also emerged as a potential solution to meet the demand for rapid adaptation in the current and future generation of manufacturing systems. In their parallel arrangement/configuration, these machines have features of high rigidity, high speed, compact structure and high dynamic capacities. They are designed with customized flexibility, provide high stiffness and lower moving masses that reduce inertia effects.

The first design of a parallel mechanism was the Gough platform, invented by Dr. Eric Gough in the early 1950's. This design saw its first industrial application, when implemented as a tyre testing machine around 1955 [1]. Some years later, around 1965, Steward published a paper on the design of a flight simulator based upon a 6 DOF parallel platform [2]. Since then, parallel mechanisms have drawn interest from researchers both academically and in industry, due to merits in terms of high stiffness, high accuracy and high load carrying capacity over its serial counterpart. However, the design of parallel mechanisms and improvement of characteristics thereof, are hard tasks that require further research studies before wide industrial use can be expected. Experiments with real prototypes also show that parallel structures currently do not leave up to their

* Corresponding author: Tel.: (+27) 12 841-2747; Fax: (123) 12 841-4209; E-mail: dmodungwa@csir.co.za

expectation: their accuracy is about an order of magnitude worse than for serial machines. The reasons are: (i) the compliance of the ball screws in the prismatic joints, (ii) the complexity of the construction with many passive joints that all have to be manufactured and assembled with strict tolerance, (iii) the complexity of kinematic calibration of this structure, (iv) the high forces that some passive joints have to resist, and (v) their limited workspace: legs can collide and the many passive joints which lead to joint limit constraints [3].

L. E. Bruzzone et al [4], present a parallel robot for industrial applications supplying force driven tasks. The design exploits a task driven approach to fix the output force by steering the actuator's torque via impedance feedback from the measurement of the joint co-ordinates. Many machining tasks require at least 3 translational DOF, as a result several 3 axis translational parallel kinematic machines have been proposed [5], [6], [7]. Several design methodologies for such mechanisms have been presented. In one family [8], [9] there is the Tsai mechanism and its variants, in which the mobile platform is connected to the base by three extensible limbs with a special arrangement of the universal joints that restrain completely the orientation of the mobile platform. The second family have fixed length struts with movable foot point gliding on fixed linear joints. An example is the HEXAGLIDE (ETH Zurich) which features 6 parallel and coplanar linear joints. Other examples are the Hexa M (Toyoda), with 3 pairs of adjacent linear joints lying on a vertical cone [10], the LINAPOD, TRIGLIDE and INDEX V100 [11], which use an architecture close to the linear DELTA robot, developed and patented by Clavel in the 1980s [12]. R. Alizade and C. Bayram [13], present a procedure to synthesize the structures of parallel manipulators using simple structural groups. A classification of parallel manipulators based on number of mobile platforms, number of joints on the mobile platforms, number of legs and branches and types of kinematic pairs is given along with examples. Y. Jin, I. Ming Chen and G. Yang [14], classify parallel manipulators with decoupled motion and introduce the concept of Group Decoupling. An idea of sharing sub-chain composed by only passive joint is introduced. A systematic approach based on this idea is proposed for structure synthesis of 3 limb symmetrical 6 DOF parallel manipulators with 3-3 decoupled motion. Two classes of 3-3 decoupled parallel manipulators are obtained, in which 7 noble structures are obtained. Various applications for which these decoupled parallel manipulators can be suitable are mentioned, such as: fibre alignment, light machining tools for deburring, polishing and grinding of curved surfaces, precision assembly tasks of heavy parts and fast micro- manipulation. Y. Fang and L-W. Tsai [15], use the same methodology as [13], for the structural synthesis of a class of 4 DOF and 5 DOF parallel manipulators with identical limb structures. R. Katz [16] introduces design principles for reconfigurable machines. Based on these principles, three types of reconfigurable machines were designed and presented for machining, inspection and assembly operations. D. Zhang and Z. Bi [17], present a series of novel reconfigurable parallel kinematic machines using modular design methodology. A conceptual design is introduced, and detail configurations of potential structures are showed.

The remainder of this paper is organized as follows. In section 2, gives a description of the conceptual design of the PRMT. Section 3 presents the intended kinematic capabilities of the PRMT. Finally, this paper concludes with a summary of this work and a prospectus of further activities.

## 2. DESCRIPTION OF THE CONCEPTUAL DESIGN

The architecture of the PRMT is shown in Fig. 2.1, which is composed of 3 vertical column structures (all serving as a fixed base), 3branches/limbs, 3 blocks, a circular rod and a hexapod (serving as a tool holder). Each vertical column connects to a single branch/limb by a revolute joint and a prismatic joint, and each branch/limb then connects to a square block by a revolute joint. These three identical sub-structures are connected together by a circular rod, which is fixed to the 3 square blocks. The prismatic joints are actuated by linear actuators/motors, allowing the branches/limbs to slide up and down the vertical column structures. The revolute joint connecting the branch/limb and the vertical column structure, on the driver/master sub-structure (i.e. vertical column and branch), is actuated by a motor. This will cause rotation of all 3 branches/limbs, thus it is called the "driver/master sub-structure", as it drives the rest of the sub-structures. The centre branch/limb connects to the hexapod, by a revolute joint. The hexapod holds the tool and takes orientation of the branch/limb. The mechanism with the circular rod and the three blocks is employed to increase the rigidity of the entire structure, as opposed to having a single sub-structure.

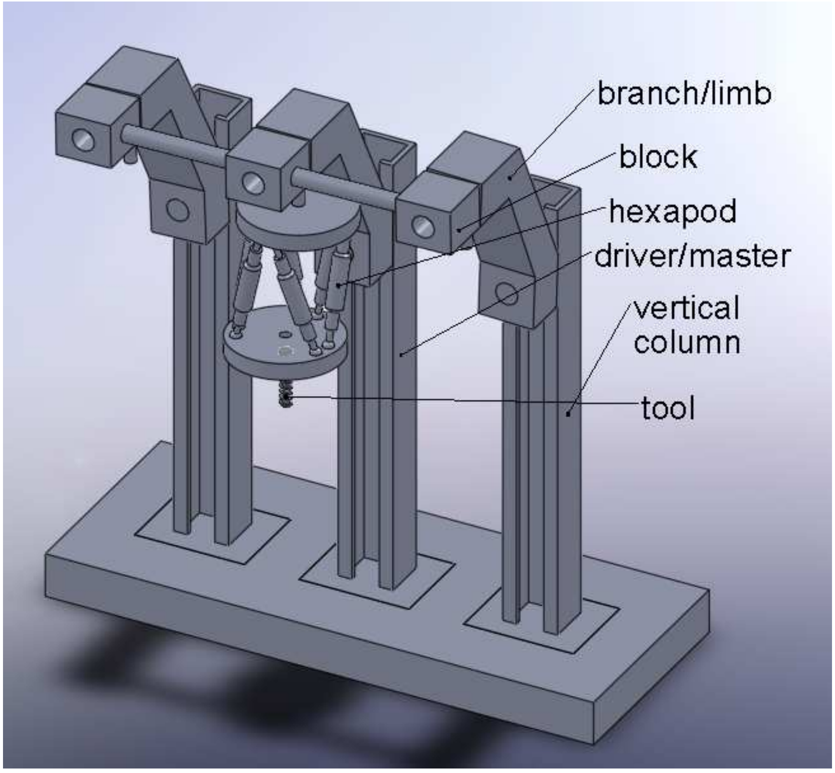


Figure 2.1: Conceptual Design of the PRMT.

The machine is 5 axis machine, 3 translational and 2 rotational. The tool provides rotation about the Z-axis and translation about the Y-axis. Translation about X and Z-axis and rotation about Y-axis will be provided by the work-piece table. The hexapod provides the actual tool with 6 degrees of freedom, coming from the spherical joints. Prismatic and revolute joints each provide a single degree of freedom.

It is envisaged that by using three identical sub-structures as opposed to one sub-structure, the PRMT will become dynamically stable and this would mean reduction or possibly elimination of vibration. The hexapod also offers some advantages with respect to stiffness and speed, due to the use of high- resolution actuators. These positioning operations can be performed with far settling times than conventional stacked multi-axis systems. The use of direct drives avoids the reduction in overall system stiffness that is caused by transmission system elements and thus leads to an increase in the mechanical bandwidth of an increase in the mechanical bandwidth of an axis by a factor of 5 to 10 in comparison with conventional axes with transmission systems [11].

## 3. INTENDED KINEMATIC CAPABILITIES

Machining Degrees Of Freedom will be modularized according to the adopted design approach. Modules contributing to the DOF are referred to as Motion Modules. It should be noted that for turning and tread cutting operations the work piece rotates about its axis, while the cutting tool performs linear traverses to cut into the material. On the contrary, in most other machining operations the tool rotates while the work piece traverses linearly into the cutting tool to perform the necessary cutting action [18]. The following absolute co-ordinate system, which is fixed to a stationary point on the machine base, will be used to reference cutting motions.

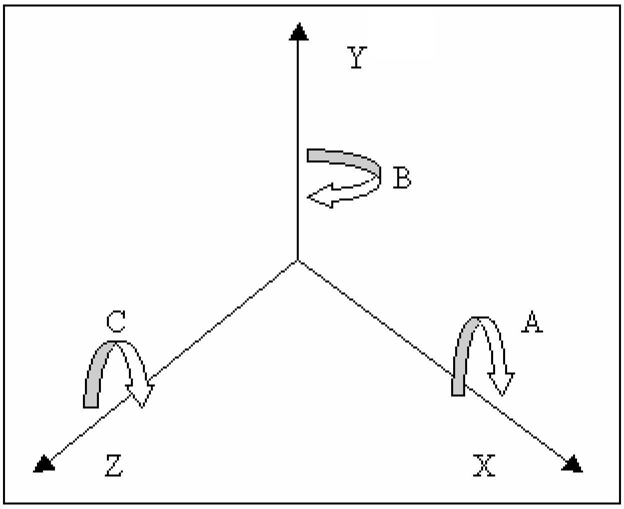


Figure 3.1: Absolute reference frame for kinematic DOF

For milling, drilling, reaming, tapping, engraving, polishing and grinding operations, modules providing the following DOF will be available. All rotary movements may be either clockwise or anti-clockwise:

- X translation module: attributed to work table
- Y translation module: attributed to cutting tool
- Z translation module: attributed to cutting tool
- A rotation module: attributed to cutting tool
- B rotation module: attributed to work table
- C rotation module: attributed to cutting tool

For turning and thread cutting operations the following DOF will be available

- Z translation module: attributed to cutting tool carriage
- X translation module: attributed to cutting tool
- B rotation module: attributed to cutting tool

For a given operation, only the required DOF available from the complete range will be selected, resulting in machinery with precise kinematic capabilities.

## 4. CONCLUSION

In this paper a conceptual design of parallel re-configurable machine tool to be utilized in the reconditioning of moulds and dies is presented. The architecture and intended kinematic capabilities are discussed. In future work, simulation and modelling will be carried out in order to analyze and determine the PRMT performance. There are factors that cause kinematics model performance not to coincide with the performance of the prototype and these are;- unknown length of struts, incorrect connection points of the struts are used, machine base is flexible and correct location of spindle is unknown [19]. Thereafter, a prototype will be built and further testing and will be carried out on the PRMT, in order to optimize it and validate the actual results with the simulated results.

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