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KINEMATICS AT THE MAIN MECHANISM OF A RAILBOUND FORGING MANIPULATOR

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ABSTRACT

Heavy payload forging manipulators are mainly characterized by large load output and large capacitive load input. The relationship between outputs and inputs will greatly influence the control and the reliability. Forging manipulators have become more prevalent in the industry today. They are used to manipulate objects to be forged. The most common forging manipulators are moving on a railway to have a greater precision and stability. They have been called the rail bound forging manipulators. In this paper we analyse general kinematics of the main mechanism from such manipulator. Kinematic scheme shows a typical forging manipulator, with the basic motions in operation process: walking, motion of the tong and buffering. The lifting mechanism consists of several parts including linkages, hydraulic drives and motion pairs. The principle of type design from the viewpoints of the relationship between output characteristics and actuator inputs is discussed. An idea of establishing the incidence relationship between output characteristics and actuator inputs is proposed. These novel forging manipulators which satisfy certain functional requirements provide an effective help for the design of forging manipulators.

Keywords: Mechatronics, Robotics, Heavy payload forging manipulators, Rail bound forging manipulator, Kinematics

1. INTRODUCTION

Heavy payload forging manipulators are mainly characterized by large load output and large capacitive load input. The relationship between outputs and inputs, which will greatly influence the control and the reliability, is the key issue in type design for heavy payload forging manipulators. Forging manipulators have become more prevalent in the industry today. They are used to manipulate objects to be forged [1-3].

The most common forging manipulators are moving on a railway to have a greater precision and stability. They have been called the railbound forging manipulators. In this paper we analyse the general kinematics of the main mechanism from such manipulator [1-5].

Kinematic scheme shows a typical forging manipulator, with the basic motions in operation process: walking, motion of the tong and buffering. The lifting mechanism consists of several parts including linkages, hydraulic drives and motion pairs. Hydraulic drives are with the lifting hydraulic cylinder, the buffer hydraulic cylinder and the leaning hydraulic cylinder, which are individually denoted by c1, c2 and c3. In lifting process, the cylinder c1 controls the vertical movement of work piece through inputting lifting signal. At the same time, the cylinders c2 and c3 are perfectly closed. While c1 and c3 are closed cylinders, cylinder c2 performs horizontal movement. While, the cylinders c1and c2 are closed the cylinder c3 realizes leaning movement by inputting leaning signal in leaning condition.

In direct kinematics one knows l1, l2 and must be determined: intermediary l3, FI1, FI3, FI6, FI8, FI10 and finally xM, yM. In inverse kinematics one knows xM, yM (imposed) and must be determined FI1, FI3, FI6, FI8, FI10, l1, l2, l3 so that the FI angle keeps its constant value (FI=PI-TETA) to maintain permanently the segment GM horizontally [6-11].

In this work we are solving positions (in inverse kinematics) with systems V, VI. When we know all these parameters (angles and lengths) one may determine all kinematics parameters. The concept of modelling method based on the outputs tasks is defined and investigated. The principle of type design from the viewpoints of the relationship between output characteristics and actuator inputs is discussed. An idea of establishing the incidence relationship between output characteristics and actuator

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inputs is proposed. These novel forging manipulators which satisfy certain functional requirements provide an effective help for the design of forging manipulators [1-5].

In the next 14 photos one can see some forging manipulators (independent or on rail) at work [1-5, 11-12].

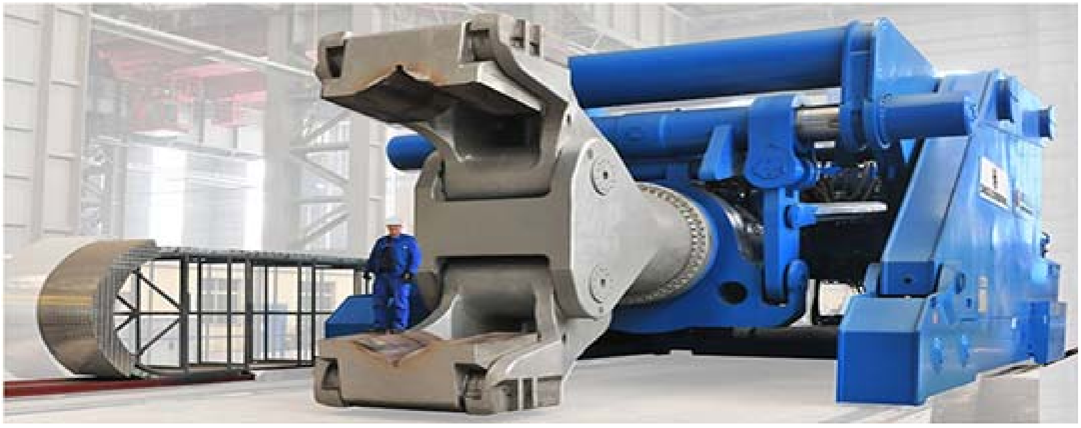

Figure 1: Forging Manipulator (Rail Mobile)
Source: Dango & Dienenthal

Figure 2: Forging Manipulator (Rail Mobile)
Source: Dango & Dienenthal

Figure 3: Forging Manipulator (Rail Mobile)
Source: Dango & Dienenthal

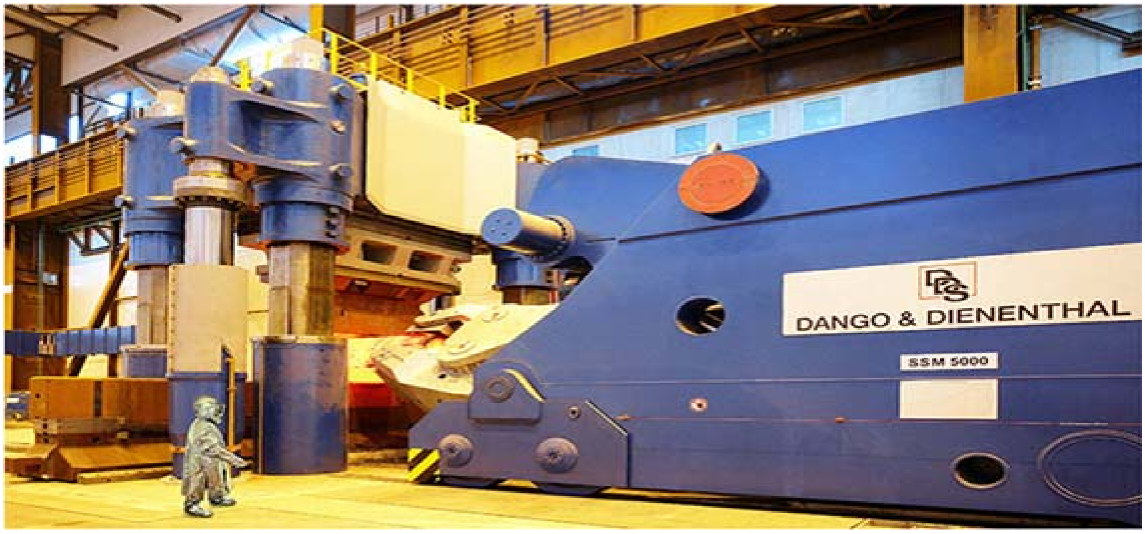

Figure 4: Forging Manipulator (Rail Mobile)
Source: Dango & Dienenthal

Figure 5: Forging Manipulator (Mobile)
Source: Dango & Dienenthal

Figure 6: Forging Manipulator (Rail Mobile)
Source: Dango & Dienenthal

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Figure 7: Forging Manipulator (Independent Mobile)
Source: Dango & Dienenthal

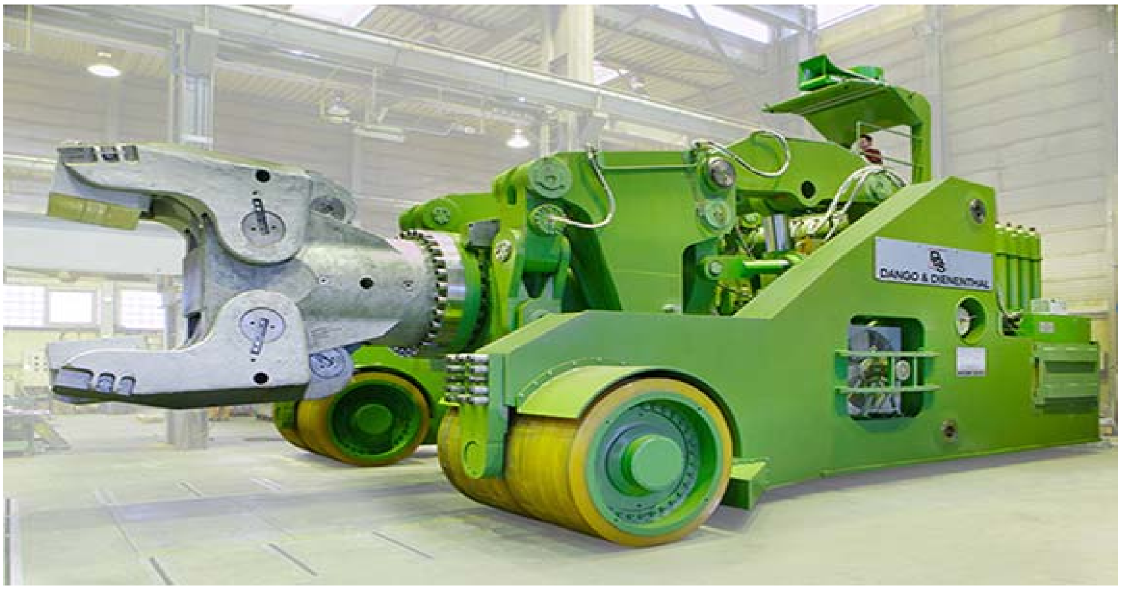

Figure 8: Forging Manipulator (Independent Mobile)
Source: Dango & Dienenthal

Figure 9: Forging Manipulator (Independent Mobile)
Source: Dango & Dienenthal

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Figure 10: Forging Manipulator (Independent Mobile)
Source: Dango & Dienenthal

Figure 11: Forging Manipulator (Independent Mobile)
Source: Dango & Dienenthal

Figure 12: Forging Manipulator (Rail Mobile)
Source: Dango & Dienenthal

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Figure 13: Forging Manipulator (Rail Mobile)
Source: Dango & Dienenthal

Figure 14: Workstation SSM120 equipment
Source: Dango & Dienenthal

1.1. Nomenclature

c_1 - lifting hydraulic cylinder; c_2 - the buffer hydraulic cylinder;

c_3 - leaning hydraulic cylinder; l_1, l_2, l_3 – variable lengths;

A-L – linkages; A, B, K, F – fixed linkages; φ_1, φ_3, φ_6, φ_8, φ_{10} - variable angles; a-g – constant lengths; x_B, y_B, x_A, y_A, x_K, y_K, x_F, y_F – constant coordinates; β, θ, φ_4 – constant angles; φ - an angle which must be maintained constant ($\varphi=\pi-\theta$) to keep permanently the segment GM horizontally (as shown in Figure 15).

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2. THE STRUCTURE, GEOMETRY AND KINEMATICS OF A RAILBOUND FORGING MANIPULATOR

In fig. 15 one can see the kinematics schema of the main mechanism from a railbound forging manipulator [11].

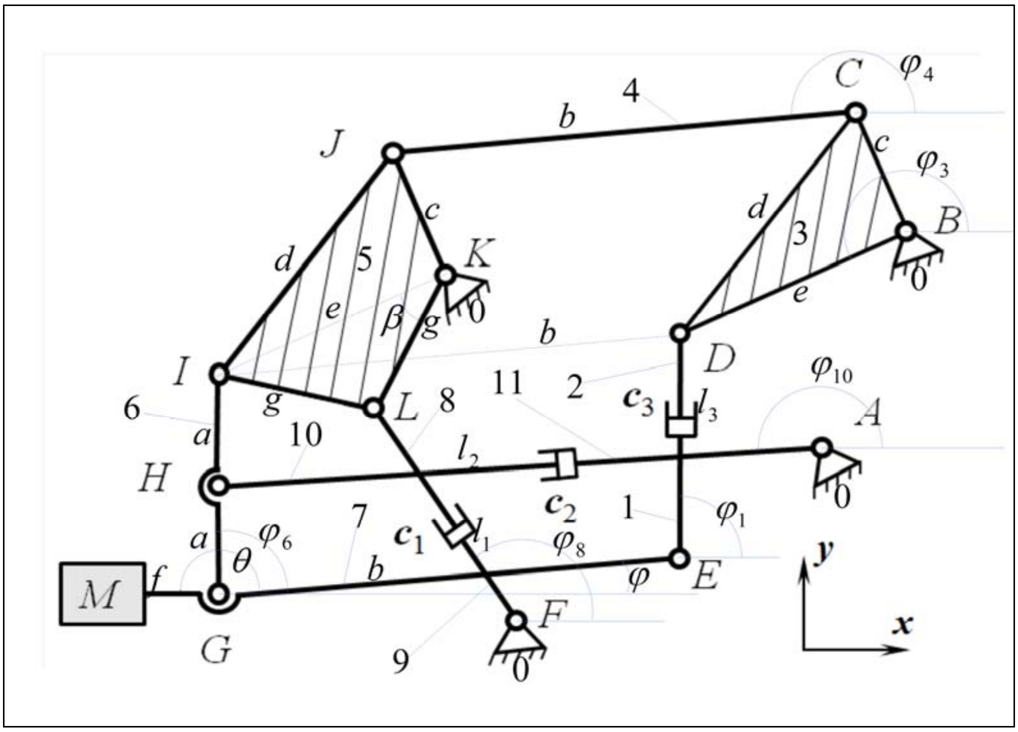

Figure 15: Cinematic schema of a forging manipulator main mechanism

Permanently one knows the constant lengths (a-g) (a to b)and the coordinates (x_B, y_B, x_A, y_A, x_K, y_K, x_F, y_F), (not identify the coordinated) and the φ angle who must to be maintained constant [1-5, 9-12]. (constant angle of 1 to 3 or 1 and 3)

In direct kinematics one knows l_1, l_2 and must be determined: intermediary (with systems I, II, III) l_3, φ_1, φ_3, φ_6, φ_8, φ_{10} and finaly (with system IV) x_M, y_M [1-5, 9-12].

In inverse kinematics one knows x_M, y_M and must be determined φ_1, φ_3, φ_6, φ_8, φ_{10}, l_1, l_2, l_3 with systems I, II, III, IV.

It takes four independent vector contours (KLFK, KIGEDB, AHIK, AHGM) and one can write the below systems (I, II, III, IV) [1-5, 9-12].

$$\begin{cases}(x_K - x_F) + g \cdot \cos(\varphi_3 + \beta) = l_1 \cdot \cos\varphi_8 \\ (y_K - y_F) + g \cdot \sin(\varphi_3 + \beta) = l_1 \cdot \sin\varphi_8\end{cases} \quad \text{(I)}$$

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$$\begin{cases} x_K + b \cdot \cos\varphi + l_3 \cdot \cos\varphi_1 = 2a \cdot \cos\varphi_6 \\ y_K + b \cdot \sin\varphi + l_3 \cdot \sin\varphi_1 = 2a \cdot \sin\varphi_6 \end{cases} \quad \text{(II)}$$

$$\begin{cases} (x_A - x_K) + l_2 \cdot \cos\varphi_{10} + a \cdot \cos\varphi_6 = e \cdot \cos\varphi_3 \\ (y_A - y_K) + l_2 \cdot \sin\varphi_{10} + a \cdot \sin\varphi_6 = e \cdot \sin\varphi_3 \end{cases} \quad \text{(III)}$$

$$\begin{cases} (x_A - x_M) + l_3 \cdot \cos\varphi_{10} + f \cdot \cos(\varphi + \theta) = a \cdot \cos\varphi_6 \\ (y_A - y_M) + l_3 \cdot \sin\varphi_{10} + f \cdot \sin(\varphi + \theta) = a \cdot \sin\varphi_6 \end{cases} \quad \text{(IV)}$$

2.1. Inverse kinematics relationships computing

Then can be determined easily the parameters φ_1, φ_3, φ_6, φ_8, φ_{10}, l_1, l_2, l_3 solving the four systems I, II, III, IV. Following relationships (systems V, VI) are obtained [1-5, 9-12].

$$\begin{cases} \cos\varphi_6 = \dfrac{A_1 \cdot A_2 \mp A_3 \cdot \sqrt{A_2^2 + A_3^2 - A_1^2}}{A_2^2 + A_3^2}; \quad \varphi_6 = \arccos(\cos\varphi_6) \\ A_0 = 4a^2 + (x_K + b\cos\varphi)^2 + (y_K + b\sin\varphi)^2 - \\ -4a[(x_K + b\cos\varphi)\cos\varphi_6 + (y_K + b\sin\varphi)\sin\varphi_6]; \quad l_3 = \sqrt{A_0} \\ \begin{cases} \cos\varphi_1 = \dfrac{2a \cdot \cos\varphi_6 - x_K - b \cdot \cos\varphi}{l_3} \\ \sin\varphi_1 = \dfrac{2a \cdot \sin\varphi_6 - y_K - b \cdot \sin\varphi}{l_3} \end{cases}; \begin{cases} \varphi_1 = sign(\sin\varphi_1) \cdot \\ \cdot \arccos(\cos\varphi_1) \end{cases} \\ \cos\varphi_{10} = \dfrac{a \cdot \cos\varphi_6 - f \cdot \cos(\varphi + \theta) + x_M - x_A}{l_3} \\ \sin\varphi_{10} = \dfrac{a \cdot \sin\varphi_6 - f \cdot \sin(\varphi + \theta) + y_M - y_A}{l_3} \\ \varphi_{10} = sign(\sin\varphi_{10}) \cdot \arccos(\cos\varphi_{10}) \\ l_2 = -A_4 \mp \sqrt{A_4^2 + e^2} \end{cases} \quad \text{(V)}$$

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$$
\begin{cases}
\begin{cases}
\cos \varphi_3 = \dfrac{x_A - x_K + l_2 \cdot \cos \varphi_{10} + a \cdot \cos \varphi_6}{e} \\
\sin \varphi_3 = \dfrac{y_A - y_K + l_2 \cdot \sin \varphi_{10} + a \cdot \sin \varphi_6}{e}
\end{cases} \Rightarrow \\
\Rightarrow \varphi_3 = sign(\sin \varphi_3) \cdot \arccos(\cos \varphi_3) \\
\\
l_1 = \\
= \sqrt{[x_K - x_F + g \cos(\varphi_3 + \beta)]^2 + [y_K - y_F + g \sin(\varphi_3 + \beta)]^2} \\
\\
\begin{cases}
\cos \varphi_8 = \dfrac{x_K - x_F + g \cdot \cos(\varphi_3 + \beta)}{l_1} \\
\sin \varphi_8 = \dfrac{y_K - y_F + g \cdot \sin(\varphi_3 + \beta)}{l_1}
\end{cases} \Rightarrow \\
\Rightarrow \varphi_8 = sign(\sin \varphi_8) \cdot \arccos(\cos \varphi_8) \\
A_1 = 3a^2 + (x_K + b \cdot \cos \varphi)^2 + (y_K + b \cdot \sin \varphi)^2 - \\
-[x_M - x_A - f \cdot \cos(\varphi + \theta)]^2 - [y_M - y_A - f \cdot \sin(\varphi + \theta)]^2 \\
A_2 = 4a \cdot (x_K + b \cdot \cos \varphi) + 2a \cdot [x_M - x_A - f \cdot \cos(\varphi + \theta)] \\
A_3 = 4a \cdot (y_K + b \cdot \sin \varphi) + 2a \cdot [y_M - y_A - f \cdot \sin(\varphi + \theta)] \\
A_4 = \cos \varphi_{10} \cdot (a \cdot \cos \varphi_6 + x_A - x_K) + \sin \varphi_{10} \cdot \\
\cdot (a \cdot \sin \varphi_6 + y_A - y_K)
\end{cases}
\qquad \text{(VI)}
$$

2.2. General kinematics relationships computing

In the fig. 16 one can see the general kinematics schema of a railbound forging manipulator main mechanism [11].

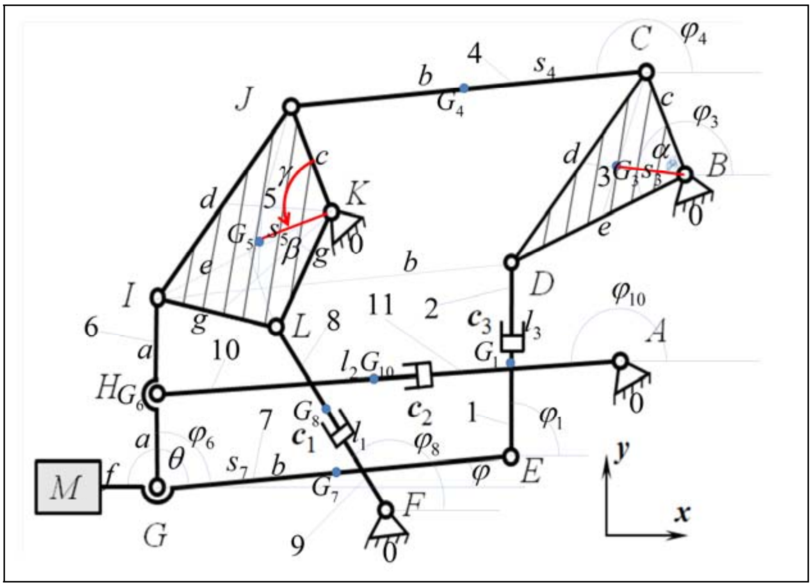

Figure 16: General cinematic schema of a forging manipulator main mechanism

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At the first step, starting from the system I derived by time (in function of time), one calculates the angular velocities $\dot{\varphi}_3, \dot{\varphi}_8$ in function of the linear velocity of the engine c1, $\dot{l}_1$ (see the system 1) [11].

$$\begin{cases} \begin{cases} -g \cdot \sin(\varphi_3 + \beta) \cdot \dot{\varphi}_3 = -l_1 \cdot \sin\varphi_8 \cdot \dot{\varphi}_8 + \cos\varphi_8 \cdot \dot{l}_1 \\ g \cdot \cos(\varphi_3 + \beta) \cdot \dot{\varphi}_3 = l_1 \cdot \cos\varphi_8 \cdot \dot{\varphi}_8 + \sin\varphi_8 \cdot \dot{l}_1 \end{cases} \left| \begin{matrix} Ia \\ \cdot \cos\varphi_8 \\ \cdot \sin\varphi_8 \end{matrix} \right\| \left. \begin{matrix} Ib \\ \cdot \cos(\varphi_3 + \beta) \\ \cdot \sin(\varphi_3 + \beta) \end{matrix} \right\| \\ Ia \Rightarrow \dot{\varphi}_3 \cdot g \cdot \sin(\varphi_8 - \varphi_3 - \beta) = \dot{l}_1 \Rightarrow \dot{\varphi}_3 = \dfrac{\dot{l}_1}{g \cdot \sin(\varphi_8 - \varphi_3 - \beta)} \\ \varphi_8 - \varphi_3 - \beta \neq k\pi \\ Ib \Rightarrow \dot{\varphi}_8 \cdot l_1 \cdot \sin(\varphi_8 - \varphi_3 - \beta) = \cos(\varphi_8 - \varphi_3 - \beta) \cdot \dot{l}_1 \Rightarrow \\ \Rightarrow \dot{\varphi}_8 = \dfrac{\cos(\varphi_8 - \varphi_3 - \beta) \cdot \dot{l}_1}{l_1 \cdot \sin(\varphi_8 - \varphi_3 - \beta)} \quad \varphi_8 - \varphi_3 - \beta \neq k\pi \end{cases} \tag{1}$$

At the step two, starting from the system II derivated by time, one calculates the angular velocities $\dot{\varphi}_6, \dot{\varphi}_{10}$ in function of linear velocities $\dot{l}_1, \dot{l}_2$ of engines c1, c2 (resulting the system 2). Solving every sytem is simple and direct; multiply at the step a the first equation with a cosine and the second equation with a sine, one add the two relations rezulted and one obtains an equation linear grade 1 with a single unknown. To the pass b one repeat the procedure but the multiply of the two equations is different [1-4, 9-11].

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$$\begin{cases} \begin{cases} \cos\varphi_{10}\dot{l}_2 - l_2\sin\varphi_{10}\dot{\varphi}_{10} - a\sin\varphi_6\dot{\varphi}_6 = -e\sin\varphi_3\dot{\varphi}_3 \\ \sin\varphi_{10}\dot{l}_2 + l_2\cos\varphi_{10}\dot{\varphi}_{10} + a\cos\varphi_6\dot{\varphi}_6 = e\cos\varphi_3\dot{\varphi}_3 \end{cases} \left| \begin{matrix} IIa \\ \cdot\cos\varphi_{10} \\ \cdot\sin\varphi_{10} \end{matrix} \right\| \begin{matrix} IIb \\ \cdot\cos\varphi_6 \\ \cdot\sin\varphi_6 \end{matrix} \right\| \\ IIa \Rightarrow \dot{l}_2 + a\cdot\sin(\varphi_{10}-\varphi_6)\cdot\dot{\varphi}_6 = e\cdot\sin(\varphi_6-\varphi_3)\cdot\dot{\varphi}_3 \Rightarrow \\ \Rightarrow \dot{\varphi}_6 = \dfrac{e\cdot\sin(\varphi_6-\varphi_3)\cdot\dot{\varphi}_3 - \dot{l}_2}{a\cdot\sin(\varphi_{10}-\varphi_6)} \quad \varphi_{10}-\varphi_6 \neq k\pi \\ \\ IIb \Rightarrow \cos(\varphi_{10}-\varphi_6)\cdot\dot{l}_2 - l_2\cdot\sin(\varphi_{10}-\varphi_6)\cdot\dot{\varphi}_{10} = e\cdot\sin(\varphi_6-\varphi_3)\cdot\dot{\varphi}_3 \Rightarrow \\ \Rightarrow \dot{\varphi}_{10} = \dfrac{\cos(\varphi_{10}-\varphi_6)\cdot\dot{l}_2 - e\cdot\sin(\varphi_6-\varphi_3)\cdot\dot{\varphi}_3}{l_2\cdot\sin(\varphi_{10}-\varphi_6)} \quad \varphi_{10}-\varphi_6 \neq k\pi \end{cases} \tag{2}$$

At the step three, starting from the system III derivated by time, it calculates the angular velocity $\dot{\varphi}_1$ in function of linear velocities $\dot{l}_1, \dot{l}_2$ of the engines (actuators) c1, c2 (result the system 3) [6-11].

$$\begin{cases} \begin{cases} \dot{l}_3\cdot\cos\varphi_1 - l_3\cdot\sin\varphi_1\cdot\dot{\varphi}_1 = -2a\cdot\sin\varphi_6\cdot\dot{\varphi}_6 \\ \dot{l}_3\cdot\sin\varphi_1 + l_3\cdot\cos\varphi_1\cdot\dot{\varphi}_1 = 2a\cdot\cos\varphi_6\cdot\dot{\varphi}_6 \end{cases} \left| \begin{matrix} IIIa \\ \cdot -\sin\varphi_1 \\ \cdot\cos\varphi_1 \end{matrix} \right| \\ IIIa \Rightarrow l_3\cdot\dot{\varphi}_1 = 2a\cdot\cos(\varphi_1-\varphi_6)\cdot\dot{\varphi}_6 \Rightarrow \dot{\varphi}_1 = \dfrac{2a}{l_3}\cdot\cos(\varphi_6-\varphi_1)\cdot\dot{\varphi}_6 \end{cases} \tag{3}$$

At the step four we arrange the system IV and then one derivated it by time and it obtains directly the scalar velocities of the endeffector point M (system 4) [11].

$$\begin{cases} \begin{cases} x_M = l_3\cdot\cos\varphi_{10} + f\cdot\cos(\varphi+\theta) - a\cdot\cos\varphi_6 \\ y_M = l_3\cdot\sin\varphi_{10} + f\cdot\sin(\varphi+\theta) - a\cdot\sin\varphi_6 \end{cases} \\ \begin{cases} \dot{x}_M = \dot{l}_3\cdot\cos\varphi_{10} - l_3\cdot\sin\varphi_{10}\cdot\dot{\varphi}_{10} + a\cdot\sin\varphi_6\cdot\dot{\varphi}_6 \\ \dot{y}_M = \dot{l}_3\cdot\sin\varphi_{10} + l_3\cdot\cos\varphi_{10}\cdot\dot{\varphi}_{10} - a\cdot\cos\varphi_6\cdot\dot{\varphi}_6 \end{cases} \end{cases} \tag{4}$$

For determining of accelerations must to derivate the systems I-IV, but we take in consideration a method rapid and directly: we know now the velocities and one derivate directly their relations; it obtains the relations from the system 5 [11].

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$$
\begin{cases}
\left\{\ddot{\varphi}_3 = \dfrac{\ddot{l}_1 - \dot{\varphi}_3 \cdot g \cdot \cos(\varphi_8 - \varphi_3 - \beta) \cdot (\dot{\varphi}_8 - \dot{\varphi}_3)}{g \cdot \sin(\varphi_8 - \varphi_3 - \beta)}\right. \\
\begin{cases}
\ddot{\varphi}_8 = \dfrac{\cos(\varphi_8 - \varphi_3 - \beta) \cdot \ddot{l}_1 - \dot{l}_1 \cdot \sin(\varphi_8 - \varphi_3 - \beta) \cdot (\dot{\varphi}_8 - \dot{\varphi}_3)}{l_1 \cdot \sin(\varphi_8 - \varphi_3 - \beta)} - \\
- \dfrac{\dot{\varphi}_8 \cdot l_1 \cdot \cos(\varphi_8 - \varphi_3 - \beta) \cdot (\dot{\varphi}_8 - \dot{\varphi}_3) + \dot{\varphi}_8 \cdot \dot{l}_1 \cdot \sin(\varphi_8 - \varphi_3 - \beta)}{l_1 \cdot \sin(\varphi_8 - \varphi_3 - \beta)}
\end{cases} \\
\begin{cases}
\ddot{\varphi}_6 = \dfrac{e \cdot \cos(\varphi_6 - \varphi_3) \cdot (\dot{\varphi}_6 - \dot{\varphi}_3) \cdot \dot{\varphi}_3 + e \cdot \sin(\varphi_6 - \varphi_3) \cdot \ddot{\varphi}_3 - \ddot{l}_2}{a \cdot \sin(\varphi_{10} - \varphi_6)} - \\
- \dfrac{\dot{\varphi}_6 \cdot a \cdot \cos(\varphi_{10} - \varphi_6) \cdot (\dot{\varphi}_{10} - \dot{\varphi}_6)}{a \cdot \sin(\varphi_{10} - \varphi_6)}
\end{cases} \\
\begin{cases}
\ddot{\varphi}_{10} = \dfrac{\ddot{l}_2 \cdot \cos(\varphi_{10} - \varphi_6) - \dot{l}_2 \cdot \sin(\varphi_{10} - \varphi_6) \cdot (\dot{\varphi}_{10} - \dot{\varphi}_6)}{l_2 \cdot \sin(\varphi_{10} - \varphi_6)} - \\
- \dfrac{e \cdot \cos(\varphi_6 - \varphi_3) \cdot (\dot{\varphi}_6 - \dot{\varphi}_3) \cdot \dot{\varphi}_3 + e \cdot \sin(\varphi_6 - \varphi_3) \cdot \ddot{\varphi}_3}{l_2 \cdot \sin(\varphi_{10} - \varphi_6)} - \\
- \dfrac{\dot{\varphi}_{10} \cdot \dot{l}_2 \cdot \sin(\varphi_{10} - \varphi_6) + \dot{\varphi}_{10} \cdot l_2 \cdot \cos(\varphi_{10} - \varphi_6) \cdot (\dot{\varphi}_{10} - \dot{\varphi}_6)}{l_2 \cdot \sin(\varphi_{10} - \varphi_6)}
\end{cases} \\
\left\{\ddot{\varphi}_1 = \dfrac{2a \cdot \cos(\varphi_6 - \varphi_1) \cdot \ddot{\varphi}_6 - 2a \cdot \sin(\varphi_6 - \varphi_1) \cdot (\dot{\varphi}_6 - \dot{\varphi}_1) \cdot \dot{\varphi}_6 - \dot{\varphi}_1 \cdot \dot{l}_3}{l_3}\right. \\
\begin{cases}
\ddot{x}_M = \ddot{l}_3 \cdot \cos\varphi_{10} - \dot{l}_3 \cdot \sin\varphi_{10} \cdot \dot{\varphi}_{10} - \dot{l}_3 \cdot \sin\varphi_{10} \cdot \dot{\varphi}_{10} - l_3 \cdot \cos\varphi_{10} \cdot \dot{\varphi}_{10}^2 - \\
- l_3 \cdot \sin\varphi_{10} \cdot \ddot{\varphi}_{10} + a \cdot \cos\varphi_6 \cdot \dot{\varphi}_6^2 + a \cdot \sin\varphi_6 \cdot \ddot{\varphi}_6 \\
\ddot{y}_M = \ddot{l}_3 \cdot \sin\varphi_{10} + \dot{l}_3 \cdot \cos\varphi_{10} \cdot \dot{\varphi}_{10} + \dot{l}_3 \cdot \cos\varphi_{10} \cdot \dot{\varphi}_{10} - l_3 \cdot \sin\varphi_{10} \cdot \dot{\varphi}_{10}^2 + \\
+ l_3 \cdot \cos\varphi_{10} \cdot \ddot{\varphi}_{10} + a \cdot \sin\varphi_6 \cdot \dot{\varphi}_6^2 - a \cdot \cos\varphi_6 \cdot \ddot{\varphi}_6
\end{cases}
\end{cases}
\quad (5)
$$

One determines now and the last kinematics parameters of the mechanism, for to have a complete cinematic of the main mechanism, which is necessary and in the kinetostatic and dynamic calculations (systems 6-21) [11].

$$
\begin{cases}
\begin{cases}
x_C = c \cdot \cos(\varphi_3 - CBD) \\
y_C = c \cdot \sin(\varphi_3 - CBD)
\end{cases}
\begin{cases}
\dot{x}_C = -c \cdot \sin(\varphi_3 - CBD) \cdot \dot{\varphi}_3 \\
\dot{y}_C = c \cdot \cos(\varphi_3 - CBD) \cdot \dot{\varphi}_3
\end{cases} \\
\begin{cases}
\ddot{x}_C = -c \cdot \cos(\varphi_3 - CBD) \cdot \dot{\varphi}_3^2 - c \cdot \sin(\varphi_3 - CBD) \cdot \ddot{\varphi}_3 \\
\ddot{y}_C = -c \cdot \sin(\varphi_3 - CBD) \cdot \dot{\varphi}_3^2 + c \cdot \cos(\varphi_3 - CBD) \cdot \ddot{\varphi}_3
\end{cases}
\end{cases}
\quad (6)
$$

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$$\begin{cases}\begin{cases}x_{G_3} = s_3 \cdot \cos(\varphi_3 - CBD + \alpha) \\ y_{G_3} = s_3 \cdot \sin(\varphi_3 - CBD + \alpha)\end{cases}\begin{cases}\dot{x}_{G_3} = -s_3 \cdot \sin(\varphi_3 - CBD + \alpha) \cdot \dot{\varphi}_3 \\ \dot{y}_{G_3} = s_3 \cdot \cos(\varphi_3 - CBD + \alpha) \cdot \dot{\varphi}_3\end{cases} \\ \begin{cases}\ddot{x}_{G_3} = -s_3 \cdot \cos(\varphi_3 - CBD + \alpha) \cdot \dot{\varphi}_3^2 - s_3 \cdot \sin(\varphi_3 - CBD + \alpha) \cdot \ddot{\varphi}_3 \\ \ddot{y}_{G_3} = -s_3 \cdot \sin(\varphi_3 - CBD + \alpha) \cdot \dot{\varphi}_3^2 + s_3 \cdot \cos(\varphi_3 - CBD + \alpha) \cdot \ddot{\varphi}_3\end{cases}\end{cases} \quad (7)$$

$$\begin{cases}\begin{cases}x_D = e \cdot \cos\varphi_3 \\ y_D = e \cdot \sin\varphi_3\end{cases}\begin{cases}\dot{x}_D = -e \cdot \sin\varphi_3 \cdot \dot{\varphi}_3 \\ \dot{y}_D = e \cdot \cos\varphi_3 \cdot \dot{\varphi}_3\end{cases}\begin{cases}\ddot{x}_D = -e \cdot \cos\varphi_3 \cdot \dot{\varphi}_3^2 - e \cdot \sin\varphi_3 \cdot \ddot{\varphi}_3 \\ \ddot{y}_D = -e \cdot \sin\varphi_3 \cdot \dot{\varphi}_3^2 + e \cdot \cos\varphi_3 \cdot \ddot{\varphi}_3\end{cases}\end{cases} \quad (8)$$

$$\begin{cases}\begin{cases}x_{G_4} = x_C + s_4 \cdot \cos\varphi_4 \\ y_{G_4} = y_C + s_4 \cdot \sin\varphi_4\end{cases}\begin{cases}\dot{x}_{G_4} = \dot{x}_C \\ \dot{y}_{G_4} = \dot{y}_C\end{cases}\begin{cases}\ddot{x}_{G_4} = \ddot{x}_C \\ \ddot{y}_{G_4} = \ddot{y}_C\end{cases}\end{cases} \quad (9)$$

$$\begin{cases}\begin{cases}x_J = x_K + c \cdot \cos(\varphi_3 - JKI) \\ y_J = y_K + c \cdot \sin(\varphi_3 - JKI)\end{cases}\begin{cases}\dot{x}_J = -c \cdot \sin(\varphi_3 - JKI) \cdot \dot{\varphi}_3 \\ \dot{y}_J = c \cdot \cos(\varphi_3 - JKI) \cdot \dot{\varphi}_3\end{cases} \\ \begin{cases}\ddot{x}_J = -c \cdot \cos(\varphi_3 - JKI) \cdot \dot{\varphi}_3^2 - c \cdot \sin(\varphi_3 - JKI) \cdot \ddot{\varphi}_3 \\ \ddot{y}_J = -c \cdot \sin(\varphi_3 - JKI) \cdot \dot{\varphi}_3^2 + c \cdot \cos(\varphi_3 - JKI) \cdot \ddot{\varphi}_3\end{cases}\end{cases} \quad (10)$$

$$\begin{cases}\begin{cases}x_I = x_K + e \cdot \cos\varphi_3 \\ y_I = y_K + e \cdot \sin\varphi_3\end{cases}\begin{cases}\dot{x}_I = -e \cdot \sin\varphi_3 \cdot \dot{\varphi}_3 \\ \dot{y}_I = e \cdot \cos\varphi_3 \cdot \dot{\varphi}_3\end{cases} \\ \begin{cases}\ddot{x}_I = -e \cdot \cos\varphi_3 \cdot \dot{\varphi}_3^2 - e \cdot \sin\varphi_3 \cdot \ddot{\varphi}_3 \\ \ddot{y}_I = -e \cdot \sin\varphi_3 \cdot \dot{\varphi}_3^2 + e \cdot \cos\varphi_3 \cdot \ddot{\varphi}_3\end{cases}\end{cases} \quad (11)$$

$$\begin{cases}\begin{cases}x_L = x_K + g \cdot \cos(\varphi_3 + \beta) \\ y_L = y_K + g \cdot \sin(\varphi_3 + \beta)\end{cases}\begin{cases}\dot{x}_L = -g \cdot \sin(\varphi_3 + \beta) \cdot \dot{\varphi}_3 \\ \dot{y}_L = g \cdot \cos(\varphi_3 + \beta) \cdot \dot{\varphi}_3\end{cases} \\ \begin{cases}\ddot{x}_L = -g \cdot \cos(\varphi_3 + \beta) \cdot \dot{\varphi}_3^2 - g \cdot \sin(\varphi_3 + \beta) \cdot \ddot{\varphi}_3 \\ \ddot{y}_L = -g \cdot \sin(\varphi_3 + \beta) \cdot \dot{\varphi}_3^2 + g \cdot \cos(\varphi_3 + \beta) \cdot \ddot{\varphi}_3\end{cases}\end{cases} \quad (12)$$

$$\begin{cases}\begin{cases}x_{G_5} = x_K + s_5 \cdot \cos(\varphi_3 - JKI + \gamma) \\ y_{G_5} = y_K + s_5 \cdot \sin(\varphi_3 - JKI + \gamma)\end{cases}\begin{cases}\dot{x}_{G_5} = -s_5 \cdot \sin(\varphi_3 - JKI + \gamma) \cdot \dot{\varphi}_3 \\ \dot{y}_{G_5} = s_5 \cdot \cos(\varphi_3 - JKI + \gamma) \cdot \dot{\varphi}_3\end{cases} \\ \begin{cases}\ddot{x}_{G_5} = -s_5 \cdot \cos(\varphi_3 - JKI + \gamma) \cdot \dot{\varphi}_3^2 - s_5 \cdot \sin(\varphi_3 - JKI + \gamma) \cdot \ddot{\varphi}_3 \\ \ddot{y}_{G_5} = -s_5 \cdot \sin(\varphi_3 - JKI + \gamma) \cdot \dot{\varphi}_3^2 + s_5 \cdot \cos(\varphi_3 - JKI + \gamma) \cdot \ddot{\varphi}_3\end{cases}\end{cases} \quad (13)$$

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$$\begin{cases} \begin{cases} x_{G_8} = x_F + \frac{1}{2} l_1 \cdot \cos\varphi_8 \\ y_{G_8} = y_F + \frac{1}{2} l_1 \cdot \sin\varphi_8 \end{cases} \begin{cases} \dot{x}_{G_8} = \frac{1}{2}\dot{l}_1 \cdot \cos\varphi_8 - \frac{1}{2} l_1 \cdot \sin\varphi_8 \cdot \dot{\varphi}_8 \\ \dot{y}_{G_8} = \frac{1}{2}\dot{l}_1 \cdot \sin\varphi_8 + \frac{1}{2} l_1 \cdot \cos\varphi_8 \cdot \dot{\varphi}_8 \end{cases} \\ \begin{cases} \ddot{x}_{G_8} = \frac{1}{2}\ddot{l}_1 \cdot \cos\varphi_8 - \frac{1}{2}\dot{l}_1 \cdot \sin\varphi_8 \cdot \dot{\varphi}_8 - \frac{1}{2}\dot{l}_1 \cdot \sin\varphi_8 \cdot \dot{\varphi}_8 - \\ -\frac{1}{2} l_1 \cdot \cos\varphi_8 \cdot \dot{\varphi}_8^2 - \frac{1}{2} l_1 \cdot \sin\varphi_8 \cdot \ddot{\varphi}_8 \\ \ddot{y}_{G_8} = \frac{1}{2}\ddot{l}_1 \cdot \sin\varphi_8 + \frac{1}{2}\dot{l}_1 \cdot \cos\varphi_8 \cdot \dot{\varphi}_8 + \frac{1}{2}\dot{l}_1 \cdot \cos\varphi_8 \cdot \dot{\varphi}_8 - \\ -\frac{1}{2} l_1 \cdot \sin\varphi_8 \cdot \dot{\varphi}_8^2 + \frac{1}{2} l_1 \cdot \cos\varphi_8 \cdot \ddot{\varphi}_8 \end{cases} \end{cases} \tag{14}$$

$$\begin{cases} \begin{cases} x_{G_{10}} = x_A + \frac{1}{2} l_2 \cdot \cos\varphi_{10} \\ y_{G_{10}} = y_A + \frac{1}{2} l_2 \cdot \sin\varphi_{10} \end{cases} \begin{cases} \dot{x}_{G_{10}} = \frac{1}{2}\dot{l}_2 \cdot \cos\varphi_{10} - \frac{1}{2} l_2 \cdot \sin\varphi_{10} \cdot \dot{\varphi}_{10} \\ \dot{y}_{G_{10}} = \frac{1}{2}\dot{l}_2 \cdot \sin\varphi_{10} + \frac{1}{2} l_2 \cdot \cos\varphi_{10} \cdot \dot{\varphi}_{10} \end{cases} \\ \begin{cases} \ddot{x}_{G_{10}} = \frac{1}{2}\ddot{l}_2 \cdot \cos\varphi_{10} - \frac{1}{2}\dot{l}_2 \cdot \sin\varphi_{10} \cdot \dot{\varphi}_{10} - \frac{1}{2}\dot{l}_2 \cdot \sin\varphi_{10} \cdot \dot{\varphi}_{10} - \\ -\frac{1}{2} l_2 \cdot \cos\varphi_{10} \cdot \dot{\varphi}_{10}^2 - \frac{1}{2} l_2 \cdot \sin\varphi_{10} \cdot \ddot{\varphi}_{10} \\ \ddot{y}_{G_{10}} = \frac{1}{2}\ddot{l}_2 \cdot \sin\varphi_{10} + \frac{1}{2}\dot{l}_2 \cdot \cos\varphi_{10} \cdot \dot{\varphi}_{10} + \frac{1}{2}\dot{l}_2 \cdot \cos\varphi_{10} \cdot \dot{\varphi}_{10} - \\ -\frac{1}{2} l_2 \cdot \sin\varphi_{10} \cdot \dot{\varphi}_{10}^2 + \frac{1}{2} l_2 \cdot \cos\varphi_{10} \cdot \ddot{\varphi}_{10} \end{cases} \end{cases} \tag{15}$$

$$\begin{cases} \begin{cases} x_E = x_D - l_3 \cdot \cos\varphi_1 \\ y_E = y_D - l_3 \cdot \sin\varphi_1 \end{cases} \begin{cases} \dot{x}_E = \dot{x}_D - \dot{l}_3 \cdot \cos\varphi_1 + l_3 \cdot \sin\varphi_1 \cdot \dot{\varphi}_1 \\ \dot{y}_E = \dot{y}_D - \dot{l}_3 \cdot \sin\varphi_1 - l_3 \cdot \cos\varphi_1 \cdot \dot{\varphi}_1 \end{cases} \\ \begin{cases} \ddot{x}_E = \ddot{x}_D - \ddot{l}_3 \cdot \cos\varphi_1 + \dot{l}_3 \cdot \sin\varphi_1 \cdot \dot{\varphi}_1 + \dot{l}_3 \cdot \sin\varphi_1 \cdot \dot{\varphi}_1 + \\ + l_3 \cdot \cos\varphi_1 \cdot \dot{\varphi}_1^2 + l_3 \cdot \sin\varphi_1 \cdot \ddot{\varphi}_1 \\ \ddot{y}_E = \ddot{y}_D - \ddot{l}_3 \cdot \sin\varphi_1 - \dot{l}_3 \cdot \cos\varphi_1 \cdot \dot{\varphi}_1 - \dot{l}_3 \cdot \cos\varphi_1 \cdot \dot{\varphi}_1 + \\ + l_3 \cdot \sin\varphi_1 \cdot \dot{\varphi}_1^2 - l_3 \cdot \cos\varphi_1 \cdot \ddot{\varphi}_1 \end{cases} \end{cases} \tag{16}$$

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$$\begin{cases}\begin{cases}x_{G_1}=x_E+\frac{1}{2}l_3\cdot\cos\varphi_1\\ y_{G_1}=y_E+\frac{1}{2}l_3\cdot\sin\varphi_1\end{cases}\begin{cases}\dot{x}_{G_1}=\dot{x}_E+\frac{1}{2}\dot{l}_3\cdot\cos\varphi_1-\frac{1}{2}l_3\cdot\sin\varphi_1\cdot\dot{\varphi}_1\\ \dot{y}_{G_1}=\dot{y}_E+\frac{1}{2}\dot{l}_3\cdot\sin\varphi_1+\frac{1}{2}l_3\cdot\cos\varphi_1\cdot\dot{\varphi}_1\end{cases}\\ \begin{cases}\ddot{x}_{G_1}=\ddot{x}_E+\frac{1}{2}\ddot{l}_3\cdot\cos\varphi_1-\frac{1}{2}\dot{l}_3\cdot\sin\varphi_1\cdot\dot{\varphi}_1-\frac{1}{2}\dot{l}_3\cdot\sin\varphi_1\cdot\dot{\varphi}_1-\\ -\frac{1}{2}l_3\cdot\cos\varphi_1\cdot\dot{\varphi}_1^2-\frac{1}{2}l_3\cdot\sin\varphi_1\cdot\ddot{\varphi}_1\\ \ddot{y}_{G_1}=\ddot{y}_E+\frac{1}{2}\ddot{l}_3\cdot\sin\varphi_1+\frac{1}{2}\dot{l}_3\cdot\cos\varphi_1\cdot\dot{\varphi}_1+\frac{1}{2}\dot{l}_3\cdot\cos\varphi_1\cdot\dot{\varphi}_1-\\ -\frac{1}{2}l_3\cdot\sin\varphi_1\cdot\dot{\varphi}_1^2+\frac{1}{2}l_3\cdot\cos\varphi_1\cdot\ddot{\varphi}_1\end{cases}\end{cases}\quad(17)$$

$$\begin{cases}\begin{cases}x_G=x_I-2a\cdot\cos\varphi_6\\ y_G=y_I-2a\cdot\sin\varphi_6\end{cases}\begin{cases}\dot{x}_G=\dot{x}_I+2a\cdot\sin\varphi_6\cdot\dot{\varphi}_6\\ \dot{y}_G=\dot{y}_I-2a\cdot\cos\varphi_6\cdot\dot{\varphi}_6\end{cases}\\ \begin{cases}\ddot{x}_G=\ddot{x}_I+2a\cdot\cos\varphi_6\cdot\dot{\varphi}_6^2+2a\cdot\sin\varphi_6\cdot\ddot{\varphi}_6\\ \ddot{y}_G=\ddot{y}_I+2a\cdot\sin\varphi_6\cdot\dot{\varphi}_6^2-2a\cdot\cos\varphi_6\cdot\ddot{\varphi}_6\end{cases}\end{cases}\quad(18)$$

$$\begin{cases}\begin{cases}x_H\equiv x_{G_6}=x_I-a\cdot\cos\varphi_6\\ y_H\equiv y_{G_6}=y_I-a\cdot\sin\varphi_6\end{cases}\begin{cases}\dot{x}_H=\dot{x}_I+a\cdot\sin\varphi_6\cdot\dot{\varphi}_6\\ \dot{y}_H=\dot{y}_I-a\cdot\cos\varphi_6\cdot\dot{\varphi}_6\end{cases}\\ \begin{cases}\ddot{x}_H=\ddot{x}_I+a\cdot\cos\varphi_6\cdot\dot{\varphi}_6^2+a\cdot\sin\varphi_6\cdot\ddot{\varphi}_6\\ \ddot{y}_H=\ddot{y}_I+a\cdot\sin\varphi_6\cdot\dot{\varphi}_6^2-a\cdot\cos\varphi_6\cdot\ddot{\varphi}_6\end{cases}\end{cases}\quad(19)$$

$$\begin{cases}\begin{cases}x_{G_7}=x_G+s_7\cdot\cos\varphi\\ y_{G_7}=y_G+s_7\cdot\sin\varphi\end{cases}\begin{cases}\dot{x}_{G_7}=\dot{x}_G\\ \dot{y}_{G_7}=\dot{y}_G\end{cases}\begin{cases}\ddot{x}_{G_7}=\ddot{x}_G\\ \ddot{y}_{G_7}=\ddot{y}_G\end{cases}\end{cases}\quad(20)$$

$$\begin{cases}\begin{cases}x_M=x_G+f\cdot\cos(\varphi+\theta)\\ y_M=y_G+f\cdot\sin(\varphi+\theta)\end{cases}\begin{cases}\dot{x}_M=\dot{x}_G\\ \dot{y}_M=\dot{y}_G\end{cases}\begin{cases}\ddot{x}_M=\ddot{x}_G\\ \ddot{y}_M=\ddot{y}_G\end{cases}\end{cases}\quad(21)$$

3. APPLICATIONS

Presented system can be useful in all forging oversized, and in particular to the forging manipulators (independent or on the rail) [1-12]. Railbound forging manipulators are used when is require an accuracy of positioning very high and a greater stability.

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4. CONCLUSIONS

Heavy payload forging manipulators are mainly characterized by large load output and large capacitive load input. The relationship between outputs and inputs, which will greatly influence the control and the reliability, is the key issue in type design for heavy payload forging manipulators. Forging manipulators have become more prevalent in the industry today. They are used to manipulate objects to be forged.

The most common forging manipulators are moving on a railway to have a greater precision and stability. They have been called the railbound forging manipulators. In this paper we analyse the general kinematics of the main mechanism from such manipulator.

Kinematic scheme shows a typical forging manipulator, with the basic motions in operation process: walking, motion of the tong and buffering. The lifting mechanism consists of several parts including linkages, hydraulic drives and motion pairs. Hydraulic drives are with the lifting hydraulic cylinder, the buffer hydraulic cylinder and the leaning hydraulic cylinder, which are individually denoted by c1, c2 and c3. In lifting process, the cylinder c1 controls the vertical movement of work piece through inputting lifting signal. At the same time, the cylinders c2 and c3 are perfectly closed. While c1 and c3 are closed cylinders, cylinder c2 performs horizontal movement. While, the cylinders c1and c2 are closed the cylinder c3 realizes leaning movement by inputting leaning signal in leaning condition.

In direct kinematics one knows l1, l2 and must be determined: intermediary l3, FI1, FI3, FI6, FI8, FI10 and finally xM, yM. In inverse kinematics one knows xM, yM (imposed) and must be determined FI1, FI3, FI6, FI8, FI10, l1, l2, l3 so that the FI angle keeps its constant value (FI=PI-TETA) to maintain permanently the segment GM horizontally.

In this work we are solving positions (in inverse kinematics) with systems V, VI. When we know all these parameters (angles and lengths) one may determine all kinematics parameters. The concept of modelling method based on the outputs tasks is defined and investigated. The principle of type design from the viewpoints of the relationship between output characteristics and actuator inputs is discussed. An idea of establishing the incidence relationship between output characteristics and actuator

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inputs is proposed. These novel forging manipulators which satisfy certain functional requirements provide an effective help for the design of forging manipulators.

Presented system can be useful in all forging oversized, and in particular to the forging manipulators (independent or on the rail). Railbound forging manipulators are used when is require an accuracy of positioning very high and a greater stability.

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