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OCTOGLIDE – TABLE POSITIONING DEVICE FOR DIFFRACTION APPLICATIONS

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Abstract

A new Table Positioning Device (TPD) for high precision and heavy load manipulations has been developed. Conceived as an alternative to the precision hexapods, it fulfils the gap of sample (and/or, instruments) positioning in smaller (height) available working spaces of synchrotron Diffractometers (Dm). The concept is based on a Redundant Parallel Kinematic Structure (Rd-PKS) with four (4) legs having 2dof active joints (actuators). In the Proof of Functionality (PoF) step, a stacked solution has been adopted for the actuators' design using precision XY translation Positioning units (Pu). The symmetrically 6-4(**PP**)PS mechanism – OCTOGLIDE(OG) having eight (8) gliding actuators (**P**) is implying also a pair of wedges–Elevation (El) and socket/ball–Guiding (G) Pu, as passive joints (P and S) forming one of the Positioning modules (Pm). Spatial positions in the working space can be reached without any singularities and planar motions along X or Y axis performed very intuitively with only some of the actuators (decoupled) motions. The first tests of the prototype are revealing both, high precision geometry of motion (straightness, flatness, etc.) and stiffness capabilities.

INTRODUCTION

Diffraction using standard or advanced X-ray methods is still the most common techniques to investigate the structure of various materials [1]. In the synchrotron case, the dedicated machines – Diffractometers (Dm) have been built in a large variety to fulfil the specific requirements (NEWPORT, HUBER, KOHZU, etc). Sometimes, these requirements implied the use of special environmental conditions' instruments. They could be sophisticated, large in size and heavy; but, must be manipulated with high precision (i.e. I07/DLS [2]), too. In order to comply with the actual existent space of standard available Dm machines, the designers of positioning devices must adapt. Till now, the serial stacked solution has been largely used. Each of the motion axes – X, Y and/or Z (translation and/or rotations) has been materialized through standard independent stages to pose the sample (and, instrument) in the right position. However, in the case of more than 3 dof, the available space cannot be enough for packing all axes, or doing the necessary tasks-especially, variable distance rotations around Dm - Center of Rotation(CoR) point, which in this case is fixed. Precision Hexapods has been foreseen as next solution [3]. By being more compact, they are precise and able to freely choose the pivot point (P). However, when the combination of the specifications is including heavy load, and appreciable rotation distance (dP), the design of the products could be a challenge [4], especially the height (250mm). In order to fulfil the gap, a new product has been developed. The specificity of its kinematics, design and performance are now presented.

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KINEMATICS

Topology

The new Table Positioning Device (TPD) is based on a more general parallel kinematic (PK) [5] topology having four (4) legs. This QUADROPOD (QP) family has a good natural static stability, being perfect adapted to the common shape of a working table. With all the actuators at the base, the 6-4(**2**)13 structure is a redundant one (Rd=2) which can be an advantage (power). By choosing DD (or, in-parallel) actuated joints, the dynamic capabilities will increase [6], too.

Mechanism

However, the Figure 1 shows a TPD kinematic structure with 2dof active joints ($\mathbf{P}_i\mathbf{P}_{i+4}$, i=1…4) stacked on two levels (i,i+4). In the Prove of Functionality (PoF) step, the standard (electromechanically) motorized stages were an easy way of implementation and the motor / screw mechanical principle (stability) another one. 6-4(**PP**)PS mechanism (6-dof, PPPS-kinematic chains, P-prismatic/linear and S-spherical joints) can be seen as composed from two pair of orthogonal arranged kinematic chains (K_i,K_{i+2}, i=1,2), each having a pair of active joints with motion axis perpendicular on each other ($\mathbf{P}_i \perp \mathbf{P}_{i+4}$) and parallel on the opposed ones($\mathbf{P}_i \parallel \mathbf{P}_{i+2}$).

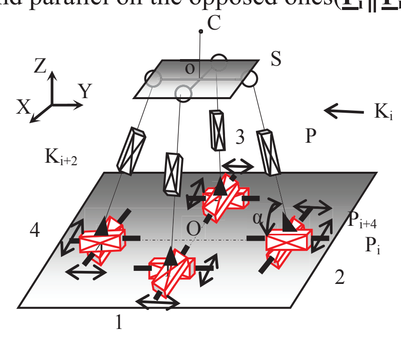

Figure 1: Mechanism kinematics.

By this symmetric arrangement of the eight (8) planar sliding/gliding actuators (OCTOGLIDE), together with the specificity of the passive joints on the next level (P, *α*

Table 1: Basic Motions

Motion	Actuation	Ki
X	P_i(i=2,4)P_{i+4}(i=1,3)	2
Y	P_i(i=1,3)P_{i+4}(i=2,4)	2
Z	P_{i+4}(i=1,...,4)*	2

* ±X & ±Y sign should apply.

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fixed angle) the mechanism is able to provide a way of moving the table in one direction with only two (2) couples of opposed pairs, Table 1. Moreover, for horizontal motions - X (or, Y), a displacement in the positive/negative direction implies displacements (4) with exactly the same values, i.e. X=Xi(i=2,4)=Yi(i=1,3).

Following these (decoupled) motions, the control at: a) workshop and b) programming sites is becoming more intuitive (a desire of technicians) and simplified. Note: For the entire mechanism, two joints – P and S types have been used, only.

DESIGN

Concept

Based on the above mechanism, in a modular design concept (specific to PKMs), between a base (B) and table (T) four Positioning modules Pm have been arranged around the centre of the base (O); each of them consisting from a well-defined combination of active and/or passive Positioning units (Pu), Fig. 2.

Active (Ac) Pu have been chosen as compact translational XY stages with high accuracy (and, stiffness) based on screw principle. The first passive Pu is built as Elevation unit (El) based on inclined plane principle. A pair of wedges - W1 and W2 is materializing a precise and compact stiff up / down motion.

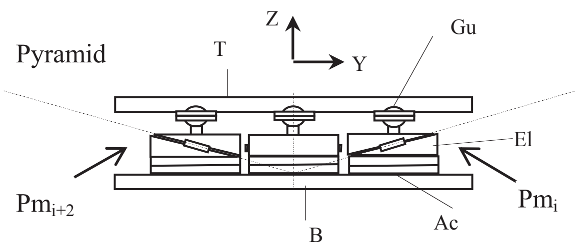

Figure 2: Design concept.

A compact ball & socket design has been chosen for the Guiding unit (Gu) passive positioning based on sliding principle. It consists from a vertical pillar with a high precision ball - B at one end and an adjusted socket - S house (two parts). Through a combined Pm (Pm_i, Pm_{i+2}, i=1,2) motions (and, constrains), precision and stiff : a) translations – X,Y,Z and/or b) rotations - Rx, Ry or Rz can be obtained based on the resulting pyramid principle.

CAD

The above design concept – principle and components has been implemented in specialized software (ProE) to produce functional (solid models) and, manufacturing (drawings) graphical products. The main features of: a) standard (XY) and b) customized (W, SJ) precision used components [7] are included in Table 2.

Table 2: Device Positioning Module

Pu	Principle	Type
Ac	XY	5102.15
El	W1/W2	Z(α=30°)
Gu	B&S	SSJ(ϕ20mm)

A picture of the 3D solid model representing the product (nominal position) with the overall dimensions can be seen in Fig. 3. Note: The height value h=225(<250mm).

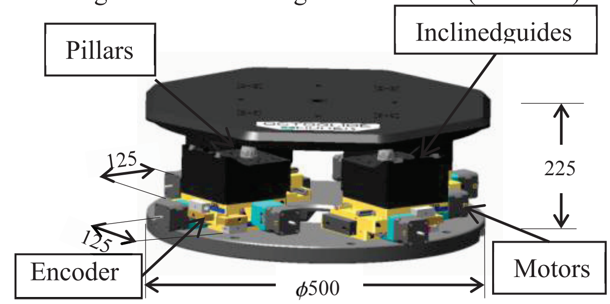

Figure 3: Device layout.

Workspace

In order to characterize a PKM product, its specific features (e.g. workspace) should be determined or, at least evaluated before the production even started. Generally, the multi degrees of freedom Workspace (WS) of a PK device is a complex 6D shape resulting from the total number of pose (translation & rotations) reached by a chosen (center of platform) point taken in to account max/min permitted actuators displacements. The determination is an issue. A more easy way is to determine a 3D shape with constant orientation (Rx=Ry=Rz=0). By using the geometrical features of each guided point intersected in the table's center (geometric method), the OG final rectangular WS shape – double pyramids is coming as an intersection of four partial prisms (Ws_i, i=1,…,4). The overall dimensions are included in Fig. 4. As expected, the shape & size are affected by the actuation and elevation (wedges) maximum strokes. However, there are no singularities inside. A smaller rectangular (cubic) WS_c can be defined as inscribed (l=9.6mm). Note: With an optimum design, it can be enlarged.

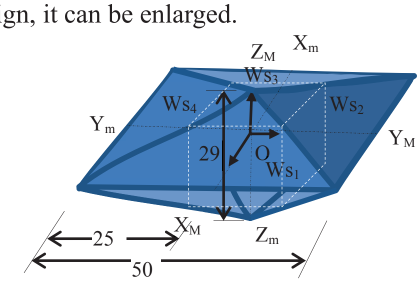

Figure 4: Maximal & inscribed (dashed) workspace.

PROTOTYPE

Manufacturing

An experimental prototype has been built based on the drawings of the above design process. It is mainly consisting from two parts: a) Mechanical device (Md) and b) Controller(C) units. Latter, a PC with the software (graphical interface) has been included. The entire manufacturing process has been based on - standard and specific set of operations like machining, assembly and control based

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on the well-established rules and the specific expertise acquired by the company in precision manufacturing.

Control

In order to produce a motion (positioning) with the desired accuracy, the mechanical (motors), electronic (hardware) and software components must be chosen accordingly and work perfectly together. The main component in the loop (controller) must manage input/output informational flux safely and in time, by being very robust. For OG a digital controller (SMC9300PP) has been built using BISS interface. The dedicated motion software which is using the Invers Positional Problem (IPP) is not taken (yet!) in to account the linear encoders (RESOLUTE) standard components of each of the actuators. It is controlling the device in an open loop, only. A simple graphical interface has been implemented including the menu for the: a) desired point linear & angular (X,Y,Z, Roll, Pitch, Yaw) coordinates, b) Pivot/probe point (X,Y,Z) coordinates and c) maximum translation & rotation (Tmax,Rmax) range visual parameters.

Tests

In order to fully characterize a positioning product, some specific features must be experimentally verified before the small/mass production release. After the OCTOGLIDE prototype has been completed (and the motion control functions integrated) the first investigations started with a set of measurements consisted in to determine: a) range, b) accuracy and c) stability of functional motions. The setup shown in Fig. 5 is mainly based on using a laser interferometer (RENISHAW) - source, retroreflectors, etc., stable table (granite) with an additional frame (Z axis) and PC to record the data.

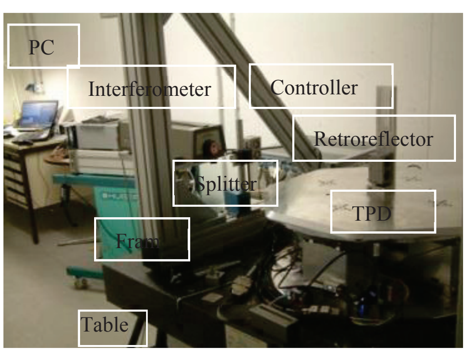

Figure 5: Measurements Set-up.

The basic motions range have been proved to be carried out as expected (designed). The max/min values are the direct result of the actuation values (XY=±25mm), Table 3.

Table 3: Motion Range

Parameter	Unit	Min/Max
X, Y, Z	mm	50, 50, 29
Rx,Ry,Rz	°	11, 11, 18

The measurements to determine the errors (accuracy & geometrical) in both, horizontal /vertical (X/Z) axis with out load has been performed; and, in addition, for rotational motions – roll, pitch and yaw have been performed. The first obtained results proved a good positioning behaviour of the device: a) accuracy (±3,1/4µm) / repeatability (1,5/1,6µm), b) geometric / straightness (flatness) and c) stiffness (0,55Nm/", m=50 kg, r=145 mm) features, Fig. 6 and Table 4.

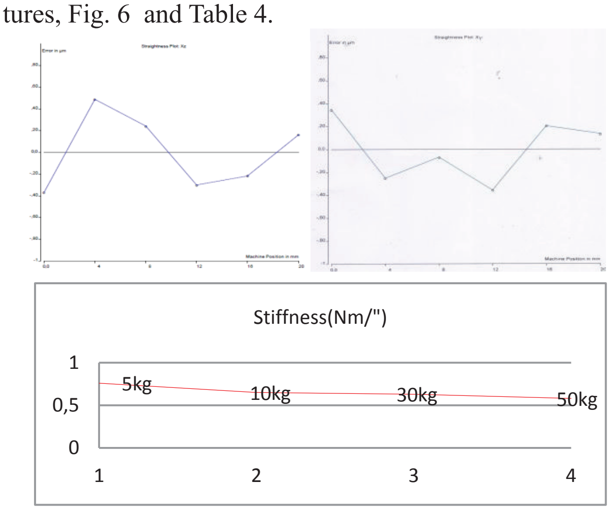

Figure 6: Straight-, flat- and stiffness errors (X).

Table 4: Positional Accuracy

Parameter	Unit	X(Z)
Straightness	µm	0,856 (2,61)
Flatness	µm	0,704 (1,9)
Stiffness	Nm/“	0,55

CONCLUSION

A high precision and heavy load, compact Table Positioning Device (TPD) called OCTOGLIDE, to be used with standard diffractometers in synchrotron X-ray advanced applications has been presented. Built on the Design for Precision (DfP) concept and with specific requirements of using heavy load/size instruments it shows a good behaviour to be considered as a solution for further precise positioning tasks. With minimal design modifications it can be used in other diffraction machines having small working spaces, as well.

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