

Characterization of the Tau Parallel Kinematic Machine for Aerospace Application

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ABSTRACT

A consortium of interested parties has conducted an experimental characterization of two Tau parallel kinematic machines which were built as a part of the EU-funded project, SMErobot¹. Characteristics such as machine stiffness, work envelope, repeatability and accuracy were considered. This paper will present a brief history of the Tau parallel machine, the results of this testing and some comment on prospective application to the aerospace industry.

INTRODUCTION

Boeing has successfully engineered the use of commercial grade light robotics and automation in the manufacturing process of high-volume component parts for the 787 Moving Trailing Edge (MTE) being produced at Boeing Aerostructures Australia in Melbourne, amongst other implementations throughout The Boeing Company. Boeing Research & Technology (BR&T) is now developing light robotics through new and emerging robotic platforms to compliment traditional gantry systems and standard, industrial robotics.

Parallel kinematic machines (PKMs) have been developed in innumerable formats and have resulted in machines with excellent accuracy, high speed and acceleration characteristics and high stiffness. However, they have generally suffered from small working envelopes compared to the size of the machine. ABB have patented a format of PKM, the Tau, which has the desired characteristics of a PKM with a working

envelope equivalent to an industrial robot or gantry of the same machine size. With this innovation, it could be seen as the breakthrough characteristic for PKMs in the aerospace industry, where industrial robotics have generally required enhancement in accuracy and deflection compensation to enable application.

As a part of the EU funded-project, SMErobot, two Tau machines in gantry format have been built. BR&T, in partnership with a wider consortium of companies, has benchmarked these machines in machine stiffness, work envelope and repeatability. This paper will present a brief history of the Tau machine and summarize the performance of the prototypes as measured by the consortium. A short discussion is also included on the potential application of the Tau PKM concept within the aerospace industry.

PKM DEVELOPMENT

GENERAL HISTORY – PKMs stem from centuries old interest in parallel geometries and were recently brought to modern application by Cappel, Gough, Pollard and Stewart², in the form of the “Stewart” platform. However, widespread use in manufacturing operations did not occur until the invention and licensing of the Delta parallel robot configuration by Clavel³. The centralization of the actuators enable the platform to find application in pick and place operations due to its accelerations of up to 10 G or more. However, its wider use in different applications has been limited by the possible payload (generally of 1kg maximum) and a typical ‘banana-shaped’ workspace giving a relatively

small workspace in relation to the footprint of the robot. (ABB FlexPicker workspace 0.3 m high for a robot of 1 m height) . The sale of these machines now ranks in the thousands with ABB, SIG, Bosch and Adept being the main players.

For machining operations, the most successful application of the PKM concept has been the Tricept which found its first application in 1996⁴ and has now over 300 robots sold. Others on the market include the Exechon^{5,6} and DST Ecospeed. However, when compared with robot or machine tool sales in machining applications, the application of PKMs can be considered very small. The characteristics of high stiffness and accuracy given by these machines would seem ideal for the aerospace industry. However, this industry has also not taken to the concept in large numbers. One of the main reasons may be the work envelope of the machines which may require the combination of the parallel kinematics with serial kinematics, such as a gantry, to access larger components. The main question being, "Why not just have a gantry?"

TAU PKM DEVELOPMENT – As introduced, traditional parallel kinematic manipulators (PKMs) have not found any widespread application in industry, mainly because of the large machine footprint in relation to the work space.

SCARA (Articulated) Tau PKM – ABB began investigating scale-related improvements to its delta platform through non-symmetric configurations and mounting the arms to rotate about a central axis. This led to the creation of the SCARA-Tau format. This format redistributes the links in a 3/2/1 structure to give only axial forces in the links and enable large accessible working envelope movements, equivalent to those of a serial, industrial robot, without reducing the performance advantages of the delta structure: low inertia, high stiffness, high mechanical bandwidth, high accelerations and speeds, etc⁷⁻⁹. A prototype of this format was built and it achieved exceptional performance and work envelope figures, as shown in Figures 1-3.



Figure 1. SCARA Tau PKM prototype¹⁰ with all arms having a common rotation axis.

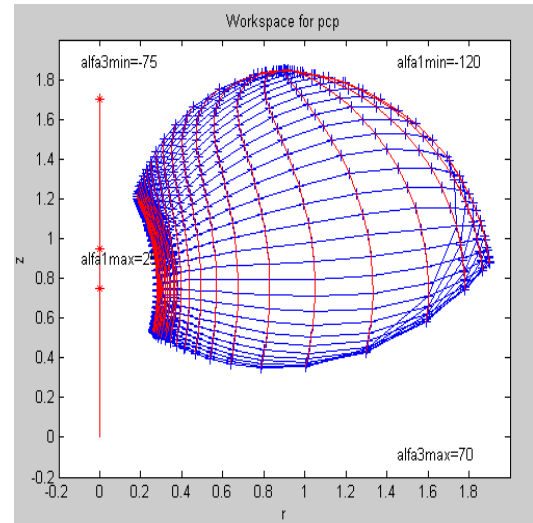


Figure 2. The working envelope of the prototype in Figure 1.

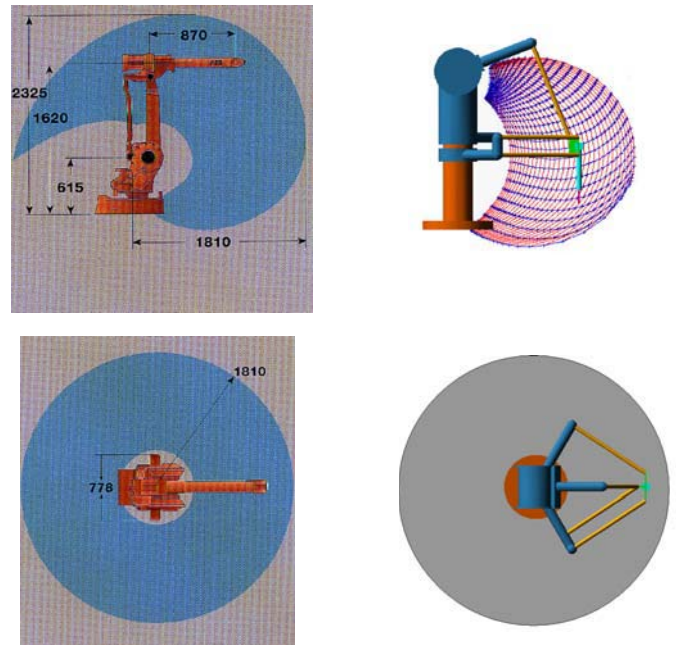


Figure 3. The working envelope of a SCARA Tau with orthogonal upper arm axis, work space comparison with IRB2400.

Gantry Tau PKM – The stiffness of an articulated PKM like the Delta or the SCARA Tau is limited by the actuated arms because of the lever effect. The forces from the links on the tips of the arms give rise to large forces in the gears and bearings at the base of the arms and the compliance movements in these components will be magnified to larger movements in the tips of the arms. Therefore, for higher force applications with high accuracy requirements, it is necessary to use linear actuators instead of actuated arms to manipulate the PKM link structure¹⁰. This was achieved, again using the 3/2/1 link structure, as shown in Figure 4¹⁰.

novel development, the alignment of the link mounting points and the addition of a telescopic actuator for the single link is modeled to increase the work envelope and also increase stiffness-based performance, as shown in Figures 5-6¹⁰ and Table 1-2¹⁰.

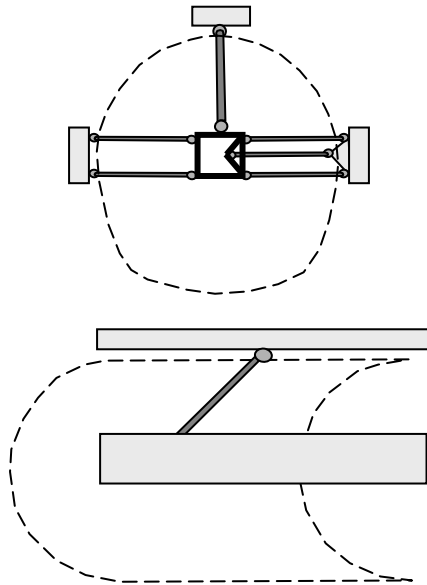


Figure 4. Assembly of the 3/2/1 link structure showing the work envelope. Note the hole in the right hand of the envelope¹⁰.

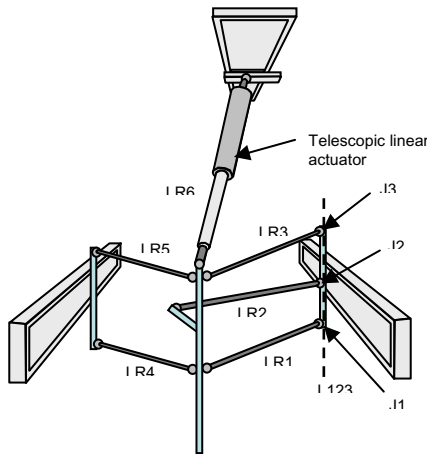


Figure 5. Modification of the link structure to enable reconfiguration¹⁰.

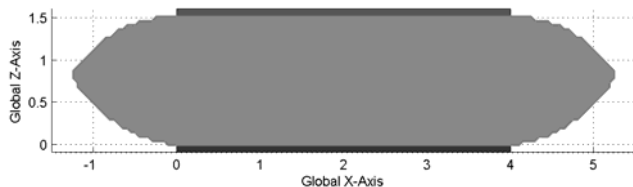


Figure 6. Work envelope with reconfiguration¹⁰.

Table 1. Cartesian stiffness values (N/ μ m) in the X-, Y- and Z-directions of the reconfigurable PKM with one telescopic link (Y-direction is aligned to the single link in the 3/2/1 configuration). Link stiffness of 232N/ μ m and joint stiffness 50 N/ μ m. The max, min and average values are for the whole work space where the telescopic link can be positioned at the same X-position as the TCP. In the best 70% workspace case the border work space has been removed¹⁰.

Entire Workspace	X	Y	Z
Minimum	19.50	5.06	18.69
Maximum	67.51	57.88	55.46
Average	53.20	22.28	29.36
Best 70% Workspace	X	Y	Z
Minimum	49.37	13.81	22.55
Maximum	67.51	57.88	55.46
Average	59.13	27.70	33.08

Table 2. Cartesian stiffness values (N/ μ m) in the X-, Y- and Z-directions of the PKM with fixed single link length for comparison with Table 3¹⁰.

Entire Workspace	X	Y	Z
Minimum	26.59	2.05	19.02
Maximum	82.82	50.90	42.29
Average	65.49	13.04	26.32
Best 70% Workspace	X	Y	Z
Minimum	60.56	3.89	21.45
Maximum	82.82	50.90	42.29
Average	72.76	17.48	28.89