

Defining a Service Angle for Planar Mechanisms of Manipulators based on the Instantaneous States Analysis

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Abstract. The paper provides an algorithm of defining a service angle for planar mechanisms of manipulators having different structures of kinematic chains. The algorithm is based on the motion synthesis in the vector of velocities. The functions defining specified angle determination accuracy by the developed method are obtained.

1. Introduction

The development of universal algorithms that enable us to explore the functionality of manipulators mechanisms is still a crucial task [1-4]. A virtual construction of the manipulator motion implementing the method of instantaneous states allows one to predict fine precision motion of a real mechanism and its interference with known in advance objects of the environment. The method is based on the division of the planned path of the output link into segments and finding a configuration relevant to a motion volume minimization criterion (under motion redundancy). If there are forbidden zones in the service area of a manipulator the use of the configuration relevant to the motion minimization criterion is unlikely to be practical. If that is the case, it is necessary for the intelligent control system to search for different configurations that provide output link shifting to the target point with the required positional accuracy and choose those ones providing avoidance of the forbidden zones, minimum power losses being desirable. A method of searching arrays of configurations defining the service angle based on the instantaneous states analysis of planar mechanisms of manipulators is proposed.

2. The analysis of instantaneous states implementation

The convention is that the value of the generalized velocities vector relevant to the volume minimization criterion is defined as point M^Q . Index Q means pertaining to multidimensional space of generalized velocities Q_n . Figure 1 shows two configurations of a planar seven-link mechanism of the manipulator, links lengths being equal to 120 mm. Figure 1 also represents the results of the instantaneous states implementation under the specified velocity vector of output link $V(V_x, V_y) - V_x = 1$ mm/s, $V_y = 0$ and position accuracy $\delta \leq 1$ mm. Parameter $r = 2$ assigns vector length V , the orientation of the output link not being considered. The sets of configurations relevant to $\delta \leq 1$ mm are obtained by applying AutoCAD and algorithmic programming language AutoLISP. The arrays of configurations are constructed as follows. Point M^Q in the space of generalized velocities Q_n is known to be found with the linear system of equations reflecting dependence of V and Q , where Q is the vector of generalized velocities of length n . In addition to the equations expressing individual components of vector V (output link linear motions) the system (in case $n > r$) uses the equation of



complementary mutually perpendicular planes, their amount being equal to the length of p -plane, determining motion redundancy. Normals of the complementary planes reduced to unit vectors $Q_{l1}, Q_{l2}, \dots, Q_{lp}$ specify an orthonormal basis in coordinate system O_k^Q defining point position N^Q in p -plane about point M^Q . System O_k^Q coordinates are determined by means of parameters $k_1, k_2, \dots, k_p$ defining point N^Q motion length towards vectors $Q_{l1}, Q_{l2}, \dots, Q_{lp}$ accordingly. The vector equation defining point N^Q position in space Q_n is as follows:

$$Q_N = Q_M + k_1 Q_{l1} + k_2 Q_{l2} + \dots + k_p Q_{lp}, \quad (1)$$

Where Q_M and Q_N – vectors defining M^Q and N^Q points position in space Q_n . Thus, implementation of vector Q_N values with parameter δ allows constructing zone of A^Q configurations. Figure 1a, b shows that the angle formed by a gripping device for two different configurations corresponds to zones A^Q and equals one and twenty four degrees and it does not detect the service angle.

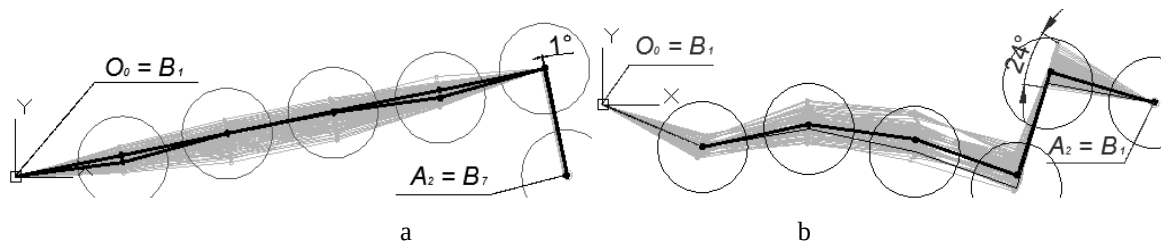


Figure 1. Zone A^Q defining manipulator configuration arrays.

3. Defining a service angle implementing instantaneous states

The accuracy of detection of angle U_p , which with certain assumptions detects service angle U_p will be examined with the use of the developed algorithm based on instantaneous states implementation. To configure the mechanism shown in Figure 2a, the service angle specified by the position of segments $B_6^1 B_7$ and $B_6 B_7$ for the point of service zone $A_2 = B_7$ is detected by an intersection of two circles. The centers of the circles specified coincide with points O_o and A_2 , their radii being equal to $120 \cdot 5 = 600$ mm and 120 mm, respectively. To configure the datum of the gripper unit center position determined by A_2 ($q_1 = 11.5^\circ$, $q_{2-5} = 0$, $q_6 = 90^\circ$) the service angle specified equals to 169° , where parameters q_i determine the values of generalized coordinates. Points $B_1 \div B_7$ in Figure 2 define the node points of mechanisms. Thus, to configure the mechanism in Figure 2b the service angle is determined by the position of segments $B_6 B_7$ and $B_6^1 B_7$. For the mechanism given the limited values of the generalized coordinates prescribing the translational motions of joints are predetermined with inequality $50 \text{ mm} \geq \varphi_{1-2} \geq 0$, values of generalized coordinates being $\varphi_3 = 11.5^\circ$, $\varphi_{4-5} = 0^\circ$, $\varphi_6 = 90^\circ$, the service angle of the mechanism equals 151° . Point B_6^1 is determined as the tangency point of line l with circle a_o , its radius being defined by segment $B_7 B_6$ and it equals 120 mm. Here $B_3^1 \in l$, $B_3^1 = l_1 \cap a_1$, where $\in$ and $\cap$ denote the relation of the membership and intersection, respectively. In Figure 2b the distance between vertical line l_1 and origin of the fixed coordinate system is 50 mm, a_1 is a circle with the centre at point B_7 , its radius being defined by segment $B_3 B_7$.

Let us define the aggregate of angle U_p values implementing instantaneous states for the configurations of the mechanism, whereby point A_i (the gripper centre) is in segment $A_1 A_3$. The length of the segment equals the double length of the link ($A_1 A_3 = 240$ mm, wherein $\varphi_{2-5} = 0^\circ$ for the configuration under study).

We shall consider seven different positions of point A_i in segment A_1A_3 . Neighboring points A_i are at a distance of 30 mm. The output links of two configurations calculated during the start and k iterations (Figure 2a) determine angle U_m^k . The angle between segments B_6B_7 and $B_6^1B_7$ determines the angle specified, wherein $U_m^k = U_2 - U_1$. We shall construct the aggregate of configurations implementing instantaneous states, the value of angle U_m^k being changed counterclockwise. This value is more than value U_m^{k-1} , calculated during the previous iteration. The starting position of the mechanism configuration (Figure 2a) for point A_2 corresponds to the values of generalized coordinates $q_1 = 11.5^\circ$, $q_{2-5} = 0$, $q_6 = 90^\circ$.

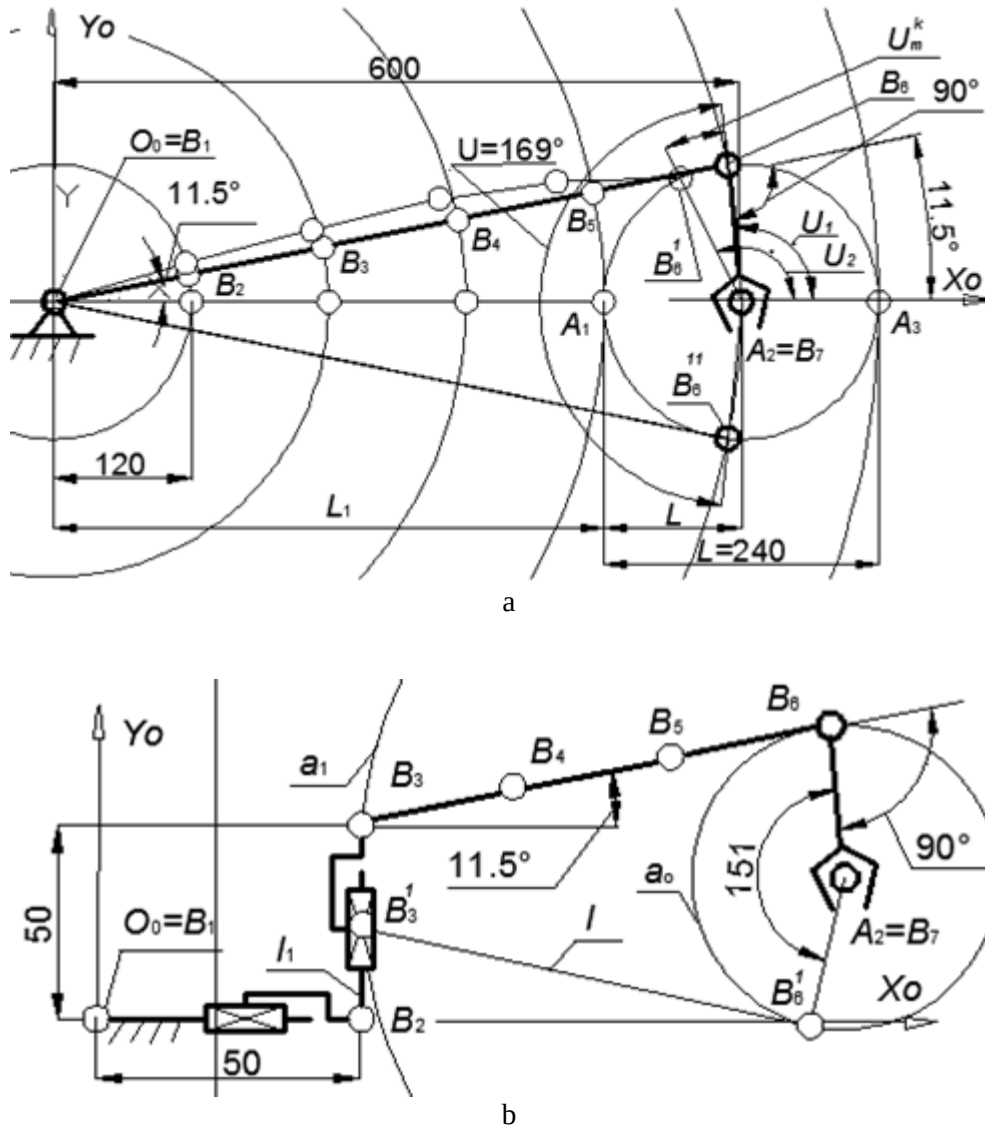


Figure 2. Determination of service angle U using graphic constructions.

Angle $U_m^k = 0$ for the configuration given. An important point is that at each calculation step the maximum value of angle $(U_m^k)^{\max}$ is defined based on values U_m^k and U_m^{k+1} :

$$(U_m^k)^{\max} = \max(U_m^k, U_m^{k+1}).$$

As soon as the configuration satisfying the conditions is defined as

$$U_m^{k+1} > (U_m^k)^{\max}, \quad (2)$$

$$\delta < \delta_{\min}, \quad (3)$$

the next $(k+2)$ configuration is determined, the list of generalized coordinates $q_{pi} = q_i$ being retained. Parameter $\delta_{\min}$ imposes the prescribed positioning accuracy. Here the $(k+1)$ configuration is counted as the initially prescribed configuration, conditions (1, 2) being satisfied for that configuration. The case considered corresponds to the synthesis of link B_6B_7 motions rotating about point B_7 counterclockwise. If we consider the motion of link B_6B_7 rotating clockwise, condition (1) B_6B_7 is substituted by the following condition:

$$\begin{aligned} (U_m^k)^{\min} &= \min(U_m^k, U_m^{k+1}), \\ U_m^{k+1} &< (U_m^k)^{\min}. \end{aligned} \quad (4)$$

We use variable kk to define the rotation variant: when $kk = 0$, the counterclockwise rotation is considered; when $kk = 1$, clockwise rotation is viewed.

The algorithm of constructing configurations satisfying conditions (2-4) is shown in Figure 3.

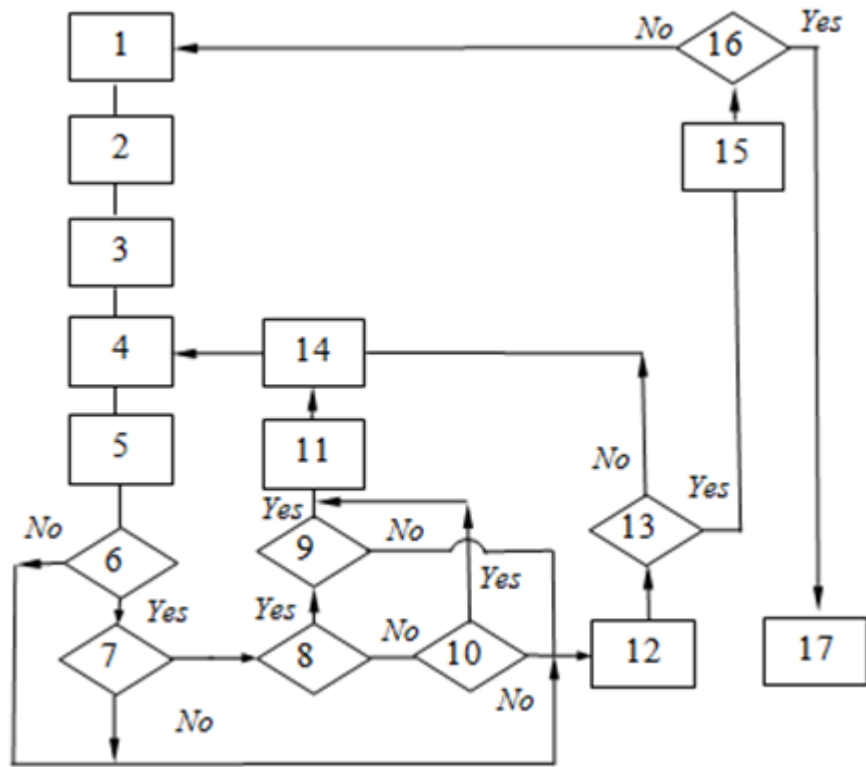


Figure 3. A diagram of constructing the angle U_p algorithm implementing instantaneous states.

The following notations are used in Figure 3: 1 – start, determining the value of vector L_n ($q_1, \dots, q_6$) and parameter kk ; 2 – calculation of point A_i of the service zone, the target point and vector V ; 3 – calculation of the matrix of particular gear ratios J and vector Q with the criterion of minimizing the motion range; 4 – calculation of the configuration L_n^{k+1} position corresponding to vector Q , $q_i := q_i + \dot{q}_i$ (assumption $\Delta q_i \approx q_i$ is admitted); 5 – calculation of implementations errors δ ; 6 – conditional test $\delta < \delta_{\min}$; 7 – conditional tests $q_i^{\min} > q_i > q_i^{\max}$, where $q_i^{\min}, q_i^{\max}$ – prescribed limit values of generalized coordinates (calculating test cases $q_i^{\min} = -180^\circ, q_i^{\max} = 180^\circ$); 8 – $kk = 0$; 9 – $U_m^{k+1} > (U_m^k)^{\max}$; 10 – $U_m^{k+1} < (U_m^k)^{\min}$; 11 – configuration of image formation: $kk=0$ value assignment $\Rightarrow (U_m^k)^{\max} := \max(U_m^k, U_m^{k+1})$, $kk = 1 \Rightarrow$ value assignment $(U_m^k)^{\min} := \min(U_m^k, U_m^{k+1})$, $q_{pi} = q_i$, where q_{pi} – list of generalized coordinates satisfying conditions (2), (3) or (3), (4), q_i – list of generalized coordinates of the current configuration; 12 – parameters $k_1, k_2, \dots, k_4$ values change

defining coordinates of point N^Q in p -plane I ; 13 – $k_1 > k^{\max}$, $k_2 > k^{\max}$, ..., $k_4 > k^{\max}$ (where $k^{\max}$ – limit – prescribed largest extremum experimentally determined in research process $k^{\max} = 20$); 14 – calculation of vector Q for $k_i \neq 0 q_i = q_{pi}$; 16 – $U_m^{k+1} = (U_m^k)^{\max}$; 17 – end.

In Figure 4 and Figure 5 the synthesis of motions to determine angle U_p using dependences (1-2) for three mechanism configurations studied is shown.

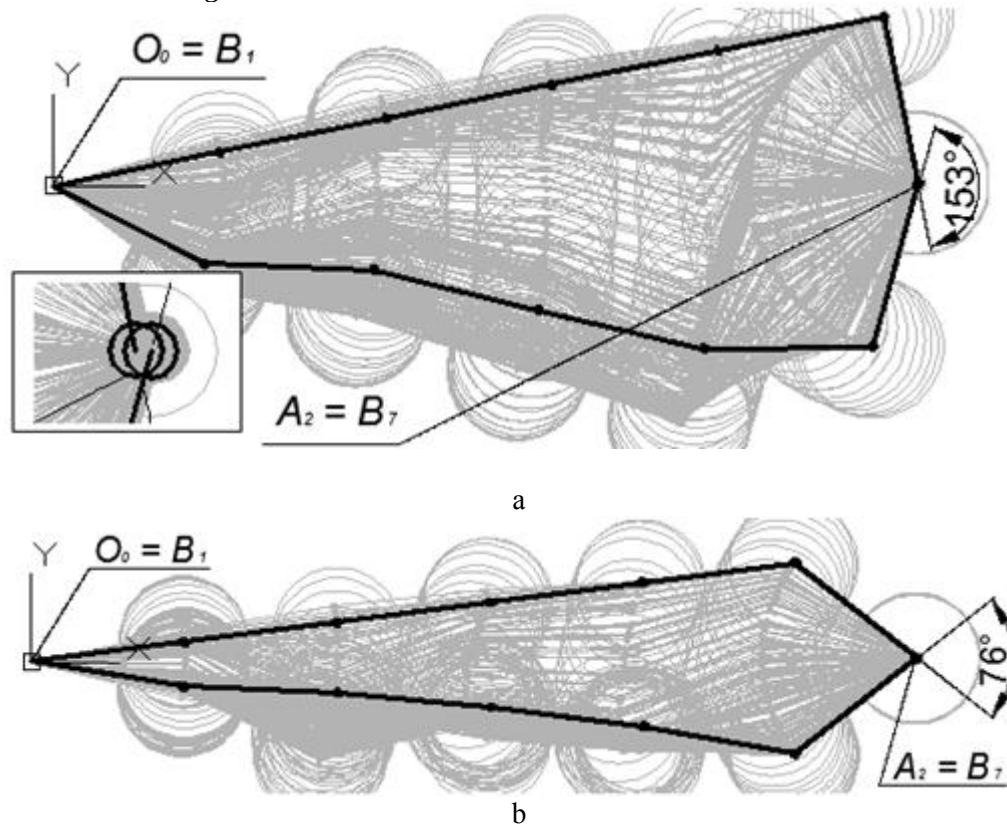


Figure 4. Determining angle U_p by implementation of instantaneous states: a – ($q_1 = 11.5^\circ$, $q_{2-5} = 0$, $q_6 = 90^\circ$); b – ($q_1 = 7.4^\circ$, $q_{2-5} = 0$, $q_6 = 45.5^\circ$).

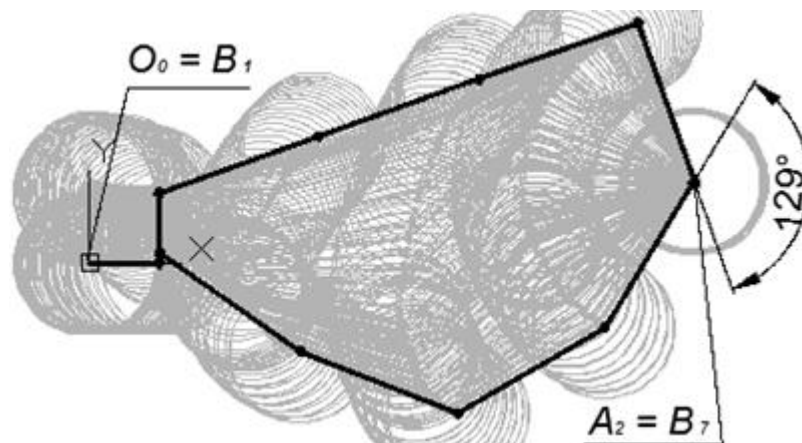


Figure 5. Determining angle U_p by implementation of instantaneous states ($\varphi_{1-2} = 50$ mm, $\varphi_3 = 11.5^\circ$, $\varphi_{4-5} = 0$, $\varphi_6 = 90^\circ$).

In Figures 6 and 7 the dependency graphs $U_{p3} = f_1(L)$, $U_{p4} = f_2(L)$, $U_{p5} = f_3(L)$, $U_{p6} = f_4(L)$ and $\mu_3 = f_1(L)$, $\mu_4 = f_2(L)$, $\mu_5 = f_3(L)$, $\mu_6 = f_4(L)$ are shown. These graphs reflect the angle U_p variation and accuracy percentage μ of service angle determination for four-, five-, six- and seven – link planar mechanisms (Figure 2a) having link lengths equal to 120 mm.

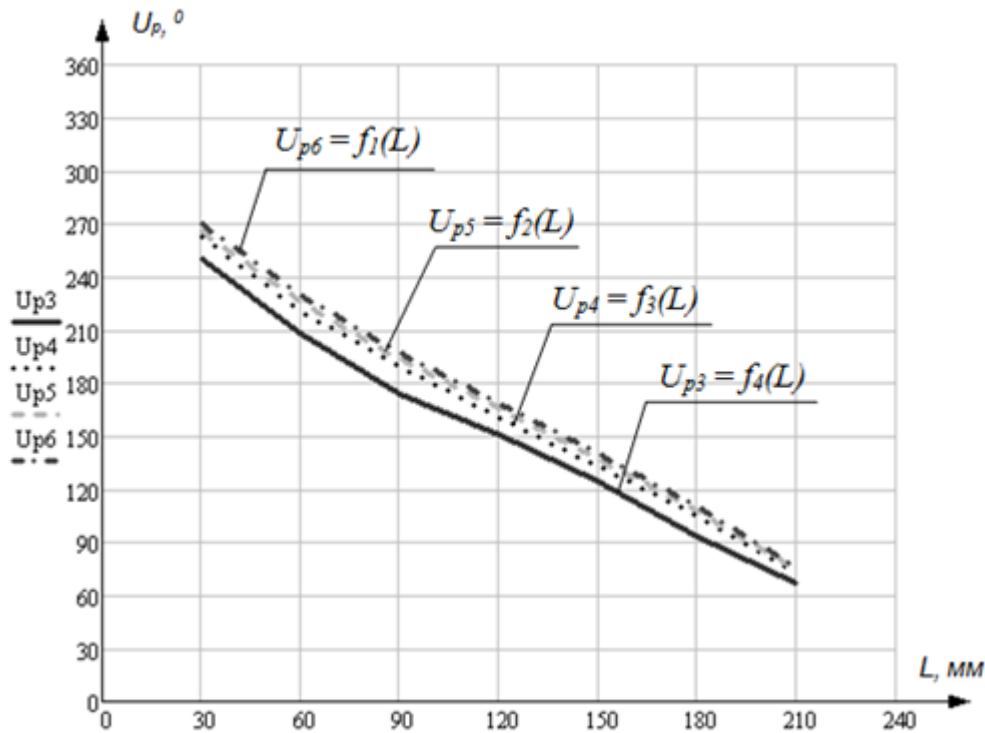


Figure 6. Dependency graphs $U_{pn} = f_1(L)$.

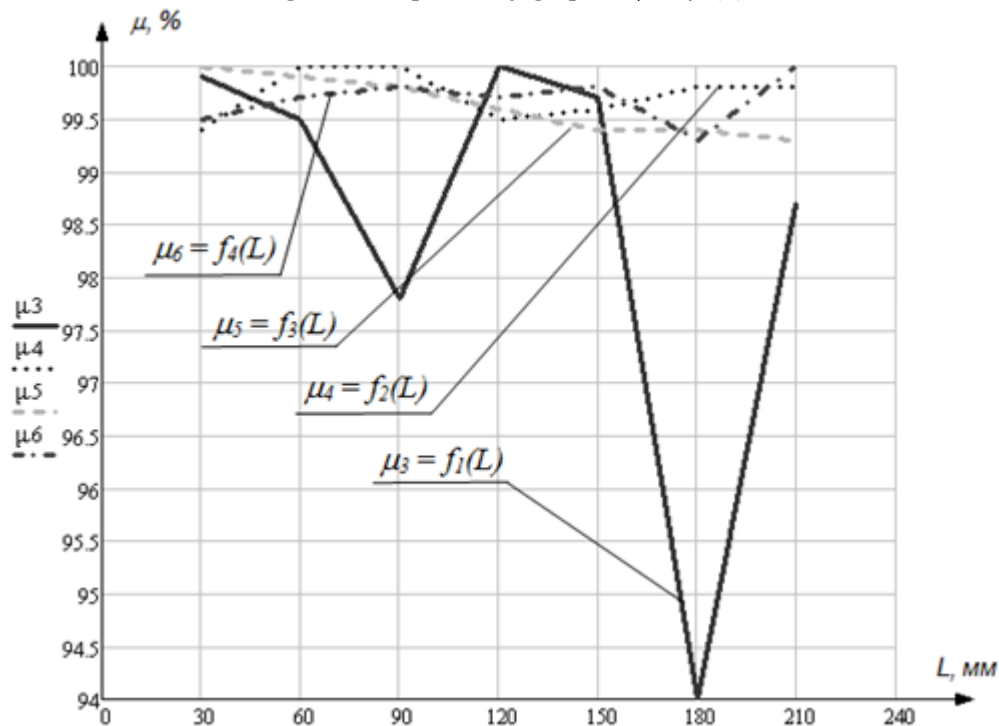


Figure 7. Dependency graphs $\mu_n = f_1(L)$.

The accuracy percentage is calculated using dependence $\mu = U_p/U \cdot 100$, where the service angle or parameter U was determined graphically. Parameter L defines deploach of point A_i from point A_1 (Figure 2a). Point A_1 for the mechanisms specified holds at distance $L_1 = 120 \cdot (n - 2)$ from origin O_o . The analysis of functions graphs shows the accuracy percentage of the service angle defined by the method developed for the mechanism in Figure 2a for $\delta_{min} \leq 1$ mm, where is from 94 to 100 percent depends on the position of the gripper center in segment A_1A_3 . The accuracy percentage for $\delta \leq 3$ mm is from 80 to 85 percent for the mechanism shown in Figure 2b.

4. Conclusion

The proposed algorithm of determining angle U_p with certain assumption defining the service angle is described as universal and can be used for manipulators having a random structure of planar kinematic chains, a random degree of motion redundancy and prescribed limited values of generalized coordinates. The construction of solid angles projections using the algorithm proposed is possible for spatial mechanisms of robots. The method of the output link reorientation can be applied for intelligent robot control systems to change the output link orientation relative to the prescribed objects of manipulation.

References

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