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Redundant parallel positioning table device with linear dof

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Abstract
In experimental diffraction, by using standard or advanced X-ray techniques, the Diffractometers (Dm) are still the most used machines in any synchrotron facility. For sample positioning, the machines' designers equipped the Dm with standard stage (stacked) devices as a preferably solution. However, in a variety of situations, large size and heavy load specific instruments (vacuum, cryo, spectrometers, etc) must be used. And, the standard available working space of Dms not always enough. A more compact multi-axis positioning device is desirable; at least, to condense some of the degrees of freedom (e.g. 3). The proposed Redundant Parallel Positioning Table Device (Rd-PPTD) is based on parallel kinematic (PK) principle. The symmetric 3-4**P**PP mechanism belonging to QUDROPOD family has four active legs from which one is redundant (Rd=1). Each of them has two (X, Y) orthogonal linear glides / slides all acting in a plane. The specific kinematic features are analysed and the design concept presented. As Proof of Concept (PoC) an experimental model has been built.

Positioning, Parallel Kinematics, Redundancy, Kinematics, Design

1. Introduction

Synchrotron research is an important field of research today [1]. By using the power of light, the investigations are focused on various issues from material and biological worlds. The new advanced facilities built with improved tools characteristics (brightness, size, pulse) are adapted to the specific applications. Subsequently, the afferent machines and the instruments too, become highly specialized and more complex.

In X-ray experimental diffraction, the positioning machines called Diffractometers (Dm), e.g. [2] are manipulating the sample and detector in well-defined positions to investigate the molecular (and/or, atomic) structure of materials based on well-established principles of diffraction. The key point of the process is the correlation between the incident and diffracted rays angle. Or, with another words, the relative position between the detector, sample and X-ray.

Generally, the sample manipulation involves a simple (point to point) motion of positioning. However, by applying modern techniques (e.g. XRR, GIXRD, etc)[3] the complex instruments e.g. baby chamber, spectrometers, etc including the sample (inside) must be manipulated with high precision and kept in the position for relative long time (e.g. days).

The afferent multi-axes positioning devices(>3) must carry these (heavy) loads and (big) size parts in a relative small available 3D working space of Dms. As very often, the operation implies a spherical positioning around the Dm's Center of Rotation (CoR), this is reducing from the available height of the devices.

Till now, the positioning devices have been built largely on Serial (Stacked) Mechanism (SPM) solution. (Every axis of motion has been materialized by a stage/positioning unit). More recently, Parallel Kinematic Mechanisms (PKM) has been adopted as another solution. Fully PKM's Precision Hexapods (e.g. PI, SYMETRIE, etc) are increasingly used now. However, their standard height (with, CoR distance) not always perfectly fit inside the existent standard Dm(s) working space, e.g. [4]). And, their final motion is also difficult to be predicted in the alignment phase. In addition, there are some applications when less than 6 dof are necessary.

An alternative to those above is presented here; especially, when at least 3 dof in translation are necessary. Compared with the above SKM (or, PKM) devices, the Redundant Table Positioning Device (Rd-TPD) new concept is delivering 3dof (XYZ) in a compact way, having low profile (height), and intuitively motion.

2. Kinematics

The static, kinematic and, dynamic features of any PKM are strong related with its structure. And, the shape…(Similar as the properties of materials are defined by the atomic structure). A short analysis is given below for a proposed structure based on the above requirements.

2.1. Topology

The proposed Rd-TPD structure shown in Fig. 1 is belonging to QUATROPOD 'species' of PKMs [5]. This four (4) point architecture suits well with the rectangular shape of a table.

A 3-4(111) general class is representing fully symmetric structures with fixed Base (B), mobile table (T) and four kinematic chains (K_i).

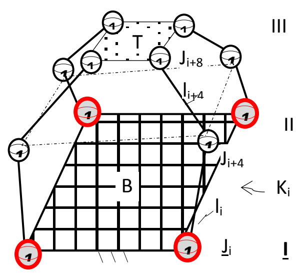

Figure 1. 3-4(**1**11) Topology

One of the levels (**I**-**III**) can be actuated. The 3-4(**1**11) member, shown in Fig. 1 has a total of three degrees of freedom (F=3) and all the actuators (**1**) at the base, one being redundant (Rd=1), from stability (and, dynamic) point of view.
Note: Every (K_i) is using joints (J_i) with maximum one (1) dof (f_i=1), and has few links (l_i,l_{i+4}=8) which can be an advantage from precision point of view, Tab. 1 (F_i, f_i – chains and joints partial dof).

2.2. Mechanism

In Fig. 1 a 3-4(**P**PP) mechanism is proposed based on above structure (and, initial requirements). It consists from using two (2) pairs of kinematic chains (K_i,K_{i+2},i=1,2), with - orthogonal (α_{i+4}=90°) and inclined (α_{i+8}<90°) axes ($P_i \perp P_{i+4}/P_{i+8}$,i=1,…,4) connecting the rectangular shaped base(B) and table(T), Tab.1.

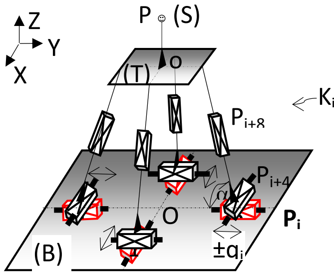

Figure 2. 3-4(**P**PP) Mechanism

Table 1 3-4(**1**11) Kinematic features

Rd-TPD	K_i	A_i
3-4(**1**11)	F_i=3	f_i=1
3-4(**P**PP)	α_{i+4}(P_{i+4}, **P_i**)=90° α_{i+8}(P_{i+8}, **P_i**)<90°	α_i(**P_i**,P_{i+1})=90°

The actuation module (**P_i**, i=1,…,4) of the mechanism is consisting from four (4) active pairs orthogonally arranged (α_a=α_i=90°) in a plane. However, the final 3D motion of a point P of sample (S) need to be positioned is mainly coming, as a result of the combination of eight (8) - 4**P** active/4P passive gliding/sliding pairs. This (OCTOGLIDE) principle [6] is providing simplicity and intuitively motions for X, Y, or Z basic displacements, Tab. 2 (nominal position).

3. Design

Based on the above proposed mechanism and taken in to account (again, the initial requirements), a design solution has been conceived. It consists from using simple - active/passive (inclined) linear positioning means to materialize the mechanism's kinematic principle between the two identical quadratic shapes – base (B) and Table (T), respectively.

In this integrated solution, the active positioning units (**A**) fixed on the base is supporting the next intermediate (I) passive ones; then, a pair of wedges (w_1, w_2) is materializing the elevation (E) units supporting the pillars (p), Fig. 3.

The final displacements – X, Y and Z are also easy to be predicted in the inversed pyramidal concept and the displacements are proportional (or, equal) with the actuation ones, Tab.2 (l_a, l_i, l_w= actuators, intermediate, wedges strokes). Note: For α=45°, the Z values are the same with X=X_i (Y=Y_i).

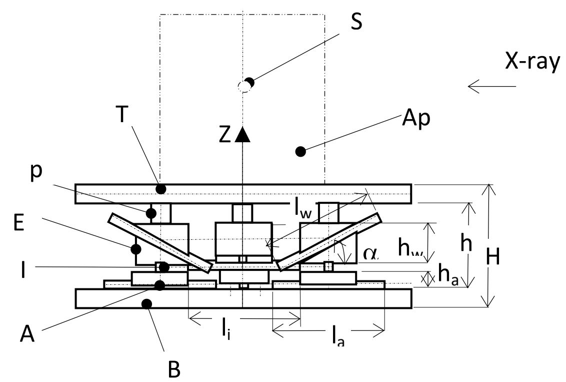

Figure 3. Rd-TPD Design Concept

Table 2 3-4(**P**PP) Motions

Rd-TPD	A_i	$X_i(Y_i)$
X	A_1A_3	X_1=X_3
Y	A_2A_4	Y_2=Y_4
Z	A_1A_3 (A_2A_4)	$X_1 tg\alpha = X_3 tg\alpha$* ($Y_2 tg\alpha = Y_4 tg\alpha$)

*Sign must be applied

4. Experimental Device

Based on all above, an experimental model (Em) has been built to fulfil the final stage of investigations - proof of concept (PoC). It helped to understand the general behaviour (collisions) and the limitations (e.g. workspace). With most of the parts manufactured from aluminium (Al), including the base/table (L=153 mm, h=10mm) and wedges (h=30,α=45°), commercially linear ball bearings guides (IKO/LWL9) has been used. With maximum actuation strokes (l_a=48mm) orthogonal displacements X=Y=Z=48mm has been performed.

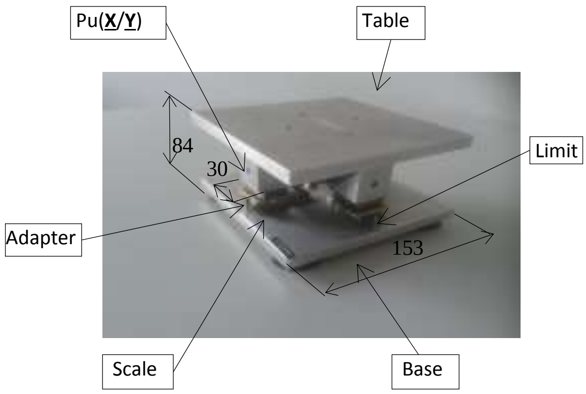

Figure 4. Rd-PPTD Experimental Model

5. Conclusion

Rd-PPT is a new concept in synchrotron positioning. The youngest member of OCTOGLIDE's family has several specific features (stability, compactness, simplicity) over the prior art qualifying it to do the specific Diffractometer (Dm) tasks. With small modifications can be suit to do jobs in another field (e.g. neutron). In the Proof of Functionality (PoF) step a real prototype will be built, and its capabilities tested after a direct and invers positioning problems (DPP/IPP) solved.

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