Mechatronic Approaches for Functional Structural Synthesis of Mechanical Systems of Industrial Robots
Part III Approaches to Structural Synthesis of Path-generator Mechanisms

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Abstract: *In this part of the study were introduced two mechatronic approaches for functional structural synthesis of mechanical systems of industrial robots, where the main manipulation mechanism is a path generator. A limited number of structures that meet the set objectives and technical requirements to design mechanisms are directly determined. Emphasis is placed on the tasks of passive (mechanical) control of manipulation systems associated with the specialized robotics.*

Keywords: *Goal motions, structural synthesis, path-generator mechanisms*

1. Introduction

In Part I of this study is laid out the necessity for new approaches to structural synthesis of mechanical systems to directly identify a limited number of structures that carry a potential for solving technical problems related to the design of specialized robots.

Part II of the study identifies five types of kinematic chains (primary, parallel, secondary, additional and subsidiary) with different functionalities [11], which allows to determine the structures of manipulators according to defined goal tasks and specific functional requirements for manipulation mechanisms, consistent with the control of industrial robots [3].

In Part III of this research topic will be introduced mechatronic approaches to functional structural synthesis of mechanical systems for industrial robots [1], where the main manipulation mechanism is a path generator [8]. Emphasis is placed on the tasks of passive (mechanical) control of manipulation systems associated with the specialized robotics [5], [3]. These problems are solved by synthesis of their structure and dimensions for minimum number of degrees of freedom required for the realization of the goal task [2], considering the so called *first principle of mechatronics* for pre physically and functionally decoupled motion in space and time [15].

The basis of the design of robotic manipulators standing functional approach to structural and dimensional synthesis of mechanisms [4], according to which their structure is built by superimposing kinematic chains with different functionality, which results in control mechanisms [9], which stands are detachable a basic kinematic chain called *primary.* These control mechanisms solve the problem of generating the geometry of motion, separating it from the task of active (electronic) control of motion in time.

Main mechanism of the mechanical system of specialized industrial robots is the actuator that performs translations and orientations [6, 7]. Typically there are 3 or 4 degrees of freedom. The structure of the mechanism is usually closed-open to at least one closed-loop of control transfer mechanism (function generator) [10, 12, 14]. The introduction of mechanisms with "kinematic intelligence" simplifies the structure and setup of the control system, but requires structural and dimensional synthesis of the mechanism according to set conditions [4].

2. Goal motions and structures of path-generator mechanisms

The goal motion at manipulation path-generator mechanisms in general can be represented by two components - the trajectory of the characteristic point *H* of the end effector (gripper or a working tool) and its speed . This decoupled representation of motion is appropriate for specialized robots, as they usually generate unchanging (invar) trajectory of the characteristic point *H* with variable (var) speed .

The kinematic components of goal motion of the end effector, respectively the main tasks for structural synthesis of manipulation systems of industrial robots and for synthesis of their active and (or) passive kinematic control can be formally divided into three groups:

groups (A) (B) (C)

(invar) (invar) (invar)

The tasks of group A are most common for the path-generator mechanisms. The minimum number of moving parts, number of degrees of freedom and independent input parameters required to open their *primary kinematic chain* (prim) are 2 (Table 1, A). Then the functions of velocities are conditional , as in other specialized robots such as extractors of casts of horizontal machines for high-pressure casting. It is possible the circuit to remain open (Table 1, A) or fully closed (Table 1, B and C). All the three groups are common for specialized robots.

To clarify the interconnections between the components of the goal motion, the topological structures, the required input parameters and consequently the distribution of the tasks of the active and passive control will be used two approaches for closing *the primary kinematic chain,* through which are constructed the topological structures presented in the next two tables 1 and 2.

Column 1 shows the components of the goal motion. In column 2 - the corresponding topological structures. The required input parameters are recorded as well (column 3) which should be achieved by actively kinematically control at groups A and B. The dependencies in relative motion (column 4) are necessary for synthesis of transfer mechanism for passive kinematical control.

First approach to build structures of path-generator mechanisms (table 1)

Group A. The trajectory and the velocity belong to defined classes of functions defined by the sets and : ; . The tasks of this group can be solved by mechanisms with tri-bar open kinematic chain operated by kinematic system for active control of two generalized coordinates or velocities:

(1) ,

(2) .

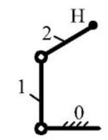
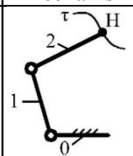
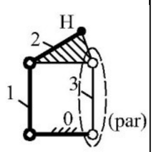
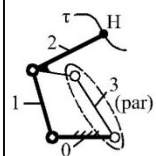
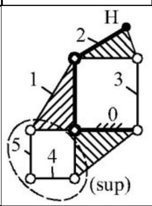
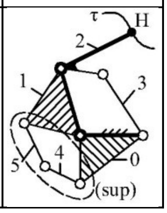
Only one of the two adjustable-speed motors can be installed directly to the frame. The open structure of the mechanism allows for decoupled motion of the two moveable links. This is achieved in the die casting supply robots such as FEEDMAT 3 of the Bulgarian-German company SPESIMA, where the third link of the *prim*-chain is the so-called “ladle”. The adjustable-speed motors mounted to the frame, move separately the links by gear-chain drives with constant transfer ratios.

Group B. Unlike *group A*, in the task of this group is not predicted a change in the goal trajectory (). They can be solved by mechanical and control systems, typical for the tasks of *group A*. A specific solution for the tasks of *group B* is part of the motion control of point *H* of the path to be achieved by the mechanism itself.

A *parallel kinematic chain* (par) with sequential topology is added to the *primary kinematic chain.* A parallel circuit connects base 0 to link 2 of the primary chain by the means of a new link 3. It is formed a control transfer mechanism (function generator) with a relative base link 1. The resulting path-generator mechanism is a four-bar topological structure with 1 degree of freedom and respectively an adjustable-speed motor mounted to the frame. The mechanism could in principle generate trajectory .

This most simple structure of the class of the so-called Q-manipulators [9], is common for of most specialized robots such as the extractors GRIPMAT of the Bulgarian-German company SPESIMA, which serve to remove the casts of horizontal machines, die casting, and for other purposes.

Table 1

N	Components of the goal motion	Topologic structures	Necessary input paramenters	Dependencies in the related movements	Sample path-generator mechanisms
A				N/A	
B				- - - - - - - - -	
C				- - - - - - - - - - - - - - - - - -	

The synthesis of the path-generator mechanism includes sizing of the primary kinematic chain, deriving the displacement function and the kinematic control transfer functions and as a solution to the inverse kinematic problem, synthesis of the control transfer mechanism in these identified transfer functions [4]. The set output speed is achieved through active control of the input speed

(3) .

Group C. In contrast to *group B*, in this task is not predicted a change in the function of the velocity. The tasks of this group can be solved by means of mechanical and control systems, typical of *groups A and B*. A specific for *group C* solution can be achieved entirely by means of the mechanical system. The motion of the point *H* on the curve is performed by the path-generator mechanism, as indicated for the tasks in *group B*. The required function of the generalized velocity

(4)

can be generated by means of a *subsidiary kinematic chain* (sub), which with two intermediate links 4 and 5 kinematically connects the base 0 with link 1 (table 1, C). There are produced two ternary links 0 and 1 and a four-bar closed topological structure of a subsidiary transfer mechanism with input speed

(5) .

The mechanism is synthesized in the function and its derivatives transfer functions, defined by solving the inverse kinematic task with a set law of motion of the outlet and the linear coordinate at the input of the mechanism [4]. The overall structure of the mechanism is six-bar of the type Watt II, typical for different types of specialized robots in the recent past, when the control function entirely belonged to the mechanical system. An example of this is the casts extractor of company NORDA (Italy). A subsidiary slot-and-crank mechanism with adjustable length of the node adequately actuates the four-bar main path-generator mechanism, forming with the latter structure of the type Watt II.

Second approach to build structures of path-generator mechanisms (table 2)

Group A. *Primary kinematic chain* is initially closed by a *secondary* (sec) *kinematic chain* which connects to link 2 in point *H*

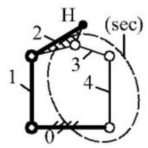
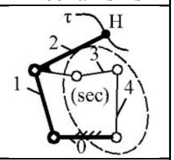
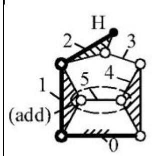
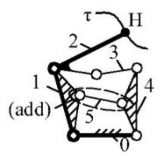
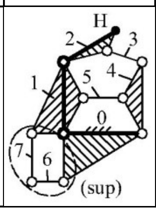
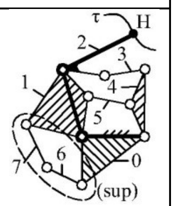
becomes parallel (par), since it is structurally identical to the primary chain, if it contains only a lower kinematic pair. In this case the structure is formed of a manipulation path-generator mechanism with parallel topology with two degrees of freedom.
The tasks of this group are solved by mechanisms with five-bar closed kinematic chain, equipped with a system for active kinematic control of two generalized coordinates or velocities:
(6) ,
(7) .

Group B. One *additional kinematic chain* (add) is superimposed on the resultant structure (*group A*). The chain includes links 1 and 4, associated with a new (intermediate) link 5. Links 1 and 4 are ternary. A four-bar loop for control transfer mechanism with base 0 is formed, that generates geometric dependencies between the relative movements of the links 1 and 4 for passive control of the geometric components of the goal motion of point *H.*

Additional introduction of binary link 5 reduces the degrees of freedom by 1. The resulting six-bar manipulation mechanism is a type Stephenson I, as is the structure of die casting robots FEEDMAT 1 of the Bulgarian-German company SPESIMA, characterized by high energy efficiency compared to the die casting robots of other companies.

Group C. In order to control the kinematic components of goal motion a *subsidiary kinematic chain* (sub) can be brought, which connects the base 0 to link 1 through the links 6 and 7 (table 2, C). So the base link 0 becomes ternary and link 1 - quaternary. Virtually forming subsidiary transfer mechanism with a four-bar topological structure (usually with a high kinematic pair), which generate the law of motion of the link 1, set by solving an inverse kinematic problem. In the past two decades, this law is generated directly by controlling the parameters of electric motors, which leads to simpler structures of manipulators of the groups B and C on table 1 and table 2.

Table 2

N	Components of the goal motion	Topologic structures	Necessary input paramenters	Dependencies in the related movements	Sample path-generator mechanisms
A				N/A	
B				- - - - - - - - -	
C				- - - - - - - - - - - - - - - - - -	

3. Conclusion

In part I of this study is the evidence of the need for new approaches to structural synthesis of mechanical systems. Part II of this study identifies five types of kinematic chains with different functionality designation, the goal tasks and functional requirements for manipulation mechanisms are formed, consistent with the control of industrial robots. On this basis, in this Part III are introduced mechatronic approaches for functional structural synthesis of mechanical systems of industrial robots, where the main manipulation mechanism is path generator. These approaches make it possible to directly identify a limited number of potential options to solve technical problems and to meet specific requirements to the design mechanisms. Emphasis is placed on the tasks of passive control of manipulation systems associated with the specialized robotics. These problems are solved by functional synthesis of their structure and dimensions for minimum number of degree of freedom, required for the realization of the goal task.

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