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A FAMILY OF REDUNDANT POSITIONING DEVICES FOR SYNCHROTRON APPLICATIONS

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Abstract

A new family of reconfigurable devices able to work in synchrotron applications, especially in diffractometer's environments has been developed. It can provide six (6) or less than six (<6) degrees of freedom (dof) motion capabilities (F≤6) being able to pose a heavy load sample (instruments) with high precision towards an X-ray incoming beam. Based on the Parallel Kinematics (PK) Quatropod concept with redundant actuation (Rd=2), it was built around the fully (F=6dof) basic topology 6-4(**2**13) where **2**- actuated and 1, 3- passive joints, respectively. By altering the passive joints dof, structures with less than six dof (F<6) can be obtained, e.g. 5-4(**2**13_2)/F=5, 4-4(**2**13_1)/F=4, 3-4(**2**13_0)/F=3 (3_2 and $3_1$and 3_0 stand for 3dof joint with constrained/less dof – f=2, 1 or 0/blocked). For a perfect symmetric arrangement and using only P, and S (P-prismatic, S-spherical) joints several useful positioning mechanisms are presented. And, in the design phase, 2dof linear actuators (2P), e.g. XY stages have been proved to be a successful choice, too.

INTRODUCTION

Today, the synchrotron light has been proved to be one of the most active tools to investigate the internal structure of materials. By using the actual and/or further advanced facilities and techniques, the mysteries of our ancient and future world are waiting to be deciphered.

The X-ray Diffraction (Df) is a well-established research technique for material characterisation. In its basic and/or modern forms [1] it is actually the largest investigative technique. Previously applied exclusively for crystalline materials, nowadays it extended to virtually any materials scattering X-rays. An appreciable number of research results have been obtained in the recent years.

The "workhorses" here have been the Diffractometers (Dm) machines. Built in standard or customized types for various specific applications they are manufactured by several companies (HUBER, NEWPORT, KOHZU, etc). Very often, the requirements are coming to use them for samples working in special environmental conditions (vacuum, cryo, magnetic) fields. These instruments could be sophisticated, large in size and heavy. In addition, they must be manipulated (together with the sample) with high precision, e.g. [2]. However, the existent working space inside of the Dm machines is relative small (constrains are coming from the beam line available room space / hutches, also). In order to comply with this restricted space (especially, height), the sample positioning systems designers must accommodate. Till now, in their concepts, they adopted a serial/stacked solution. (X, Y and/or Z motion xes have been materialized through single axis translation and/or rotational positioning units called the stages). Subsequently, a sample (and, instrument) is posed in space in the desired position, but with relative low precision (accumulation of errors). The stages are commercially available in a large variety of standard typo-dimensions and can move a heavy load in all (6) or less than six (<6) degrees of freedom (dof). However, in the case of more than 3 dof, the available Dm working space in height sometimes is not enough for stacking all the axes, especially, when rotations around the Centre of Rotation (CoR) point are required. The CoR distance is predetermined (fixed).

Precision Hexapods based on Parallel Kinematic Mechanisms (PKM [3]) are gradually replacing them. They are precise and versatile, able to perform six (6) dof by freely choosing the CoR (variable distances), e.g. PI/Micos, SYMETRIE, NEWPORT, AEROTECH. However, they came with limitations regarding the available portfolio (standard typo-dimensions). The manipulated load & overall size (especially, the height) cannot fulfil always the specific requirements; they are too week or too big. They are not perfectly adapted to Dm environment [4]. Moreover, when less than 6 (dof<6) are necessary, another solutions must be considered.

In order to fulfil all these inconvenient, a new family of positioning devices is proposed. Based on the redundant and reconfigurable principles, at least one of the members could fulfil the above expectations. The main topological, kinematical and conceptual design features for the whole family and in particular for the members will be presented below.

RD-PPTD

HUBER Diffraction & Positioning company has been for a long time a promoter of synchrotron instrumentation pushing the limit of X-ray investigations [5].

A research project (2011) aiming to develop new positioning devices for synchrotron applications based on PKM has finally resulted into the development of a new family of Parallel Positioning Devices (P-PD) based on QUADROPOD (QP) [6]'species'.

By using only fundamental joints (f=1,2,3, f-joint dof), and in the same configuration on each level from the total of three (j=I,II,III) – costs saving and by choosing 2 dof actuation–compact joints, the findings resulted in three (sub) families of topological options. Each actuated level has eight dof capabilities $(F_j)a=8$, j=I,…,III where Fj – level dof (a-actuated) being from kinematics pov redundant one. One from the above QP6_2A (2A–2 dof actuation) (sub) families exhibits useful characteristics for positioning. The 2dof actuation subfamily having all the actuators on the base(Ia) has the advantages of low dynamical effects of motion comparing with another ones - (IIa) and (IIIa), respectively. The 6-4(**2**)13 (6-dof, 4-chains) representative

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structure is providing 6dof motion and could have the actuation any single units, e.g. planar (2P), spherical (2R), roto-translation (RL) motors. This redundant positioning topology (Rd=2) is owing an increased natural static stability (Ss=4), and is perfect adapted to the common shape (quadrilateral) of a working table. Moreover, by the adequate modification–alteration and/or elimination of the dof of the passive joints – (1) and (3), e.g. 1_0; 3_2, 3_1, 3_0 (2-two dof, 1-one dof 0-nul dof/blocked), the resulted structures are performing less than six (6) dof positioning tasks with the same actuation setup [7].

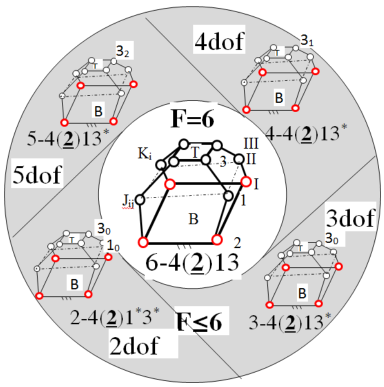

Figure 1: Rd-PPTD (QP_2A) family.

This has several advantages regarding the costs and flexibility of positioning (manufacturing, handling, etc) specific for the large scale facilities, as synchrotrons are. All the members of this family performing: a) six (F=6) and b) less than six (F≤6) dof, are shown in Fig. 1.

By using in each of the Kinematic chain (Ki, i=1,…,4) only simple P–prismatic/linear (well-established technology) and upper level S– spherical (IPP, DDP simplified) joints, a new parallel mechanism (sub)family is obtained.

The 6-4(2**P**)PS architecture shown in Fig. 2 with the pyramidal shape is using planar units for the actuation (2P) and inclined Pα (α- angle) passive joints. By adequate modifying the P and S joints, the resulted mechanisms become able to perform less than six (6) dof positioning motions. The members are shown in Fig. 2.

By performing a suitable choice of the elements in the design process for both, the actuation (2P) & passive joints (P, S), the improved results can be expected from the precision, stability and load manipulation point of view. Specifically, an increased precision is expected as a result of the averaging/minimizing the manufacturing & assembly errors effect (over-constrained mechanism). In addition, the total shape, e.g. height could be reduced. A direct drive (DD) planar motor (Pl) for actuation (2P) and the wedges (W) principles for passive (P) joints could be among the options. By the coordinate motion of each of the pairs from the four Kinematic chains (Ki), the structure can deliver in a compact way - all translational and rotational (3T&3R) dof, respectively.

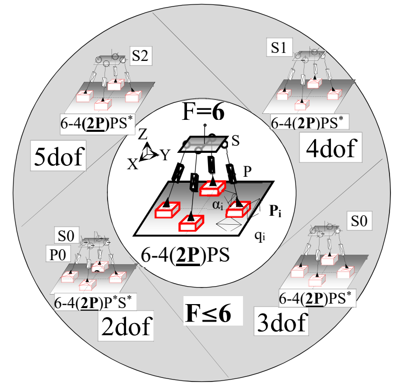

Figure 2: Rd-PPTD (QP_2P) family.

The resulted members, being able to perform either, full (6dof) and less than six (<6dof) motions of positioning with a suitable design of the components (W, S).

An overview of the whole family with these specific features is included in Table 1.

Table 1: Rd-PPTD Configurations

Rd-PPTD	F=6	F≤6
T	(**2**)13	(**2**)1*3*
M	(2**P**)PS	(2**P**)P*S*
D	(**Pl**)WS	(**Pl**)W*S*

* modified or missed

A short description of the design concept for the entire family and the particularities for each of the members is presented below.

RD-PPTD (6DOF)

Figure 3 shows the design concept for Rd-PPTD in the case of 6-4(2**P**)PS mechanism. This modular architecture stands as a base for the development of other members of the family.

Between a base (B) and table (T) four Positioning modules (Pm) are arranged around the centre of the base, each of them consisting from a well-defined combination of active(A-Actuation) and/or passive (E-Elevation, G-Guiding) positioning units (Pu). It is able to deliver 6dof (3T3R) motion of positioning in space. Active (Ac) Pu can be chosen as any compact translational XY stages with high accuracy (and, stiffness) based on DD, or electro-mechanical (e.g. motor-ball screw) principle [8].

The first passive Pu - Elevation (El) can be built as a pair of wedges (W1/W2) materializing a precise, compact and stiff up / down motion. A compact ball & socket design based on sliding principle fit for the passive Guiding (G) unit. Generally, it consists from a vertical pillar with a high precision ball (B) at one end and two adjustable houses (H=2). Through the combined (XYZ) motion of all (or, some) Pm (Pm_i, Pm_{i+2}, i=1,2) precision and stiff: a) translations - X,Y,Z and/or b) rotations - Rx, Ry or Rz can be obtained. The resulted working space is rectangular (prism)

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and inside of it, a Cartesian (cubic) one can be easy find as a solution for free of singularities motion.

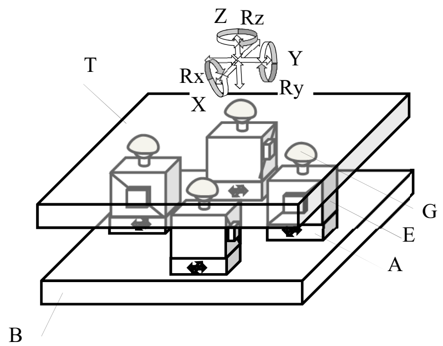

Figure 3: Rd-PPTD (F=6) design.

RD-PPTD (<6DOF)

Figure 4 shows the design concepts for Rd-PPTD with less dof (F=5, 4, 3, 2). They are derived from previously one, with full dof 6-4(**2P**)PS mechanism by adequate modifications of E(levation) and S(pherical) parts.

5dof Rd-PPTPD device is obtained by a simply modifying the upper level joints (S), Fig.4a. In this case, the joints must perform 2dof, only. Specifically, the new joint (S2) should be able to permit only the rotations – Rx and Ry, around X and Y axis, respectively. With other words, the remaining dof – the rotation around Z axis (Rz=0) should be somehow (mechanically) blocked. A ball shaft (pins) must be able to perform combined motions along of two orthogonally channels. The final design solution depends of the specificity of joint type, e.g. sliding, rolling, etc. (Note: The redundancy is changed, Rd=3).

4dof Rd-PPTD device is obtained by adequately modifying the upper level joints (S) to perform 1dof, only. Specifically, S1 joints should be able to permit only the rotations around Z axis (Rz) by blocking the remaining dof – the rotations around X and Y axis (Rx=Ry=0). As in Fig. 4b is represented, a (modified) ball-shaft must be able to rotate inside of a precision hole manufactured in the upper house, only. Effective design solutions must adapt to the type of joints. (Note: The grade of redundancy is four, Rd=4).

3dof Rd-PPTD (Fig. 4c) is obtained by fully modifying the upper level joints (S). In this case, they must not perform any rotation (Rx=Ry=Rz=0). S0 parts, ball-shaft and house(s) must be somehow fixed against each other, e.g. screws, etc. (Note: The grade of redundancy is five / Rd=5. The device can also work with four (4) actuators, only(Rd=1). And, G positioning unit can be missed [9].)

2 dof RD-TPD, Fig. 4d is obtained from the basic RD-PPTD Pu, by using the elevations (E) and spherical (S) joints with null dof. With other words, E0 and S0 must be blocked during the mechanism motion in each of the four Pm. (Note: Rd=6, but the device is working with four (4) actuators (Rd=2); E and G units both can be missing).

An overview of the above design features for whole family is given in Table 2. (Note: Each Positioning module (Pm) is resulting from a pre-established combination of Positioning units (Pu) involving a basic set of S joints).

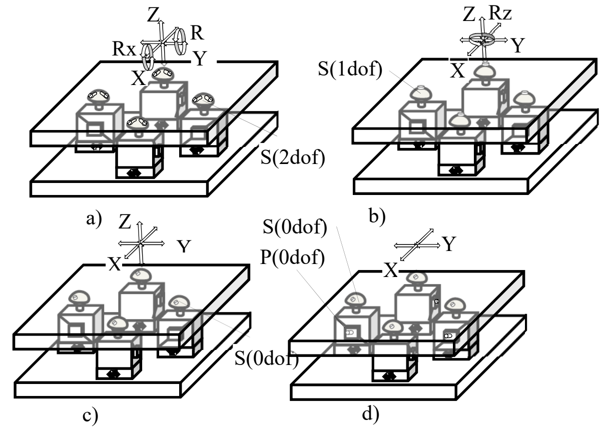

Figure 4: Rd-PPTD (F<6) design.

Table 2: Rd-PPTD Design

Pm	F=6	F=5	F=4	F=3	F=2
A			(X/Y)		
E			W1/W2		W0
G	S	S2	S1	S0	S0

0 – fixed/motionless

CONCLUSION

A new family of redundant parallel positioning table devices (Rd-PPTD) able to work in a synchrotron environment has been presented. Built on the direct requirements of the diffractometers' use, its powerful members exhibit the necessary features to qualifying it for heavy load and high precision positioning. By using the (re)configurability principle, it offers an alternative solution for fast and cost-effective positioning in synchrotrons' workshops, delivering flexibility, saving costs and time. It stands also as a first step and example towards the parallel reconfigurable positioning concept.

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