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Synthesis of a Mechanism of Stephenson I Type for Die Casting Robot "Feedmat 1"

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Abstract: *This paper is dedicated to the solution of practical problems associated with the synthesis of manipulators with basic topological structure type Stephenson I of die casting dosing robots "Feedmat 1" of the Bulgarian-German firm "SPESIMA GmbH". In the cases in which the target trajectory is given discretely by means of a multitude of closely situated points, the parameters of the kinematic diagram are defined by the method of the maximally contracted evolute. In the analytically given trajectory is used vector-matrix synthesis, which has certain advantages over other methods.*

Keywords: *Mechanism of Stephenson I type, synthesis, dosing robot.*

1. Introduction

The functional typology and the structural classification of the die casting dosing robots are thoroughly described with logical consistency in [7]. The dissertation of Slavkov [8] is an extensive monograph, devoted to the synthesis of mechanisms of die casting dosing robots.

The primary mechanisms of the die casting dosing robots, designed for supplying horizontal machines for high-pressure die casting with melted steel, most commonly have a six unit topological structure from the Stephenson III type. Such a structure have the robotic mechanisms of the die casting robots manufactured by the companies "Snair" and "Buhler". They have this topological structure with a higher kinematic pair, whereas the ones made by "Toshiba" and "Advance" are entirely with a lever mechanism. An exception from that is Stephenson I mechanism of the die casting robots "Feedmat 1" [2] of the Bulgarian-German company “SPESIMA GmbH”. These six-bar linkage can be synthesized by different methods [5, 4, 13, 12].

In this work for synthesis of six unit lever mechanisms type Stephenson I, including the ones for die casting dosing robots “Feedmat 1” [3], will be used as a part of the generalized method for structural & dimensional synthesis [1, 2], one of the most efficient ones for practical application. Furthermore, comparison of the structural level for energy efficiency of the six-bar linkage will be made, comparing the foreign casting dosing robots to the ones of “SPESIMA GmbH”.

2. Structures of the basic mechanisms of famous die casting robots

In accordance with the method for structural & dimensional synthesis, the structure of Stephenson III type mechanisms is developed in a specific sequence. The first defined is the structure of the main kinematic chain, called *primary* [9]. By definition it is the shortest (in terms of amount of links) chain (links 0, 1, and 2), which only with lower kinematic pairs (in this case revolute) connects the end-effector (in this case the ladle) with the stand 0 (Fig. 1). Afterwards a *secondary* kinematic chain is added (units 0, 3, 4, and 2), which by definition connects two nonadjacent links (in this case 0 and 2) of the primary chain. In this way a closed five-bar chain of mechanism is formed with two number of degrees of freedom (F=2). Such a chain has the observed manipulation mechanisms.

Structure Stephenson III (Fig. 1) can be obtained if binary link 5 is added to the five-bar chain, which by means of lower kinematic pairs (in this case revolute) connects the units 0 and 4 of the secondary kinematic chain. This is the structure of the basic mechanism of the die casting robots of the firms “Toshiba” and “Advance”.

Structure Stephenson I (Fig. 2) can be obtained if binary link is added to the five-bar chain, which by means of lower kinematic pairs (in this case revolute) connects the links 1 and 3 respectively of the primary and secondary kinematic chains, as it is in the die casting dosing robots “Feedmat 1” of “SPESIMA GmbH”.

A comparison of the structural level for energy efficiency of the mechanisms of the foreign die casting dosing robots with the ones of “SPESIMA GmbH” [7] can be done by a test, including the following structural energy criteria:

- the presence of a closed energy chain;
- equal number of units on both sectors of the chain;
- a branching out of the energy flow by the input;
- fusion of the energy flow on the output;
- absence of a passive energy link.

For a positive answer to each one of the criteria the valuation is 1. For a negative answer the valuation is 0. With this simple valuation system the basic mechanisms of the foreign robots have a total valuation of 0, whereas the ones of the robots “Feedmat 1 of “SPESIMA GmbH” have a total valuation of 4 out of maximally possible 5.

3. Mathematical models for synthesis

The synthesis of primary and secondary kinematic chains of the mechanisms is revealed in previous works [1, 2, 10], so in this work it is not considered due to the limited volume. The overall synthesis of mechanisms with structure Stephenson type III implies determining further the centers of the revolute kinematic pairs of binary link 5, located respectively in the planes of the links 1 and 3. In the structure of the six-bar linkage (forming a control four-bar linkage) *OABC* (Fig. 3), which should be synthesised, in order to complete the synthesis task of the six-bar linkage. For this purpose a vector-matrix method will be used, which allows mathematical models to be formed without uncertainties at the singular configurations of the mechanisms.

The mechanism synthesised so far from Fig. 2 does not include unit 5, due to which it has two number of degrees of freedom (F=2). When moving point $H(x, y)$ on the given target trajectory τ the number of degrees of freedom of this mechanism are reduced to F=1. If τ is given analytically with the parametric equations $x = x(t),\ y = y(t)$, the kinematic characteristics of the mechanisms are determined as a result of kinematic analysis, including the variable part (the variation) of the displacement function of the state $\Delta\psi = \Delta\psi(\Delta\varphi)$ and its derivative transfer functions $\psi' = \psi'(\varphi)$, $\psi'' = \psi''(\varphi)$ of the control four-bar linkage *OABC*. For simplicity, with $\psi \equiv \varphi_1$ and $\varphi \equiv \varphi_3$ respectively the exit and entry parameters of the control linkage *OABC* are written down.

The synthesis of this mechanism with already definied transfer functions can be done with various methods. In this case *the method of the maximally contracted evolute* is applied as the most efficient one for practical use. Initially, area β is determined, in which the initial state B_0 of the center B must be situated, in order to fulfill for every state of the mechanism the condition for favorable pressure angle [1, 2]. This greatly restricts the space for possible solutions.

For every state of B_0 as a result of the synthesis the trajectory is obtained (pitch curve of a cam) of the center B with radius-vector $\vec{b}$ and its evolute. Through every state of the center B passes a normal, onto which lies the center of the incurvation A with radius-vector $\vec{a}$. The radius of the incurvation $\rho_{AB} = \left|\vec{a} - \vec{b}\right|$ up until the order of the second derivatives is constant, due to which $(\vec{a} - \vec{b})^{\mathrm{T}} (\vec{a} - \vec{b}) = \text{const},$ and as a result after differentiation equations for kinematic constraint are derived:

$$(\vec{a}')^{\mathrm{T}} (\vec{a} - \vec{b}) = 0, \qquad (1)$$

$$(\vec{a}'')^{\mathrm{T}} (\vec{a} - \vec{b}) + (\vec{a}')^{\mathrm{T}} (\vec{a}') = 0.$$

Because $\vec{a}' = \left[U_0'^{r} \right] \vec{a},\ \vec{a}'' = \left[U_0''^{r} \right] \vec{a},$ where

(2) $$\left[U_0'^r\right]=\begin{bmatrix} 0 & \psi'-1 & 0 \\ 1-\psi' & 0 & L\psi' \\ 0 & 0 & 0 \end{bmatrix},$$

(3) $$\left[U_0''^r\right]=\begin{bmatrix} -(\psi'-1)^2 & \psi'' & L\psi'^2 \\ -\psi'' & -(\psi'-1)^2 & L\psi'' \\ 0 & 0 & 0 \end{bmatrix}$$

are respectively the first and the second derivative matrices for instantaneous displacement, in which L is denotes the length of the stand 0. Taking into account the matrices (2) and (3), the equations (1) can be transformed as follows:

(4) $$\begin{gathered} a\,x_A + b\,y_A = c, \\ d\,x_A + e\,y_A = f \end{gathered}$$

with coefficients

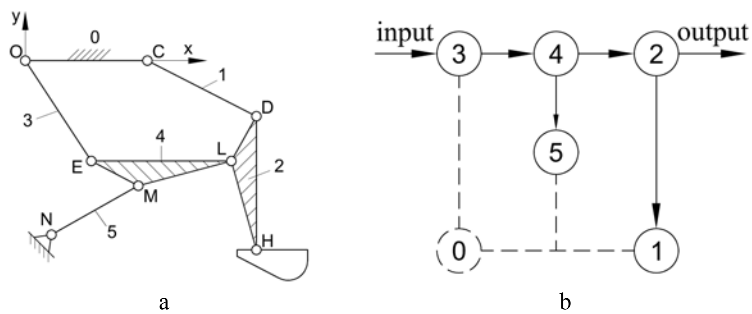
(5) $$\begin{gathered} a=(\psi'-1)y_B, \\ b=L\psi'-(\psi'-1)x_B, \\ c=L\psi' y_B, \\ d=\psi'' y_B-\psi'(\psi'-2)(L-x_B)+x_B, \\ e=\psi''(L-x_B)+(\psi'-1)^2 y_B, \\ f=L[\psi'' y_B-\psi'^2(L-x_B)] \end{gathered}$$

and solutions

(6) $$x_A=\frac{ce-bf}{ae-bd},\ y_A=\frac{af-cd}{ae-bd}.$$

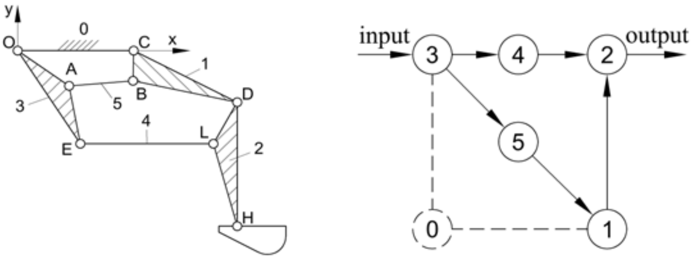
The coordinates of the center of curvature A are determined in the plane of link 3:

(7) $$\begin{gathered} X_A = x_A\cos\varphi + y_A\sin\varphi, \\ Y_A=-x_A\sin\varphi + y_A\cos\varphi. \end{gathered}$$



a b

Fig 1. Kinematic diagram (a) and structural energy graph (b) of mechanisms type Stephenson III of foreign die casting dosing robots of the firms “Toshiba” and “Advance”



a b

Fig 2. Kinematic diagram (a) and structural energy graph (b) of mechanisms type Stephenson I of die casting dosing robot "Feedmat 1"

The values of two free parameters x_{B_0} and y_{B_0} vary, which defines the initial state B_0 of the center B in the area β, while the evolute defined by equations (7) contracts maximally. Then the center of weight A^* of the evolute defines the position of the axis of the joint connecting link 5 with link 3.

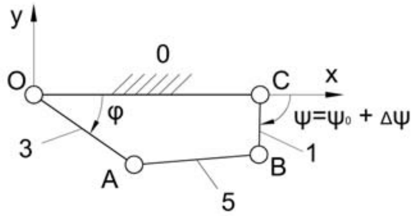


Fig. 3. Kinematic diagram of the control four-bar linkage

The method of the maximally contracted evolute can be applied in the cases, in which the trajectory τ is given discretely by means of a multitude of closely situated points. The length of l_5 of the lever 5 is defined by the extremums of the distances A^*B_j

(8) $$l_5 = 0.5[(A^*B_j)_{\max} + (A^*B_j)_{\min}],$$

where B_j is the multitude of positions of centre B in the plane of link 3, defined by the equations

(9) $$X_{B_j} = x_{B_j}\cos\varphi_j + y_{B_j}\sin\varphi_j, \quad Y_{B_j} = -x_{B_j}\sin\varphi_j + y_{B_j}\cos\varphi_j,$$

where

(10) $$x_{B_j} = L + \sqrt{x_{B_0}^2 + y_{B_0}^2}\cos\psi_j, \quad y_{B_j} = \sqrt{x_{B_0}^2 + y_{B_0}^2}\sin\psi_j.$$

More informations for the method is provided in the publication of [1, 2].

4. Conclusion

This work is dedicated to the solution of practical problems associated with the synthesis of manipulation mechanisms type Stephenson I, which are the basic mechanisms of the die casting dosing robots "Feedmat 1" of "SPESIMA GmbH". After synthesis and kinematic analysis of a closed five-bar chain and implementation of a binary link, connecting the links with simple movement the structure Stephenson I is formed, which incorporates a control five-bar linkage. Its transfer functions are defined, by which this mechanism is synthesized by *the method of the maximally contracted evolute E*, with which the entire synthesis of the six-bar linkage is completed.

The comparison of the energy efficiency on the structural level of the mechanisms of the foreign casting dosing robots with the ones of "*SPESIMA GmbH"* unambiguously shows the advantages of the robots "Feedmat 1" [3].

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Синтез литейных роботов „Feedmat 1“ с механизмами типа „Stephenson I“

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(Р е з ю м е)

Настоящая работа посвящена решению практической задачи, связанной с синтезом основного манипуляционного механизма с топологической структурой типа „Stephenson I“ литейного дозирующего робота „Feedmat 1“ фирмы SPESIMA GmbH. Параметры кинематической схемы механизма определенны методом максимально свитой эволюты с использованием векторно-матричного аппарата как у аналитически заданной целевой траектории, так и у целевой траектории, дискретно заданной с помощью множеств близко расположенных точек.