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VIRTUAL MODEL AND SIMULATION FOR A NEW TYPE OF MACHINE TOOLS

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Abstract: This paper presents two important issues in relation to new machine tools with parallel reconfigurable topology, namely, modular design and computation of kinematics if the manufacturing and assembly errors are take into consideration. Thus, the kinematics for a version of this new type of machine tools was solved. Also, a simulation model, using MOBILE software package was developed.

Key words: Machine tools, parallel kinematics, modularity.

1. INTRODUCTION

A good dynamic behavior (high stiffness), a high accuracy and a good ratio between total mass and manipulated mass are just few advantages of parallel robots compared with serial type [1]. However, the design, the trajectory planning and application development of the parallel robots are difficult and tedious because the closed-loop mechanism leads to complex kinematics. To overcome this drawback, modular design concept is introduced in the development of parallel robots [6], [7]. Also, during the last period a new type of applications were developed. These new applications are related to the machine tools with parallel topology. Utilization of parallel topology in the machine tools field creates the possibility for a reconfigurable design, which is still an open problem and lacks theoretical base. One of the problems for reconfigurable robots is to determine the topology and geometry of the robot, which is the suitable to fulfill a set of criteria. In the following sections, we first present a modular topologic synthesis, which leads to a new type of machine tools with parallel topology (named HyMaTo – Hybrid Machine Tools). Then, a method, which gives the possibility to consider the manufacturing and assembly error into the mathematic model of HyMaTo, is presented. Finally, a simulation model and numerical results is presented.

2. MODULAR TOPOLOGIC SYNTHESIS

The topologic synthesis of parallel mechanisms could be made if the relation of the number of degrees of freedom is considered [2], [3]:

$$M = (6-m)\cdot n - \sum_{k=1}^{5}(k-m)\cdot C_k - M_P \tag{1}$$

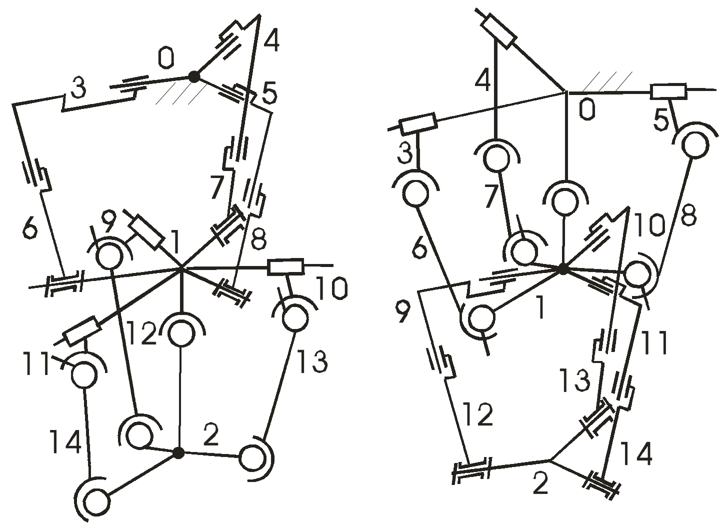
where m is the number of common restrictions for all elements, n is the number of the mobile elements, k is the number of restrictions which define a joint (for example in the case of prismatic joint k = 5), Ck is the number of joints with (6-k) degrees of freedom and MP is the number of identical degrees of freedom. Let N be the number of mobile platforms and Dk – the number of joints with (6-k) degrees of freedom which directly connect the platforms of the mechanism.

With these notations, it results that the integer solutions of the equations:

$$M - 6\cdot N + \sum_{k=1}^{5} k\cdot(C_k + D_k) = 0 \tag{2}$$

gives all variants of parallel mechanisms with assumed hypothesis

According to other criteria such as additional geometric criteria or the number of the joints, which are directly connected to the base frame, the relation (5) can describe few topologic variants. Thus, figure 1 presents two of these possibilities. It is possible to observe that each of these variants has decupled movements for position and orientation respectively. Thus, first variant has allocated for pure position first three degrees of freedom and the last three for pure orientation. This can be an important advantage related to the machine tools field of applications. Let HyMaTo1 be the name of the first variant (Fig.1a).



a) b)

Figure 1. Variants of the HyMaTo with 6 dof

3. MANUFACTURING GEOMETRICAL ERRORS

In the beginning, we assume: a) the universal joints are made as the cardanic variant, b) a spherical joint is obtained from a serial connection of a rotational joint and a universal joint. Let there be a universal joint without geometrical errors (Fig. 2a). We assume that it is possible to measure the coordinates of the points Ai , Bi . The geometrical errors, which will be considered, are measured from the deviation of the points Ai relative to the O0 x0 axes and the deviation of the points Bi relative to the O0 y0 axis (Fig. 2a).

Let there be a universal joint (Fig. 2b) which, is affected by geometrical errors (manufacturing and assembly). These errors lead to the modification of the position and orientation of the axes (D1) and (D2). We denote with e10, e20, e30 the unit vectors of the frame coordinate system. Also, let e1 = [e1x, e1y, e1z]T be the unit vector of the D1 axis and be e2 = [e2x, e2y, e2z]T the unit vector of the D2 axis respectively. These vectors are defined only for the initial positions, they are constant related to the time and describe the manufacturing and assembly errors.

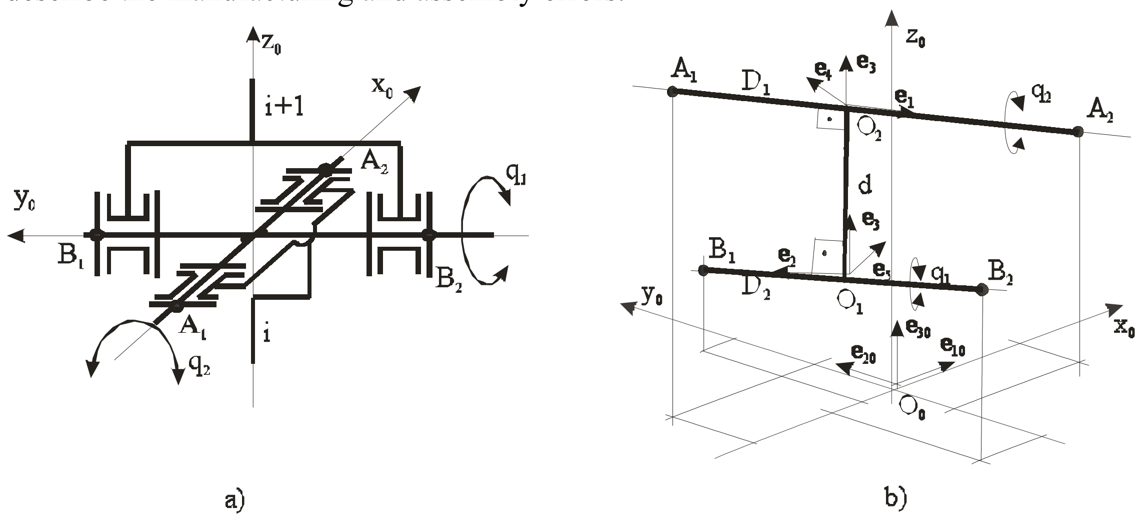


Figure 2. Universal joint without geometrical errors (a) and with errors (b)

Let e3 = [e3x, e3y, e3z] be a vector which is given by the relation:

$$\mathbf{e}_3 = \mathbf{e}_1 \times \mathbf{e}_2\,; \tag{3}$$

Using all three vectors e1, e2 and e3 it is possible to define the following coordinate systems: system TE1 with e5, e2, e3 as axes and system TE2, with e1, e4, e3 as axes:

$$\begin{aligned} \mathbf{e}_5 &= \mathbf{e}_2 \times \mathbf{e}_3\,, \\ \mathbf{e}_4 &= \mathbf{e}_3 \times \mathbf{e}_1\,. \end{aligned} \tag{4}$$

The positioning error of the first axis D2 (the relative position between T0 and TE1) can be characterized by the matrix:

$$E_1 = \begin{bmatrix} e_{10}\cdot e_5 & e_{10}\cdot e_2 & e_{10}\cdot e_3 & x_{O_1} \\ e_{20}\cdot e_5 & e_{20}\cdot e_2 & e_{20}\cdot e_3 & y_{O_1} \\ e_{30}\cdot e_5 & e_{30}\cdot e_2 & e_{30}\cdot e_3 & z_{O_1} \\ 0 & 0 & 0 & 1 \end{bmatrix}. \quad (5)$$

Similarly the matrix, which describes the error of the second axis D1, as the transformation between TE1 and TE2, which in general are not identical, is given by the relation:

$$E_2 = \begin{bmatrix} e_5\cdot e_1 & e_5\cdot e_4 & 0 & 0 \\ e_2\cdot e_1 & e_2\cdot e_4 & 0 & 0 \\ 0 & 0 & 1 & d \\ 0 & 0 & 0 & 1 \end{bmatrix}. \quad (6)$$

where d is the common normal between D1 and D2.

It results that movement at the level of the universal joint, if the errors are taken in consideration, may be characterized by:

$$H = E_1\cdot A_1\cdot E_2\cdot A_2 , \quad (7)$$

where A_i are the relative transformation matrix.
The errors for a spherical and prismatic joint may be modeled similarly.

4. ERROR COMPENSATION

General algorithms used to solve direct kinematics in the case of parallel mechanisms consider that for each independent loop of the mechanism one vector equation can be write. Simulating the overall kinematics according to a given path of the TCP (Tools Center Point), the generated program is able to once calculate the undisturbed inverse kinematics and on the other hand the error related variables of the driving joints. Let y and q be the coordinates of TCP and actuated joints, respectively. Then :

$$\mathbf{q} = \mathbf{q(y)} \quad (8)$$

is generally easy to determine for parallel kinematics machines.

With:

$$\dot{\mathbf{q}} = \prod(\mathbf{y})\dot{\mathbf{y}} \quad (9)$$

where $\prod$ as the Jacobian matrix is generated automatically.

Small deflections allow the inverse transmission of velocities and errors between workspace and parameter space the same.

Given a disturbed kinematics we distinguish between solutions $\overset{*}{\mathbf{y}}\mathbf{(q)}$ (error related forward kinematics) and y(q) (ideal forward kinematics).

Therefore, $\overset{\propto}{\mathbf{q}}$ needs to be a set of parameters that fulfills:

$$\overset{*}{y}(\overset{\propto}{q}) = y(q) \tag{10}$$

With this relation (20) the errors of the machine would be compensated due to control of corrected joint parameters. Starting with condition (20), it results:

$$\overset{*}{y}(\overset{\propto}{q}) = \overset{*}{y}(q) - \Delta(y) \tag{11}$$

where $\prod = \mathbf{J}^{-1}$, $\Delta \mathbf{y} = \mathbf{J}(\mathbf{q})\, \Delta \mathbf{q}$.

Therefore considering small errors there is:

$$\overset{*}{y}(\overset{\propto}{q}) = y_0 = \overset{*}{y}(q) - J(q)\Delta(q) \tag{12}$$

On the other hand,

$$\Delta q = J^{-1}(y)\Delta y = J^{-1}(y)\left[\overset{*}{y}(q) - y(q)\right] \tag{13}$$

is easily calculated, as in the case of parallel mechanisms $\mathbf{J}^{-1}(\mathbf{y})$ is more or less given by the inverse kinematics. According to the assumption of small deflections $\Delta \mathbf{q}$ and $\Delta \mathbf{y}$ can be neglected for the calculation of $\prod$.

5. SIMULATION RESULTS

This section presents results of simulated errors for HyMaTo1 parallel machine tool. For this mechanism, a mathematical model of errors was implemented and the simulation of the kinematics was also obtained from a simulation program using the in MOBILE software package [5].

Figure 5 shows initial position of HyMaTo1 obtained by a simulation model developed with MOBILE. Also, figure 6 presents an intermediate position during an assumed movement.

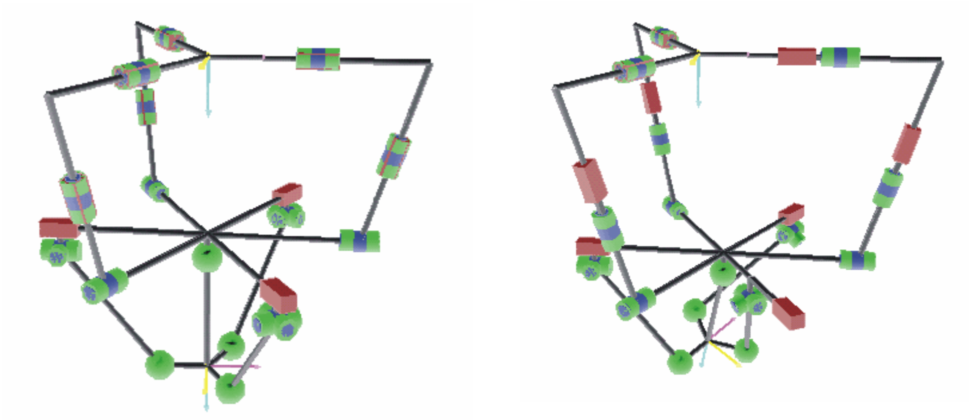
6. CONCLUSIONS

The conclusion can be drawn as follows:

a) based on assumed modules and on relation of the number of degrees of freedom for a mechanism, a topologic synthesis can be done; a new type of machine tools with parallel topology and decupled movement, for position of TCP and its orientation respectively was praised.

b) the kinematics of the whole mechanism can be developed on a modular manner, each module based on the kinematics of one leg;

c) an analytical model of the geometric and assemble errors can be developed and also an algorithm useful for error compensation was presented.



a) b)

Figure 5. a) Initial position of HyMaTo1. b) Intermediate position of HyMaTo1

7. ACKNOWLEDGMENT

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