DESIGN OF INCORPORATED MACRO-MICRO ROBOTS FOR MACRO AND MICRO OPERATIONS

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Abstract: Robots with cooperated regional macro-structures and local micro-structures are implemented in cell injection systems, production and control of micro-chips as well as other micro and nano technological operations. A structure for hybrid macro-micro robot with closed kinematic chains with piezo-actuator links is proposed. An approach for the synthesis of linkage manipulating mechanisms with two DoF is developed applying the method of Infinitesimally Close Positions. This approach allows for the synthesis of mechanisms that perform rectilinear trajectory within a specified section. The rectilinear trajectory may be obtained by controlling the actuators, but in the presence of accelerations which would decrease the precision of the trajectory.

1 INTRODUCTION

Nowadays, it is hard to enumerate the companies and types of produced robots. The kinematic chains (KC) of most universal robots are opened. There are robots with closed KC or with hybrid open–closed KC. Generally, robots with closed or hybrid KC are used in microbiology, clinical laboratories and surgery (Kobayashi, 1999). On the other hand, design and development of actuators resulted in the design of a new generation of manipulators and robots for extremely precise micro-manipulations. Robots with cooperated regional macro-structures and local micro-structures are implemented in cell injecting, production and control of micro-chips as well as other micro and nano technological operations.

The main advantages of the mechanical system with close kinematic chains are: light constructions of the mobile links because the motors are taken out of the frame; minimization of dynamic and inertia effects; dynamic control is not necessary; improved positioning precision, which is typical for the geometry of closed KC; and comparatively smaller deformation deviations. The main disadvantages are: the number of kinematic joints (bearing assemblies) increases; spatial mechanisms with closed kinematic chains require the use of specialized kinematic joints of a lower class as compared to the traditional rotation and translation bearings; in most cases the inverse kinematic problem is more difficult to solve.

There are known micro–nano robots, wherein the conventional driving systems or motors are changed with piezo-actuator modules or elastic-polymer actuators (Bacher, 2003; Codourey, 2005; Goldfarb, 2002). The various types of actuators allow for displacement varying from several nanometers to several *mm*. The ceramic actuators have wide application.

This study proposes a five-link mechanism with closed kinematic chain where actuators or piezo-ceramic links are incorporated in the links. The mechanism is linked by a translation module or kinematic joint along an axis parallel to Oz (Fig.1). The suggested five-link mechanism is designed for robots performing extremely precise linear and other micro displacements. Linear micro displacement is mainly required in cell injection systems, micro chip inspection and other micro and nano technological operations. The most crucial requirement for these robots is high precision.

Also, an approach for the synthesis of five-link macro-micro mechanisms with two degrees of freedom with infinitesimally close positions (ICP) has been developed. With slight changes the said approach can be implemented for the synthesis of mechanisms with open kinematic chains.

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2 SYNTHESIS OF MECHANISMS FOR MACRO - MICRO MECHATRONICS SYSTEMS APPLYING THE METHODS OF KINEMATIC GEOMETRY

A mechatronic system (MS) for micro and nano technological operations based on a five-link mechanism structure with closed kinematic chain is synthesized (Fig.1).

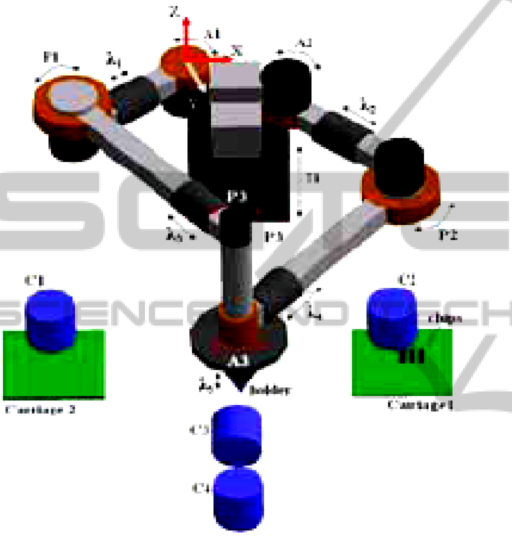

Figure 1: A model of hybrid macro-micro manipulation system for microchip control.

The links 2 and 5 are set to motion by universal motors, mounted on the fixed link 1 and perform macro motion. Actuators or micro-motors are incorporated in the linkage of this KC, whereby their lengths can be changed within a specified range. A serious problem in this solution is to maintain high precision in micro operation. We suggest a resolution by redundancy of MS for micro motions. We study the working zone of the five-link macro-micro MS at different positions and with switched on actuators. Different trajectories of the end-effector are obtained depending on the operating actuators and motors. The transmition ratio (TRs) of the MS actuators is determined analytically, as well as strategies of control of hybrid MS are developed. Also, the direct and inverse problems of kinematics for such macro–micro MS are solved (Tiankov, 2009, Genova, 2010, Kotev, 2010).

2.1 Methods of Finding the Kinematic Invariants

Micro operations are performed with small range motions. In this respect the synthesis of manipulation mechanisms (MM) by means of the methods of infinitesimally close positions (ICP) is particularly appropriate. With the mechanisms with two DoF two principally different problems can be formulated of the synthesis with ICP: a direct problem and an inverse problem, the direct problem being for a given mechanism configuration and a given transfer ratio of the velocities at the two inputs in order to find the point of Boll. Those Boll points are used which are known to have rectilinear trajectories for a limited motion interval, and which do not require any special control to be implemented.

Formulation of the Problem

The purpose is to elaborate an approach for the synthesis of MM with two DoF with open or closed kinematic chains for precise rectilinear finishing operations. To solve the direct problem of synthesis, all kinematic invariants (KI) should be found, which are necessary for the synthesis of the output link (OL), as well as a characteristic point, which in a certain position will coincide with the point of Boll. The necessary KI are: the instantaneous centers of rotation (ICR), axes of co-linearization (AC), polar tangent and normal, inflection circle (IC), constants of the circle-point curve (CPC) and centring point curve (CenPC), polar coordinates of Boll points. As a final result the rectilinear section of OL trajectory must be defined. For the inverse problem KI are also necessary, but the sequence of solution is different.

By using said synthesized MS, not only the position accuracy is improved, but also the complexity of algorithms for control is greatly reduced, since the trajectory is achieved only by the motion of the mechanical system.

2.2 Methods of Finding the Kinematic Invariants

The five-link closed kinematic chain with two DoF appears to be a more general case compared to the open one with two DoF, since it may be viewed as composed of two open KCs (OAB and DCB – Fig.2). The base point is a kinematic joint B.

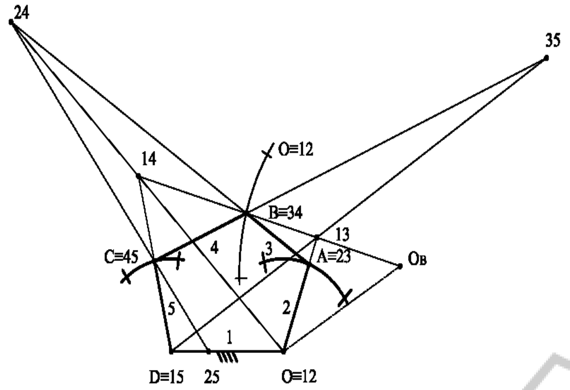

Figure 2: Five-link closed kinematic chain – ICR.

2.2.1 The Instantaneous Centers of Rotation – ICR

ICR of all links of a given KC are found using the Aranhold-Kennedy theorem. For KC with two DoF the theorem may be applied only if at least one of the five ICR which have to be found is defined. Thus, for example, with the direct problem of kinematics (DPK) the transmission ration is specified, i.e. ICR-25, and with the inverse problem of kinematics (IPK) the trajectory of point B is determined (Fig.2). On the normal to the trajectory of the end-effector lie two of the searched centres of rotation (ICR-13 and ICR-14). As these points also lie on the straight lines OA (12-23) and CD (45-15), they are the points of intersection of said lines with the normal. Fig.2 shows all ten ICR for the five-link KC. Kinematic invariants of the rocker links 3 and 4, respectively, are found by means of the general theorems of kinematic geometry or modifications thereof.

2.2.2 Axis of Co-linearization

The line AC is the straight line which connects the points of intersection of the normals to the trajectories of two points of a body moving in a plane and it is also the line which connects the two points and their centers of curvature (CC). On Fig.2 it is seen that two points, namely A and B are given on link 3 moving in a plane and only one point of CC, i.e. centre O of point A. The centre OB of point B must be found. It is known that the radius of curvature, and coordinates of CC, respectively, depend on the second derivatives of the coordinates of point B. According to the definition, co-linearization is the straight line passing through ICR H≡13 and P (Fig.3), which is marked with „к-к" and an axis line is drawn.

2.2.3 Polar Tangent and Normal

In accordance with the theorem of Bobilier, the angle γ measured from AC to one of the normals crossing in H is equal to the angle μ measured in the opposite direction from the tangent to the other normal. Hence, the polar tangent t is found and the normal n, respectively.

2.2.4 Inflection Circle

The Euler-Savary equation can be applied. The point T is on IC. In this case RC of the trajectory of point A is AO = 12. The point of Boll is the point of intersection of IC and CPC. To find this point it is necessary to find the constants of the polar equations of CPC and CenPC. According to the theory of KG, the problem is reduced to finding the Boll point of IV or V series. When the Boll point is of the IV series, it is a point of intersection of the circle of inflexions and the circle point curve (Chung 1989, Genova 1995, 2009, 2010).

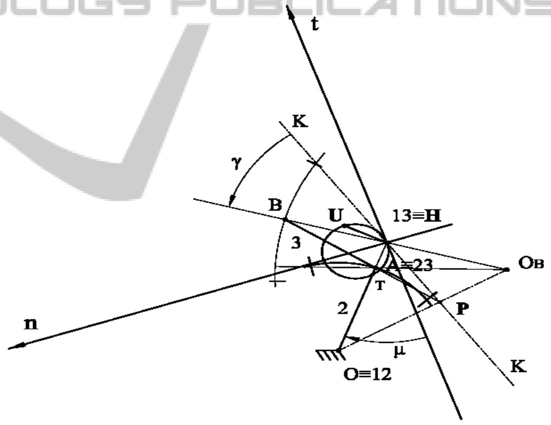

Figure 3: Kinematic invariants and point of Boll.

2.3 The Inverse Problem of the Synthesis is Formulated Applying the KG Methods of ICP

The inverse problem of KG, as we formulated it, consists of either defining the characteristic point, for example that of Boll, or some of the main dimensions to synthesize the configuration, or both, depending on which will satisfy the given problem.

The synthesis is solved with a given point of Boll. In the selected coordinate system, the directrix of the tangent of the trajectory of Boll point is also given (actually, in the synthesis of ICP, this directrix coincides with the trajectory itself up to the third series), and the conditional position of the initial link is given. These input data are enough to determine the kinematic invariants, including the CPC and CenPC for the relatively movable link, for which we already know the kinematic joint connecting it to the input link as well as the Boll point. If we synthesize a five-link mechanism, then the choice of the closed kinematic pair can be subjected to the convenient ratio of the two input velocities for the realization of the transfer function of the third series. Theoretically, the solutions are numerous, i.e. numerous four-link CKC can be synthesized (Genova 2010). Also, some special cases are studied where the first transfer function is a constant, i.e. its derivatives are zero, as well as solutions are examined for a rectilinear section of maximum length around the Boll point.

Further problems of the synthesis of hybrid macro-micro mechatronic systems (MS):

- Synthesis of MS with three DoF and given orientation of the trajectory of output link.
- Synthesis of MS with given points of Burmester.
- Synthesis of MS combined with micro motions by means of the methods of kinematic geometry of infinitesimally close positions.

3 CONCLUSIONS

A design approach for the synthesis of five-link mechanisms with two DoF with infinitesimally close positions has been developed. With slight changes this approach can also be implemented for the synthesis of mechanisms with open kinematic chains. The obtained results clearly demonstrate that with the methods of kinematic geometry rectilinear micro motions can be achieved with very high precision and they can be successfully combined with the motion of macro mechatronic systems (MS). Such macro-micro MS are useful in the performance of operations such as precise delivery of probes in microelectronics and optics, pipetting, cell injection and other microbiological operations. Of course, the rectilinear trajectory may be obtained by controlling the actuators, but inertial forces may appear which will decrease the precision of the trajectory.

With the two DoF mechanisms two principally different problems can be formulated of the synthesis with ICP: a direct problem and an inverse problem. The direct problem is solved for a given mechanism configuration and a given transfer ratio of the velocities at the two inputs in order to find the point of Boll. Furthermore, the results of these examples show that optimal solutions can be sought depending on the technological operation.

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