THE OPTIMIZATION OF THE GEOMETRIC PARAMETRES OF THE FIVE-BAR MANIPULATOR ACCORDING TO THE GIVEN WORKSPACE USING THE METHOD OF THE GENETIC ALGORITHM

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Abstract: In the last years, the manipulators with parallel topology have begun to be more and more used because of their unexploited potential. The usage of the manipulators with parallel topology instead of the manipulators with serial topology presents a series of advantages. A disadvantage of the usage of the manipulators with parallel topology would be the dimension of the workspace which is limited. Within this paper, the authors optimize the geometric parameters of the five-bar manipulator according to the given workspace by using the method of the genetic algorithms. The method helps the designer to dimension the geometrical parameters according to the workspace which is demanded.

Keywords: five-bar manipulator, optimization of the geometric parameters, the method of the genetic algorithm.

1. INTRODUCTION

In the last decade, the manipulators which contain mechanisms with parallel topology have begun to be more and more used because of their unexploited potential. Comparing the performances of the manipulators with parallel topology with the performances of the manipulators with serial topology, it is found the usage of the parallel topology presents a series of advantages: high rigidity, reduced mass, good dynamic behaviours, superior positioning accuracy [1]

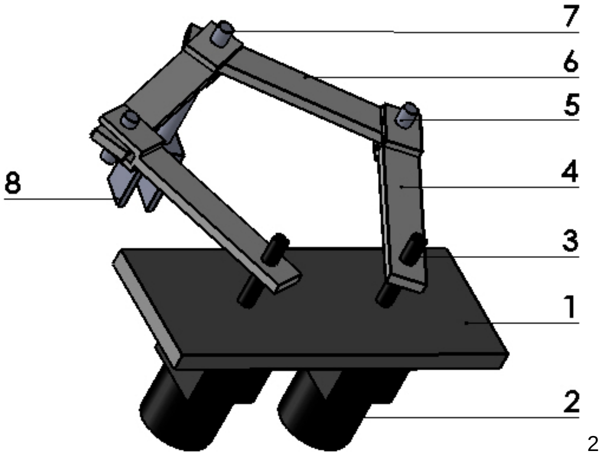

Fig.1. The CAD model of the five-bar manipulator: 1-fixed platform; 2-rotational drive system; 3-kinematic active pair of rotation; 4-conducting element; 5-kinematic passive pair of rotation; 6-conducted elements; 7-kinematic passive pair of rotation; 8-end-efectorul.

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A five-bar manipulator is one of the simplest manipulators which can be used for the positioning of the end-effector in several points of the plane workspace. The CAD model of a manipulator of this type can be visualized in figure 1. In figure 1, it can be found that this manipulator is driven within two rotational driving systems -2 positioned of the fixed platform -1. The rotational driving systems transmit the movement to the conducting elements-4 within the kinematic active pair of rotation -3. The conducting elements-4 transmits the movement within the kinematic passive pair of rotation -5 to the conducted elements -6. The two conducted elements -6 are interconnected within the kinematic passive pair-7. By the centre of the kinematic passive pair -7 the end-effector is caught -8 [1], [2], [3].The two kinematic chains are identical from the constructive point of view.

A disadvantage of the manipulators with parallel structure would be the dimension of the workspace, space which is fairly limited compared to the manipulators with serial structure. In these conditions, an optimization of the geometric parameters according to the volume of the given workspace or of the points which must be reached is necessary.
The movement of the end-effectors within the robots in the workspace can be limited by many factors such as: the constructive limits of the kinematic passive pair, the limits given by the driving devices from the kinematic active pair, cohesions given by the constructive elements of the robot as also points or areas of singularity which can divide the workspace in different component parts.

2. KINEMATIC ANALYSIS OF FIVE-BAR MANIPULATOR

The determination of the kinematic models, within the parallel robots can be realized on the basis of the positioning equations (on the basis of the method of contours), written for each kinematic chain from the structure of the mechanism.

The kinematicfive-bar manipulator model can be visualized in figure 2. From this figure, it is found that this manipulator contains two identical kinematic chains identical from the constructive point of view.

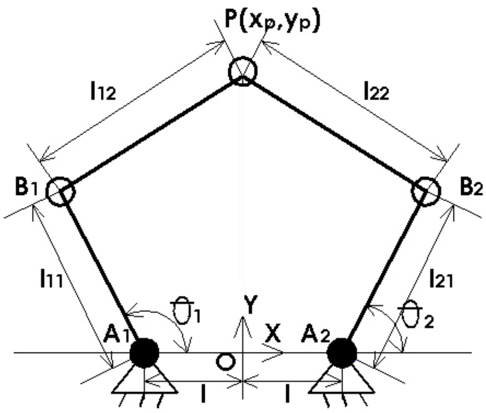

Fig.2.A five-bar manipulator kinematic model.

According to the kinematic scheme, it can be written the following equation of the closing of the kinematic chains, in which $i = 1,2$is the kinematic chain to which we refer [1], [2], [3].

$$\overline{OA_i}, +\overline{A_iB_i} + \overline{B_iP_i} = \overline{OP} \tag{1}$$

Developing the equation of the closing of the kinematic chain, we can write:

$$B_1(x_{B1}, y_{B1}) = [l_{11}\,cos(\theta_1) - l, l_{11}\,sin(\theta_1)]^T \tag{2}$$

$$B_2(x_{B2}, y_{B2}) = [l_{21}\,cos(\theta_2) + l, l_{21}\,sin(\theta_2)]^T \tag{3}$$

In order to eliminate the articulated variables from the passive kinematic pair with the purpose to simplify the final equations, the movement of the kinematic conducted elements delimited by the segments$\overline{B_i P_i}$is expressed with the help of the sphere equation. So, the final equations of closing the kinematic chains are$(i = 1,2)$:

$$(x_p - l_{i1} cos(\theta_1) + l)^2 + ((y_p - l_{11} sin(\theta_1))^2 = l_{i2}^2 \tag{4}$$

$$(x_p - l_{i1} cos(\theta_2) - l)^2 + ((y_p - l_{i1} sin(\theta_2))^2 = l_{i2}^2 \tag{5}$$

The solutions of the inversekinematic model supposethe determination of the articulated coordinates θ_1, θ_2according to the coordinates of the end-effector. From equations (4) and (5) making the needed substitution, the solutions of the inversekinematic model are [1]:

$$\theta_i = 2tan^{-1}\left(\frac{-b_i \pm \sqrt{\Delta_{in}(x_{Pn}, y_{Pn}, l_{i1}, l_{i2})}}{2a_i}\right) \tag{6}$$

Where:

$\Delta_{in}(x_{Pn}, y_{Pn}, l_{i1}, l_{i2}) = b_i^2 - 4a_i c_i$
$b_i = -4y_p l_{i1}$
$a_i = -l_{i2}^2 + 2x_p l_{i1} \pm 2ll_{i1} + l_{i1}^2 + y_p^2 + (x_p \pm l)^2$
$c_i = -l_{i2}^2 - 2x_p l_{i1} \mp 2ll_{i1} + l_{i1}^2 + y_p^2 + (x_p \pm l)^2$(7)

On the basis of the solutions of the inversekinematic model, it can be analysed if a point $P_n(x_{Pn}, y_{Pn})$belongs to the workspace or not, such as:

$$\Delta_{in}(x_{Pn}, y_{Pn}, l_{i1}, l_{i2}) \geq 0 \text{and} \theta_{i1} \in [\theta_{i1min} \dots \theta_{i1max}] => P_n(x_{Pn}, y_{Pn}) \in V \tag{8}$$

$$\Delta_{in}(x_{Pn}, y_{Pn}, l_{i1}, l_{i2}) \leq 0 \text{and} \theta_{i1} \notin [\theta_{i1min} \dots \theta_{i1max}] => P_n(x_{Pn}, y_{Pn}) \notin V \tag{9}$$

The forwardkinematic model consists in the determination of the coordinates of the end-effector$P_n(x_{Pn}, y_{Pn})$according to the articulated coordinatesθ_1, θ_2. The solutions of the forwardkinematic model can be determined by forming a system of equations (4) and (5).

Singularities in the kinematic model appear when the determining factor of the Jacobean matrix is zero. In the moment when the configuration of the parallel mechanism reaches one of the singular positions, it cannot be controlled. The stable working of the manipulator imposes the avoiding of these areas where the singular positions are. Within the five-bar manipulator, the singularities which appear divide the workspace in several areas of functioning. An analysis of the areas where these singularities appear, on the workspace, was realized by Gonçalves R. S.et. all in the paper [1].

3. THE FORMULATION OF THE METHOD OF OPTIMIZATION OF THE GEOMETRIC PARAMETERS ACCORDING TO THE GIVEN WORKSPACEOF THE FIVE-BAR MANIPULATORBY USING THE METHOD OF THE GENETIC ALGORITHMS

The problem of optimization consists in the determination of the minimal constructive dimensions when the workspace is give under the shape of several points which must be reached, which describe a volume. So, it will be demanded [4]:

$$min \; F(l_{i1}, l_{i2}), \text{so that} P_n(x_{Pn}, y_{Pn}) \in V \tag{10}$$

In which:
$P_n(x_{Pn}, y_{Pn})$-the coordinates of the points which are wished to be inside the workspace $(n = 1,2, \dots n_p)$;
n-points which must be reached by the manipulator$(n = 1,2 \dots n_p)$;

n_p-number of points which must be reached by the manipulator;
V-volume of workspace of five-bar manipulator.
For the determination of the constructive dimensions according to the maximum volume or according to the points which must be reached, several methods of optimization must be used. One of the most used methods which determine the discovery of solutions which are acceptable in a relative short time is the method of the genetic algorithms [5][7].
The method of the genetic algorithms is a method based on the evolutionist theory of the beings which apply the principle that the populations of individuals which prove to be more adaptable will survive.
The solving of a problem by using the method of the genetic algorithms supposes the codification of the possible solutions of a problem under the shape of a structure of data of type chromosome, then to these chromosomes, are applied algorithms of recombination in order to produce new chromosomes (new solutions) [5].
These data structures are evaluated and facilities are allocated for the reproduction of the chromosomes which represent a better solution for the targeted problem [5][8].
The function of evaluation is also called the objective function and represents a measure of evaluation of the population of chromosomes.By the usage of this algorithm to several populations of chromosomes, will determine the generation of solutions very closed to the targeted solution [5].The logical scheme of optimization of the geometric parameters according to the given workspace of the five-bar manipulator, by using the method of the genetic algorithms can be visualized in figure 3.

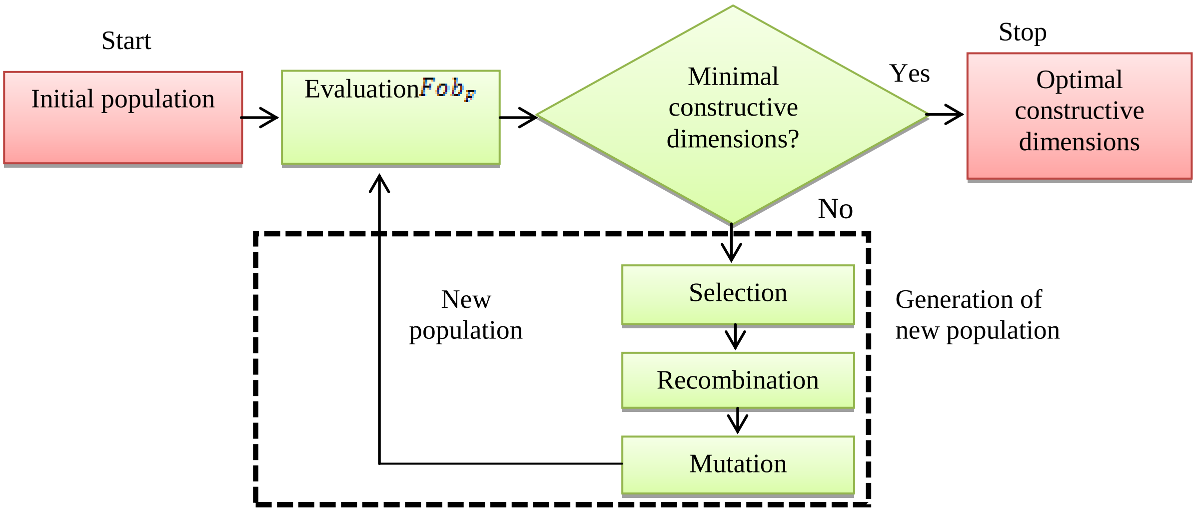

Fig.3. Logical schemeof optimization by using the method of genetic algorithms [4], [5].

So that the generated solutions for the constructive dimension $l_{i1}, l_{i2}$to be optimal, two conditions should be accomplished:
1. The$n$points analysed should be inside the workspace (for the constructive dimensionsl_{i1}, l_{i2}generated$(i = 1{,}2)$) [4].
For each analysed point$P_n(x_{Pn}, y_{Pn})$having constructive generated dimensions l_{i1}, l_{i2}it will be verified if the inversekinematic model has a solution for each of the two kinematic chains$(i = 1{,}2)$.
If the inverse kinematicmodel has no solution, the articulated coordinatesθ_1, $\theta_2$do not fit in the limits of maximum and minimum given by the mechanical restrictions or the analysed point $P_n(x_{Pn}, y_{Pn})$is placed in a singular position, then the point does not belong to this workspace.

2. The solution of the final objective function Fob_Fshould have a value as small as possible [4].
The objective function for the point$n$can be written:

$$f_n(x_{Pn}, y_{Pn}, l_{i1}, l_{i2}) = \sqrt{(\Delta_{1n}(x_{Pn}, y_{Pn}, l_{11}, l_{12}))^2} * \sqrt{(\Delta_{2n}(x_{Pn}, y_{Pn}, l_{21}, l_{22}))^2} \quad (11)$$

In order to find the minimal constructive dimensions, in the final objective function must be introduced a condition which should take into consideration the sum of the constructive lengths. So, the total objective function will be penalized with a value given by the equation (12), within the process of finding the optimal values.

$$Pen_1 = \frac{l_{i1} + l_{i2}}{100} \quad (12)$$

Along the process of optimization, if:$\Delta_{in} < 0$ or the articulated coordinatesθ_1, $\theta_2$do not fit to the limits of maximum and minimum given by the mechanical restrictions or if the condition of avoiding the points in which the singularities appear is not respected, for a point or more, it means that the found values for the constructive dimensions l_{i1}, l_{i2}will not be placed one or more from the analysed points$P_n(x_{Pn}, y_{Pn})$inside the useful workplace $(i = 1{,}2)$. In this case, the objective function will be more penalized in the process of finding the optimal values with a value as high as possible, which cannot be a minimum$Pen_2 = ct$. So, new values for the constructive dimensions will be generated.
The final objective function for the$n$points analysed presented with the help of the equation(13) is given by the product between the sum of the functions objective calculated for each point which belongs to the workspace and the coefficient of penalty or not, coefficient of penalty two.

$$Fob_F = \sum_1^n (f_n * Pen._1 * Pen._2) \tag{13}$$

Along the process of optimization, on the basis of the progressive algorithms will be generated values for the constructive dimensions: l_{i1}, l_{i2}as good as possible till the objective functionFob_Fwill have the lowest value as possible$(i = 1{,}2)$. The finding of the minimum of the function$Fob_F$is correlated with the finding of the optimal constructive dimensions.

4. RESULTS AND DISCUSSION

Within the optimization of the geometric parameters, the workspace can be given under the shape of points which design a trajectory or under the shape of a geometric shape, so the workspace was optimized from the point of view of a set of points which describe a geometric shape: a square and a triangle.
In order to avoid the appearance of the singularities, the manipulator was constraint to function in the area of the workspace presented with the help of figure 4, the shaded area. So, in the moment in which$y_{Pn} \leq y_{Bi}$the total objective functionFob_Fwill be penalized with coefficient$Pen._2 = 1.5 (i = 1{,}2)$.

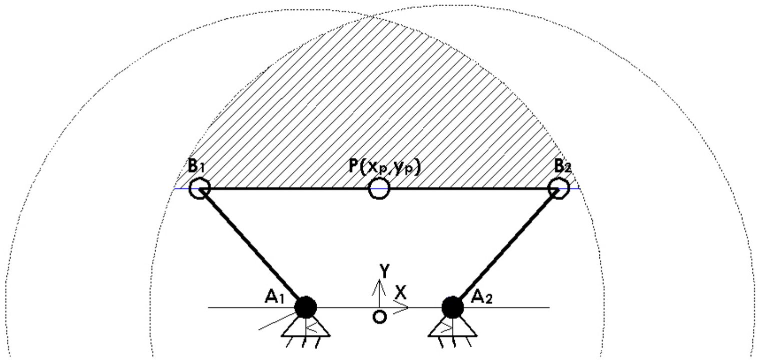

Fig.4. The area of the useful workspace

Within the optimization of the workspace from the point of view of a set of points which form a volume, the maximum coordinates of the points which must be reached by the end-effector are known and the minimum constructive dimensions are demanded.
For each constructive variable a variation interval was used. The constructive lengths can take values in a certain interval (minimum-maximum). The establishment of the variation intervals is made according to the minimal constructive dimensions of placement within the robot, of some subassemblies such as the placement of: servomotors, sensors, end-effectors .etc.The driving articulated coordinates were constrains to vary in the following intervals$\theta_{i1} \in [0^0 \dots 180^0]$. If, within the process of finding the optimal $\theta_{i1} \notin [0^0 \dots 180^0]$the total objective function Fob_Fwill be again penalized with the penalty coefficient $Pen._2 = 1.5 (i = 1{,}2)$. From constructive reasons, the length of the element *l*was established as being 20 [mm].
The theoretical results obtained within the optimization of the geometric parameters from the point of view of a set of points which form: a square and a triangle and also the limits imposed in which the kinematic elements can vary, are presented in table 1.

Table1.The theoretical results obtained within the optimization of the geometric parameters from the point of view of a set of points which form: a square and a triangle
$(i = 1,2)$

Case	The coordinates of the points which must be reached	The constructive values resulted after the minimisation	
	$P_n(x_{Pn}, y_{Pn})$ [mm]	l_{i1} (10<l_{i1}<80) [mm]	l_{i2} (10<l_{i2}<80) [mm]
1.	$P_1(12.5, 25)$ $P_2(12.5, 50)$ $P_3(-12.5, 50)$ $P_4(-12.5, 25)$	23.5	42.2
2.	$P_1(0, 40)$ $P_2(25, 40)$ $P_3(12.5, 64)$	29.8	44.0

The constructive dimensions found for the five-bar manipulator,within the two cases analysed were verified in the package CAD SolidWorks.

5. CONCLUSIONS

As a result of the optimization of the constructive dimensions of the five-bar manipulatorfrom the point of view of the given workspace by using the method of the genetic algorithms, it is found that:
1. The usage of the genetic algorithms in the optimization of the workspace determines the obtaining of minimum solutions for the constructive dimensionsl_{i1}, l_{i2}in a relative short time$(i = 1,2)$.
2. The constructive optimization from the point of view of the workspace is needed in the domains in which is demanded the design of robots specialised for specific operations;
3. The method of genetic algorithms will generate solutions for the constructive dimensions l_{i1}, l_{i2}till the moment in which it will be found the proportions of the constructive dimensions which give the maximum volume$(i = 1,2)$;
4. For a more detailed definition of the useful workspace more points can be chosen to be placed inside the workspace.

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