Chapter 1
Introduction

1.1 The History of Parallel Robots

The demands for higher performance of general-purpose industrial robots are increasing continuously. In particular, the need for truly adaptive automation in many applications has led to higher requirements for operational accuracy, load capacity, task flexibility, reliability, and cycle time with robots. Examples of such needs are higher precision assembly, faster product handling, better measurements, surface finishing, and milling capabilities. Furthermore, there is a high demand for off-line programming to eliminate touch-up of programmed positions; in other words, robots must perform their task with better load capacity and accuracy in operations. A general trend of meeting these demands and requirements is to make use of parallel robots, which have excellent potential capabilities, including high rigidity, high accuracy, and high loading capacities.

Parallel robots generally comprise two platforms, which are connected by at least two kinematic chains, and to provide relative motion between a moveable platform and a base platform. In fact, parallel robots have become an indispensable part of general robots both in industry and in academia. Besides, with the rapid development of parallel robots a few decades ago, the research on mechanism theory, mobility analysis, dimensional synthesis, kinematics and dynamics modeling, and design optimization have been increasing in a large scale.

Centuries ago, the English and French mathematicians attained a keen interest in polyhedral. It was from this obsession that the first theoretical works involving parallel mechanisms, specifically six-strut platforms, were developed. However, there were very few scholars who actually read and studied these works.

In 1928, a spherical parallel robot (shown in Fig. 1.1) as a conceptual amusement device was invented by James E. Gwinnet. This is perhaps the first spatial parallel mechanism. Unfortunately, the entertainment industry did not pay attention to such an invention at that time.

Ten years later, Willard L.V. Pollard designed a novel parallel robot for automatic spray painting, which was claimed as the first industrial parallel robot. This three-legged robot was capable of five degree-of-freedom motion – three for the position of the tool head, and the other two for orientation. However, this robot was

D. Zhang, *Parallel Robotic Machine Tools*, DOI 10.1007/978-1-4419-1117-9_1,

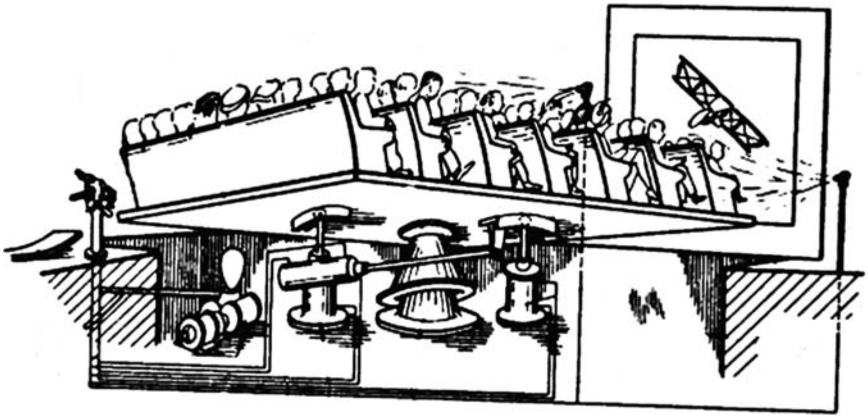

Fig. 1.1 Potentially the first spatial parallel mechanism, patented in 1931 (US Patent No. 1,789,680)

never actually built and Pollard's son, Willard L.V. Pollard Jr. actually designed and engineered the first industrial parallel robot, as shown in Fig. 1.2.

In 1947, Dr. Eric Gough invented a new six degree-of-freedom parallel robot that revolutionized the robotic industry – the first octahedral hexapod (called the universal rig by him). It was applied as a tire-testing apparatus (see Fig. 1.3 (left)) to discover properties of tires subjected to different loads. Figure 1.3 (right) shows the machine which was put into use in 1954 and retired in 2000. This platform consists of six identical extensible links, connecting the fixed base to a moving platform to which a tire is attached. The kinematic chains associated with the six legs, from base to platform, consist of a fixed Hooke joint, a moving link, an actuated prismatic joint, a second moving link and a ball-and-socket joint attached to the moving platform. The position and the orientation of the moving platform, together with the attached wheel, are changed according to the variation of the links length. This wheel is driven by a conveyor belt, and the mechanism allows the operator to measure the tire wear and tear under various conditions. The universal rig has been playing an important role in the field of industry robots and still has great effect for the academic research of parallel manipulators. Many significant advantages can be discovered when compared with conventional serial counterparts, such as higher stiffness and payload, higher force/torque capacity, lower inertia, eminent dynamic characteristics, less accumulated error of joints, and parallel robots also have simpler inverse kinematics which is convenient for real-time control. Some disadvantages also should be mentioned, such as smaller workspace, worse dexterity.

In 1965, Stewart published a paper describing a 6DOF motion platform that was designed as an aircraft simulator. The so-called "Stewart platform" was a parallel mechanism that differentiated from the octahedral hexapod. Figure 1.4 is a schematic of the Stewart platform. Stewart's work had a significant impact on the further development of parallel mechanisms in which he made many suggestions

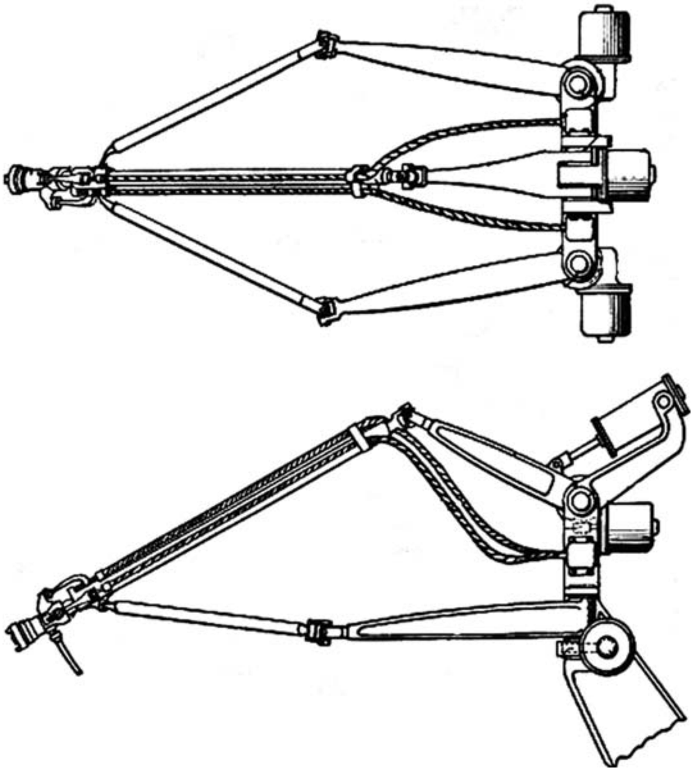

Fig. 1.2 The first spatial industrial parallel robot, patented in 1942 (US Patent No. 2,286,571)

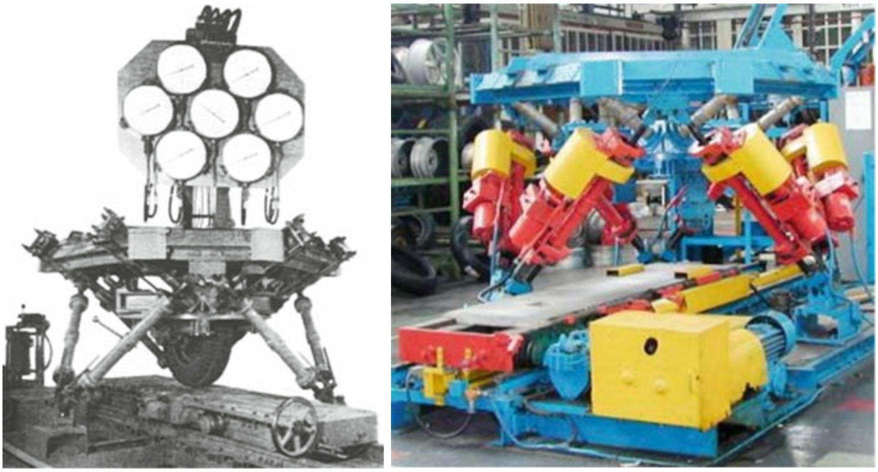

Fig. 1.3 The first octahedral hexapod (left, original Gough platform) developed in 1954; and the Gough platform for tire test (right)

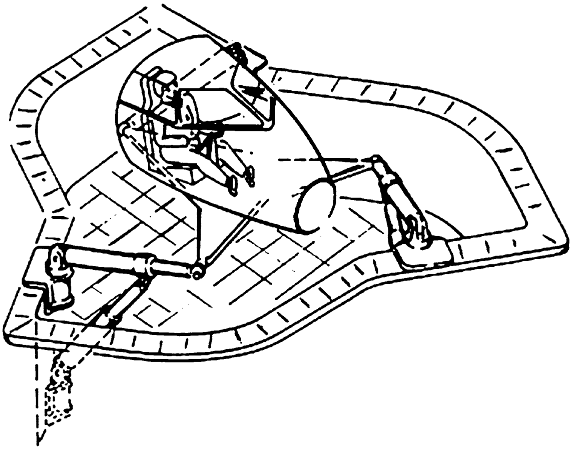

Fig. 1.4 Stewart Platform [137]

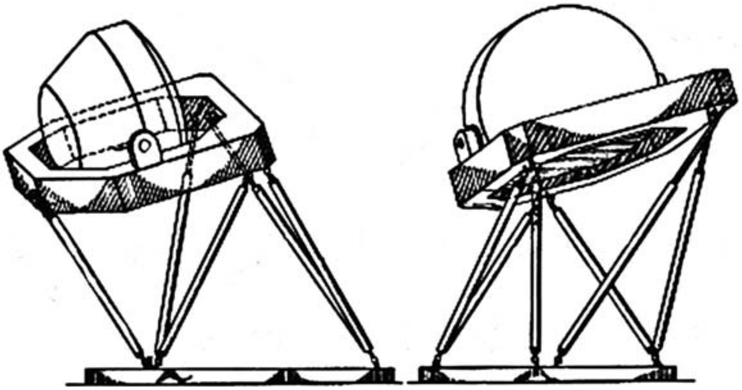

Fig. 1.5 An octahedral hexapod patent issued in 1967 (US patent No. 3,295,224)

for uses of the hexapod, and which eventually became reality. He was also responsible for popularizing Gough's design in academia. In fact, the contribution of Gough established the milestone for the development of parallel robots in industry, while, it is Stewart who introduced it to academia. Over the past decades, there were many new mechanisms that had been proposed and released by researchers, anyhow, not so many are adopted by industry.

It is noticed that, in 1962, an engineer named Klaus Cappel, who was from the Franklin Institute Research Laboratories in Philadelphia, proposed the same octahedral hexapod as Gough's, to be used as a motion simulator(as shown in Fig. 1.5). Cappel was granted a patent for his invention in 1967. He is considered as the third and last pioneer in the field of parallel robots.

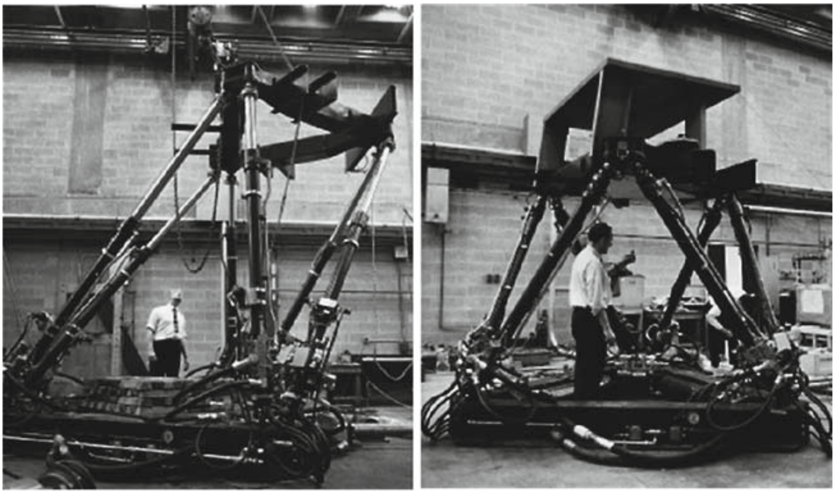

Fig. 1.6 The first flight simulator based on an octahedral hexapod as in the mid 1960s (courtesy of Klaus Cappel)

The very first flight simulator based upon Cappel's design was constructed (as shown in Fig. 1.6). Cappel has also designed various parallel robot systems for vibration testing. However, it took a long time before these designs were accepted by industry.

It was these three men (Eric Gough, D. Stewart, and Klaus Cappel) who were truly the pioneers of the parallel robot. This has paved a way for many new inventions and applications of parallel mechanisms.

Nowadays, parallel robots can be found in many practical applications, such as aircraft and vehicle simulators [7, 11, 73, 74, 111, 114], adjustable articulated trusses [35, 65, 66, 139, 161], medical devices [27, 28, 97, 113, 130, 134, 153], micro-robot [40, 41, 78, 119, 162, 163], and force/torque sensor [47, 125, 129, 135]. More recently, they have been used in the development of high precision machine tools [15, 92, 152, 167] by many companies such as Giddings & Lewis, Ingersoll, Hexel, Geodetic and Toyoda, and others. The Hexapod machine tool [12, 15, 70, 104, 122] is one of the successful applications.

1.2 Introduction of Conventional Machine Tools

Machine tools are the fundamental implements that change the shape, surface, or properties of a blank object made of metal, plastic, wood, or other material. Producers' machine portfolios traditionally focus on a single process technology. Before the advent of numerical control technology, some producers specialized in turning

Fig. 1.7 The standard engine lathe (South Bend Lathe Corp)

machines, others in grinding machines, presses, etc. These machine tools include the following:

1. The lathe, or the engine lathe (Fig. 1.7), is used to produce round work. The workpiece, held by a work-holding device mounted on the lathe spindle, is revolved against a cutting tool, which produces a cylindrical form. Straight and taper turning, facing, drilling, boring, reaming, and thread cutting are some of the common operations performed on a lathe.
2. The drill (Fig. 1.8), which is one of the most common machine tools. Drills cut cylindrical holes in objects.
3. Milling Machine: The horizontal milling machine (Fig. 1.9), and the vertical milling machine (Fig. 1.10), are the two of the most useful and versatile machine tools. Both machines use one or more rotating milling cutters having single or multiple cutting edges.
4. Grinder (Fig. 1.11): grinding wheels remove material from an object by rubbing against it, slowly wearing the material away. The grinding wheel is typically used near the end of the machining task, to smooth a finish or to obtain extremely accurate dimensions.
5. Metal Saw: Sawing is a cutting operation in which the cutting tool is a blade (saw) having a series of small teeth, with each tooth removing a small amount of material. Metal-cutting saws are used to cut metal to the proper length and shape.

Fig. 1.8 The drill press is commonly used to produce holes (Clausing Industrial Inc)

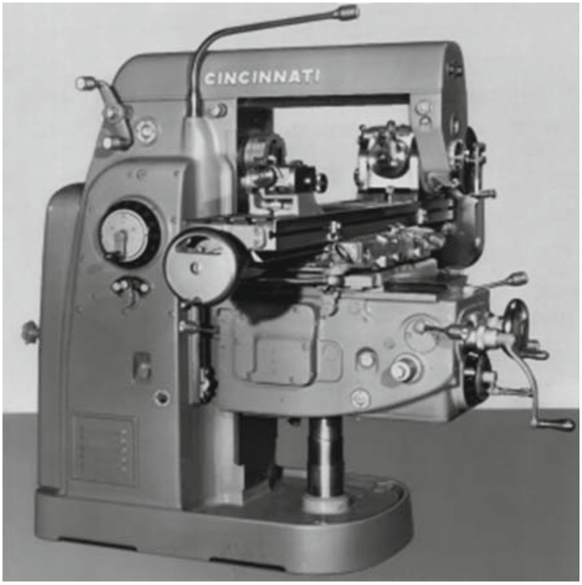

Fig. 1.9 The universal knee and column type horizontal milling machine is used for machine flat, angular, and contoured surfaces (Cincinnati Machine, a UNOVA Co.)

Fig. 1.10 A standard vertical milling machine (Bridgeport Machines, Inc.)

Fig. 1.11 The surface grinder is commonly used to finish flat surfaces (DoAll Co.)

Machine tools have advanced along with technology. Inventions such as numerical control, computer numerical control, artificial intelligence, vision systems, superabrasive cutting tools, stereo lithography, etc., have changed the way goods are manufactured. These developments have improved machine tools and forever changed manufacturing processes, so that today it is possible to automatically produce high-quality products quickly, accurately, and at lower cost than ever before, and at the same time, the mechanism is also very different from that of the conventional machine tool. Modern machine tools based on parallel kinematic (PK) technology that offer faster, more accurate and less costly alternatives to conventional systems than most conventional machine tools for component manufacture or assembly. Conventional machine tools have serial knematic archtechture, with each axial of movement supporting the following axis and providing its motion. A significant drawback of conventional machine is that the moving parts must be heavy enough to provide the necessary stiffness to control the bending movements. This impacts the dynamic performance and reduces operational flexibility.

1.3 Parallel Robot-based Machine Tools

Because of the recent trend toward high-speed machining, there is a demand to develop machine tools with high dynamic performance, improved stiffness, and reduced moving mass. Parallel mechanisms have been adopted to develop this type of machine. Generally, parallel robot-based machine tool is called parallel kinematic machine [21, 175–177].

Hexapod machine tool, as one kind of parallel kinematic machines, has been widely studied and developed by researchers. Matar [104] defines a “Hexapod” as a geometric structure where a hexagon provides the points on a frame for six struts, which are then collected into pairs to form a triangle, whose position in free space can be uniquely described by the struts length.

The parallel kinematic mechanism offers higher stiffness, lower moving mass, higher acceleration, potential higher accuracy, reduced installation requirements, and mechanical simplicity relative to existing conventional machine tools [24, 127, 154, 160, 171]. By virtue of these attributes, the parallel kinematic mechanism offers the potential to change the current manufacturing paradigm. It has the potential to be a highly modular, highly reconfigurable, and high precision machine. Other potential advantages include high dexterity, the requirement for simpler and fewer fixtures, multi-mode manufacturing capability, and a small foot print. A comparison between the Hexapod machine tools and the conventional machine tools is given by Giddings and Lewis. It shows that the Hexapod machine tool has improved machine tools substantially in terms of precision (about 7 times), rigidity (about 5 times), and speed (about 4 times) [96].

So far, there are several companies and institutes involved in research and development of this kind of machine tool. Aronson [12] summarized the four major companies, and they are Giddings and Lewis, Ingersoll Milling Machine Co., Hexel

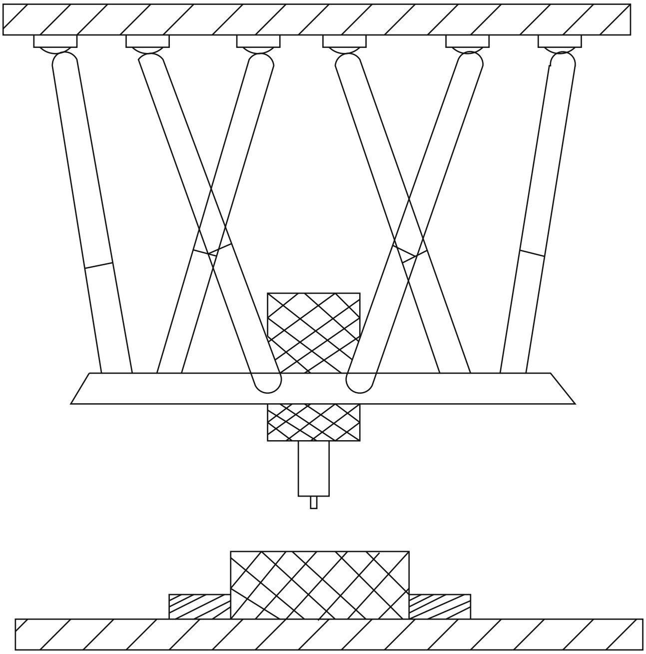

Fig. 1.12 Six-axis Hexapod machining center

Corporation and Geodetic Technology International Ltd. Giddings and Lewis did some of the early pioneering effort on the Variax, the Giddings and Lewis hexapod machine. Moreover, the industrial interest is continually growing [112].

Figure 1.12 represents a parallel mechanism module from Ingersoll Milling Machine Co. [93], it consists of a fixed upper dome platform and a moving lower platform, connected by six struts, which are precision ballscrews. On the upper platform, the six struts are driven by motor driven ballnuts. These alter the position and attitude of the lower platform by extending or retracting the struts. The ballscrews join the lower platform at three points, with two struts sharing a ball-and-socket joint. Various head attachments can be incorporated to suit a variety of applications. Each individual axis (leg drive) is independent from the others and comes with a personality file containing information such as error mapping (e.g., lead pitch variation), mounting offsets, physical performance, and thermal expansion characteristics. There are some other institutes and industry doing research and development work in this area. They are NEOS Robotics (Tricept series), Toyoda Machine Works (HexaM Machine), ITIA-CNR (ACROBAT), Seoul National University (ECLIPSE), Sandia Hexapod Testbed, Swiss Federal Institute of Technology (Hexaglide), Materials Engineering Division (MMED) from Lawrence Livermore National Laboratory (LLNL) (Octahedral Hexapod), SMARTCUTS (Simultaneous MAchining through Real Time Control of Universal Tooling System) (modular 3-DOF parallel link mechanism), LME Hexapod machine (Hexapod software model), University of Stuttgart (modular parallel mechanism design), and others.

Moreover, there are also many publications concerning the research and development of parallel kinematic machines. Heisel [68] presents the precision requirements for parallel kinematic machine tools design. Wang et al. [151] discuss the design and kinematics of parallel mechanisms for manufacturing. Pritschow and Wurst [122] describe a systematic design procedure that allows the evaluation of the technological feasibility of hexapods, and the parallel kinematic machines (PKMs) types that are currently being investigated by European researchers are presented in [121]. Wavering [155] introduces the history of PKMs research at the NIST Manufacturing Engineering laboratory, the current research areas and the potential directions for future work. Abbasi et al. [6] address a parametric design methodology for a special 6-6 parallel platform for contour milling. Warnecke et al. [154] present the analysis, designs, and variants of parallel-structure-based machine tools, different design variants are compared with regard to the load of the structures and the singularities. Gopalakrishnan and Kota [55] study various parallel manipulator configurations and the possibility of their integration under the evaluation of reconfigurable machining systems. The modular concepts for PKMs are proposed in the paper, similarly to [158]. An approach to Parallel Kinematic Machines design integrating tools for machine configuration, synthesis, and analysis is presented in [145]. Fassi et al. [45] present an approach to the development of a computer aided configuration tool for parallel kinematic machines. The goal of this tool is to enable a quick comparison between different machine structures. Bianchi et al. [22] propose a virtual prototyping environment for PKMs analysis to ease the industrial adoption of PKMs by availability of methodologies and integrated tools able to analyze PKMs of any architecture in a short period of time, providing the key data needed to design the machine. Weck et al. [156] discuss the substantial features of PKMs with special focus on structurally caused problems in design, control, and calibration and takes Ingersoll Octahedral Hexapod and the Dyna-M concept as examples for possible solutions. Some industrial applications are reported in the literature. For instance, Honegger et al. [71] present the adaptive control of the Hexaglide. Ryu et al. [132] present the “Eclipse” machine tool designed for rapid machining with their research of kinematic analysis. Powell et al. [120] focus on the Giddings and Lewis Variax Hexapod machine tool by presenting different metal cutting tests and analyzing the machine tools performances. Tönshoff et al. [144] present the structure and characteristics of the hybrid manipulator “Georg V” at Hannover University. Pierrot and Shibukawa [117] report the patented machine tools “HEXA” and “HexaM” at Toyoda Machine Works Ltd and Clavel [128] display the “Delta” parallel robot. Pritschow and Wurst [123] propose a systematic methodology for the design of different PKM topologies. Merlet [106] develops the software for the optimal design of a specific PKM class Stewart platform-based mechanisms. Boeij et al. [23] propose numerical integration and sequential quadratic programming method for optimization of a contactless electromagnetic planar 6-DOF actuator with manipulator on top of the floating platform. Chablat and

Angeles [31] investigate on optimum dimensioning of revolute-coupled planar manipulators based on the concept of distance of Jacobian matrix, to a given isotropic matrix which was used as a reference model. Zhang et al. [178] develope an integrated validation system for PKM that consists of kinematic/dynamic analysis module, kinetostatic model, CAD module, FEM module, CAM module, optimization module, and virtual environment for remote control. Pond and Carretero [118] apply the Jacobian matrix to determine the dexterity of parallel mechanisms regardless of the number and type of degrees of freedom of the mechanism. Company and Pierrot [38] develope a 3-axis PKM intended to be used for high-speed point-to-point displacement and simple machining. It was observed that the trajectory planning in the joint coordinate system is not reliable without taking into considerations of cavities or holes in the joint workspace. Li and Xu [98] study the stiffness characteristics of a three-prismatic-universal-universal translational PKM, where the stiffness matrix was derived intuitively with an alternative approach considering actuations and constraints. Bi and Lang [20] develope a concept so-called joint workspace for design optimization and control of a PKM, and some others.

In summary, all the existing parallel kinematic machines can be classified as follows:

1. From the viewpoint of the frame, two approaches to (PKMs) frame design exist. Ingersoll Milling Machine Co. (in conjunction with National Institute of Standards and Technology, NIST) (Fig. 1.12), Hexel Corporation, and Geodetic Technology International Ltd. all use a separate frame that suspends the hexapod, while Giddings and Lewis connected the spindle platform directly to the table platform (Fig. 1.13), thus avoiding thermal distortion and improving stiffness.
2. From the viewpoint of the structure, a new design called the Triax – not technically a hexapod – has been investigated by Giddings and Lewis. It will operate in only three axes. In contrast to the Hexapod machine from Ingersoll or Giddings and Lewis, The Institute for Control Technology of Machine Tools and Construction Units (ISW) of the University of Stuttgart has developed a Hexapod [122] whose motion is generated by linear movement of the base points of fixed length links and not by changing the leg length (Fig. 1.14). The Hexaglide [71] (Fig. 1.15) from Swiss Federal Institute of Technology also falls into this type.
3. From the viewpoint of workspace volume, the Hexaglide [71] (Fig. 1.15) from the Swiss Federal Institute of Technology differs from the Hexapod by the fact that the joints are placed on parallel guideways. Thus, instead of changing the total length of the legs, they have the possibility to make the guideways longer to extend the workspace of the machine in one direction. All other dimensions stay unaffected. This makes the Hexaglide an ideal mechanism for the machining of long parts. The Hexaglide is also easier to build and to measure than the Hexapod.
4. From the viewpoint of actuated joints, there are three types of parallel kinematic machines:

   - Prismatic actuated machines with variable leg lengths and fixed joints (e.g., Ingersoll, Neos Robotics),

Fig. 1.13 The Variax Hexacenter (Figure from Giddings and Lewis)

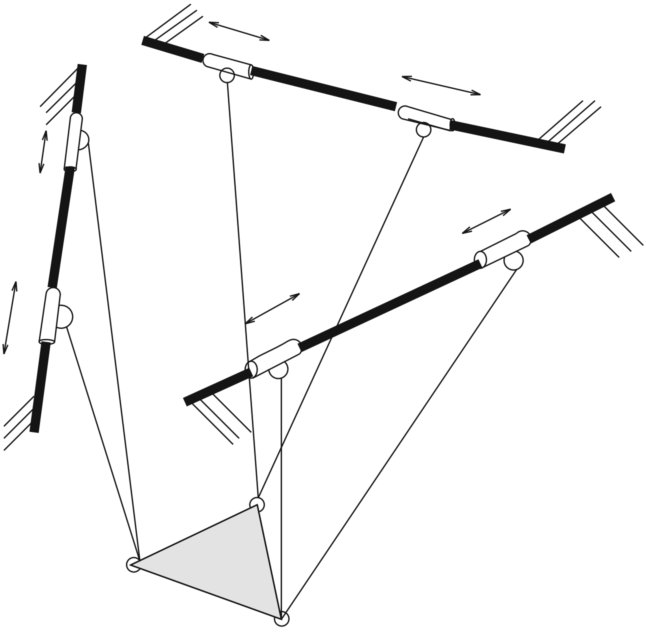

Fig. 1.14 Kinematic structure of the 6-dof machine tools

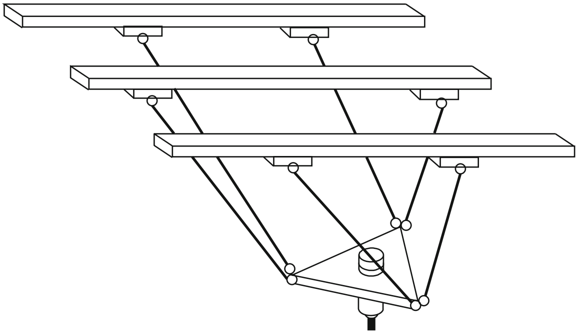

Fig. 1.15 Kinematic structure of the Hexaglide

- Linear Motion (LM) actuated machines with fixed leg lengths and base joints movable on linear guideways (e.g., HexaM, ECLIPSE, Hexaglide, Triaglide, Linapod),
- Revolute actuated machines with fixed leg lengths (e.g., Delta, Hexa),

5. From the viewpoint of research methodology, there are OKP (One-of-a-Kind Production) design methodology (e.g., Tricept, HexaM), which is suitable for those industrial companies, and systematic design of Hexapods using modular robot methodology (e.g., Linapod). Modular robot concepts and techniques have been of interest in the robotics field since the 1980s [32, 37], since selecting an industrial robot that will best suit the needs of a forecast set of tasks can be a difficult and costly exercise. This problem can be alleviated by using a modular robot (system) that consists of standard units such as joints and links, which can be efficiently configured into the most suitable leg geometry for these tasks. From this point of view, modular robots introduce a new dimension to flexible automation in terms of hardware flexibility, compared with conventional industrial robots.

Figure 1.16 shows some of the possible configurations of parallel kinematic mechanisms that can be found primarily in [1]. The patented machine tools in Fig. 1.16a "Hexa" [147] and Fig. 1.16b "Rotary Hexapod" [34] are revolute actuated ones while Fig. 1.16c 6-dof parallel mechanism [9] and Fig. 1.16d "Eclipse" [132] are the combination of revolute and prismatic actuated mechanisms. Figure 1.16e 6-dof "minimanipulator" [140] uses 2 prismatic actuators with fixed leg lengths and Fig. 1.16f [18] displays the combination of a linear driven base point and variable strut lengths.

Philosophically, most of the work above was built upon the concept of the traditional "Gough-Stewart" mechanism type. This suggests that most parallel mechanisms have six degrees of freedom. A question left open in previous work is: The vast majority of the machining is done with less than 6-dof, so why should we pay for six? In this book, we will focus our attention on 5-dof or less than 5-dof parallel mechanisms (Fig. 1.17), since machining consists in orienting an axisymmetric body (the tool), which requires only five degrees of freedom.

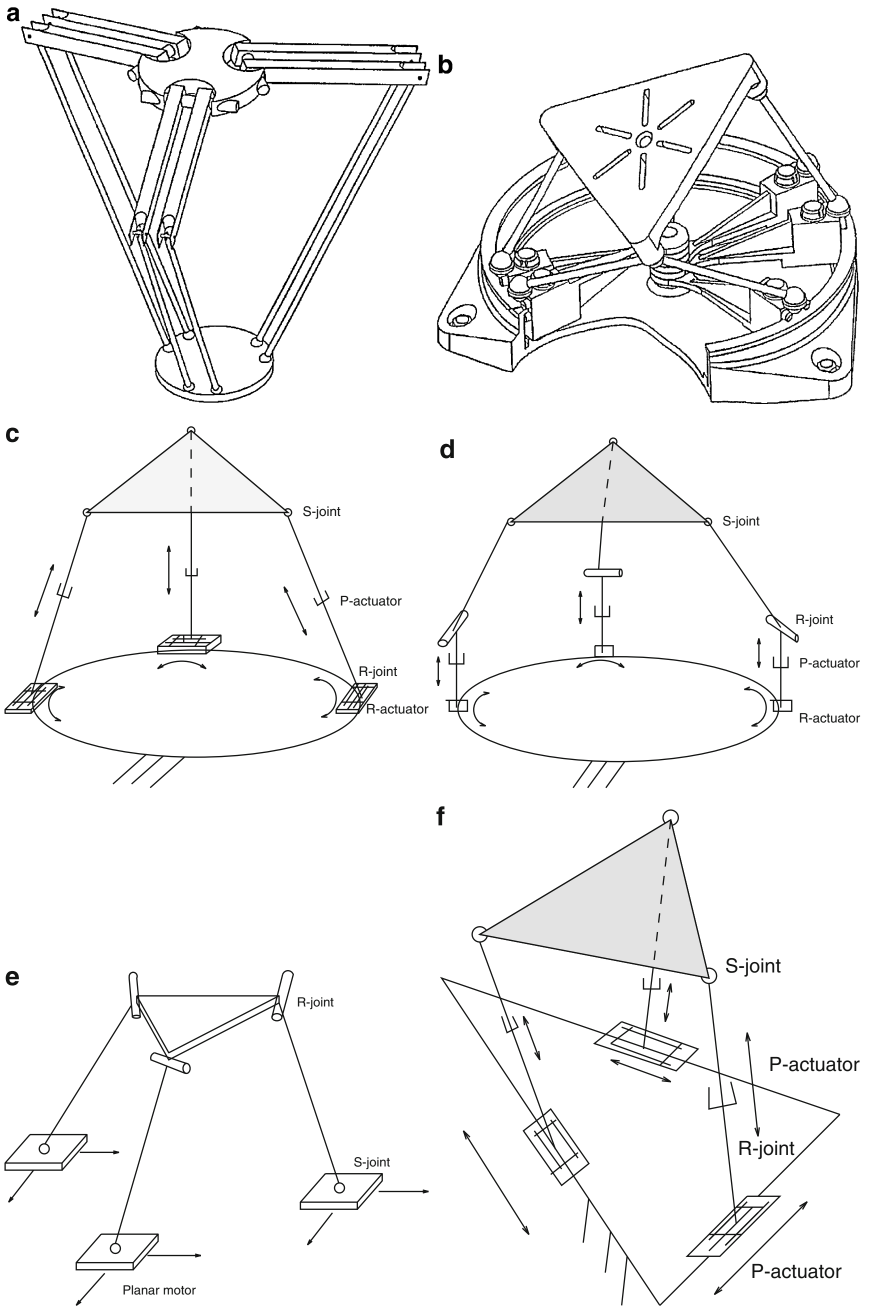

Fig. 1.16 Selected parallel kinematic mechanisms. (**a**) The "Hexa" robot (Uchiyama 1994). (**b**) The "Rotary Hexapod" by Hexel (Chi 1999). (**c**) Circular movement of the base point. (**d**) "Eclipse" from SNU. (**e**) 6-dof "minimanipulator". (**f**) Combination of linear driven base point and variable strut length

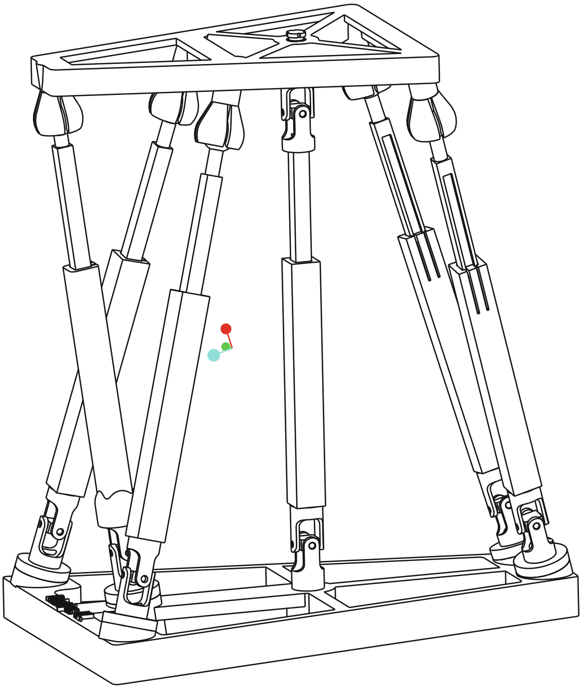

Fig. 1.17 CAD model of the 5-dof parallel mechanism (Figure by Gabriel Coté)

In this book, we propose a series of n-dof parallel mechanisms which consist of n identical actuated legs with six degrees of freedom and one passive leg with n degrees of freedom connecting the platform and the base. The degree of freedom of the mechanism is dependent on the passive leg's degree of freedom. One can improve the rigidity of this type of mechanism through optimization of the link rigidities to reach the maximal global stiffness and precision.

1.4 Scope and Organization of this Book

Conventional machine tools are usually based on a serial structure. There are as many degrees of the freedom as required, and the axes are arranged in series. This leads to a single kinematic chain. The axes are usually arranged according to the Cartesian axes, which means there is a X, Y, and Z axis and rotational axes if needed. These machines are easy to operate because each axis directly controls one Cartesian degree of freedom and there is no coupling between the axes.

A parallel kinematic machine promises to increase stiffness, higher speed, and acceleration due to reduced moving mass, reduced production, and installation costs. Research in this kind of architectures for machine tools has been growing since the 1980s [12, 15, 70]. Although a number of new devices were patented, none seems to take the structure flexibility into account. Although the joints and links have become commercially available, the study for the most promising architecture for machine tools through kinetostatic analysis, dynamics, and optimization is still a challenge. The aim of this book is to provide readers the new alternative mechanical architectures which could be used in the design of a machine tool with parallel or hybrid architecture. To reach this goal, the objectives are set as follows:

1. Development of a topological representation and generation of all possible architectures that will provide 5 degrees of freedom between the tool and the workpiece. The topological representation serves to develop a database for conceptual design to obtain the most promising kinematic architectures for 5-dof or fewer than 5-dof machine tools. The key consideration in achieving this objective are (1) both the tool and the workpiece can be actuated independently and 5 dofs are required for manufacturing tasks, (2) the possible combinations of 5 dofs are: (5, 0), (4, 1), and (3, 2), and (3) for each of these combinations, the kinematic chains involved may lead to several possibilities (serial, parallel, or hybrid) and additionally, redundancy may be an option. At the end of this study, a detailed list of possible topologies will be obtained and the most promising architectures will be highlighted.
2. Development of geometric design model. The key task is for the topologies selected in the previous study, to define geometric parameters and investigate the geometric design. The geometric design must take into account the actuation issues, the working volume, and mechanical interferences. The selected designs will be modeled using Pro-Engineer, which will facilitate this step. Again, all possibilities of configurations will be investigated.
3. Development of a general model of the stiffness of the mechanisms screened out from the list of some promising configurations. Using a formulation based on lumped flexibilities, write a general model of the stiffness of the concerned mechanisms. Using this model, all concerned mechanisms will be analyzed for their stiffness and accuracy at the tool, which is the most important property of the mechanism. In the lumped model, links and actuators will be replaced by springs whose stiffness will represent the stiffness of the link or the actuator.
4. Development of the kinetostatic modeling for parallel robot design. Kinematic/static duality can be derived by considering the power input to and output from a system, which can neither store nor dissipate energy, namely, a system in which kinetic energy, strain energy, friction and damping are all absent and where gravitational forces are considered as external forces applied to the system. Thus, term "Kinetostatic Analysis" as such: Given the mechanism motion, calculate the unknown internal joint forces and external input forces or torques. Kinetostatic analysis includes two analyzes: (1) kinematic solutions to provide the mechanism motion, (2) stiffness solutions to relate the forces and torques to the motion. Using the kinetostatic model developed in the preceding step, the most promising architectures for stiffness (accuracy) based on constraints associated with size and geometry can be optimized.

5. Development of reconfigurable parallel robotic machine tools. The new design uses an adjustable architecture, so the machine tool has the capability to machine all five sides of a workpiece, and adjust the depth, clearance of interference and dynamic performance. The proposed reconfigurable 5-DOF parallel kinematic machine can machine 5 sides of the workpiece freely with a simple mechanism, hence providing savings in the motion system construction and implementation. The reconfigurable system was implemented by an adjusting architecture. The findings have significant potential for industrial applications.
6. Development of the synthetical methodology for performance evaluation and design optimization. The mean value and the standard deviation of the stiffness distribution are proposed as the design indices. The mean value represents the average stiffness of the parallel robot manipulator over the workspace, while the standard deviation indicates the stiffness variation relative to the mean value. In general, the higher the mean value the less the deformation and the lower the standard deviation, the more uniform the stiffness distribution over the workspace. A design optimization based on these global stiffness indices is further investigated. At this point, a multi-objective optimization issue will be defined. Genetic algorithms based Pareto optimal frontier set in the solution space can be obtained as the results of comprehensive stiffness design, and other performance indices are also considered.
7. Development of the optimal calibration method. It is known that calibration is best performed in the least sensitive error region within an entire workspace. Because of the complexity of the error sources, it is difficult to develop the calibration model if all the errors will be considered. Errors including manufacturing and assembly error, thermal error, and nonlinear stiffness error are considered as a single error source (pseudo-error source), which only causes the deviation of joint variables. Artificial neural network will be applied to describe the complex nonlinear relationship between joint variables and deviation of joint variables with respect to the measured pose of the end-effector. The pseudo-error in arbitrary joint variable can be obtained and thus the control parameters can be adjusted accordingly.
8. Development integrated environment of parallel manipulator-based machine. The system included a kinematic/dynamic analysis, kinetostatic modeling, CAD module, FEM module, CAM module, optimization module and a visual environment for simulation and collision detection of the machining and deburring process. It represents an integration for the design, analysis, optimization, and simulation of the parallel kinematic machine. An approach for web-based real-time monitoring and remote control is also developed. The effectiveness of the system is shown through results obtained by the National Research Council of Canada, during the design of a 3-DOF Tripod parallel robotic machine. Notable advantages of the new system included ease and efficiency, thereby allowing a real-time simulation.

Although the proposed investigation is aimed at the most promising 5-dof or fewer than 5-dof machine tools architectures, those issues addressed in the eight objectives are fundamental. Therefore, the results of the work can provide a framework for facilitating a further study of parallel mechanisms for machine tools.