Dimensional Synthesis of a Six-bar Shaper Mechanism with the Genetic Algorithm Optimization Approach

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***Abstract*—This paper provides an approach based on the genetic algorithm for the dimensional synthesis of a six-bar mechanism for a shaper machine. The main purpose of the optimization algorithm is to maintain the velocity of the mechanism's slider constant within a specified range of the rotational motion of the input link. Therefore, first, an objective function is defined for the slider. Then, the velocity function of the slider is calculated using a set of mathematical relationships and the mechanism's kinematic constraints. In order for this function to reach the objective function, a cost function is defined. This cost function is minimized, and the output approaches the objective function by selecting the appropriate parameters for the mechanism. To this end, four accuracy points are selected within a specific range of motion of the input link. Subsequently, the distances between the points on the velocity function of the slider and the predetermined function are calculated at these four points. The goal is to minimize these four distances. Hence, a cost function is defined in the form of the squares of the sums of these distances and is minimized using the genetic algorithm. Therefore, this cost function is used to minimize the error between the desired points and the points generated by the mechanism and can be affected by factors such as the lengths of the links, the transmission angles, the Grashof condition, and the mechanism type. In the genetic algorithm, the population, crossover, or mutation determines the accuracy of the results. The purpose of this research is to find the optimal dimensions of the links in order to minimize the error between the ideal and actual slider velocity functions. Ultimately, a numerical example is provided where the optimal dimensions are suggested by the optimization algorithm.**

***Keywords*—Shaper, mechanism, optimization, genetic algorithm**

I. Introduction

Machining is one of the most useful processes for manufacturing industrial parts. The quality of a piece undergoing machining procedures is measured in terms of surface roughness. Surface quality is, in turn, determined by the machining parameters and the geometrical properties of the tool. Various mechanisms are used to perform machining. The shaper mechanism is one of the most common mechanisms incorporating a mechanical linkage. It is also one of the most useful machines for manufacturing many metal parts. One reason for the widespread use of this machine is its ability to perform various tasks at different adjustable speeds. This mechanism undergoes a linear reciprocating movement, which carries a blade cutting the workpiece. In the shaper mechanism, a rotational motion is converted to a reciprocating one, in which the forward stroke takes longer than the return stroke.

The optimization of bar mechanisms designed for shapers is one of the issues considered by their designers in order to achieve the best results under different circumstances. In this regard, graphical and analytical methods are traditionally used for the dimensional synthesis. However, such methods are relatively limited due to their low precision and, hence, cannot be used to design diverse mechanisms, especially those with large numbers of accuracy points and high synthesis complexity. In order to address these issues, optimization methods have been increasingly used in recent years for the dimensional synthesis of mechanisms, especially for path generation [1]. In path generation, synthesis could be carried out using a specific number of accuracy points to be tracked by the mechanism. Therefore, an optimization method shall be used for determining the mechanism's geometry, such as lengths, angles, and coordinates, in order to minimize the error between the desired and generated paths. It is important to note that a number of constraints must be observed during the optimization of the mechanism, such as Grashof's condition, the sequence of the input angles, and the ranges of the design variables. Genetic algorithms have been successfully used for the optimal synthesis of various mechanisms due to their high probability of finding the global optimum and their effectiveness [2, 3]. Nevertheless, all the optimization approaches presented in the mentioned references are

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based on a single objective function, i.e., the position error between the actual and desired points.

The design objective introduced by Liu *et al.* (2022) [4] is to improve the dynamic performance of the mechanism through optimal link design instead of improving the generation accuracy or changing the motion strategy of the mechanism. Specifically, the mechanism has been designed for generating a specific four-bar equation of motion considering the backlash in the joints and the dynamic performance. The influence of certain mechanisms' geometry on the energy consumption has also been investigated by Carabin *et al.* (2017) [5] and Sheppard *et al.* (2019) [6]. For example, Oosterwyck et al. in [7] and [8] have proposed mechanism models that could replace the prototypes so that the overall costs of the evaluation process would be reduced substantially. In addition, a new method for designing a slider-crank mechanism based on differential objective functions has been presented by Jong *et al.* (2016) [9]. Satisfying the constraints defined for a mechanism during design is very important. Yao *et al.* (2022) [10] address this issue by proposing a novel method for satisfying mechanism constraints during the design phase. The constraint can also be put on the output trajectory which has been discussed by Jaiswal *et al.* in [11].

Li *et al.* (2012) [12] used a MATLAB toolbox in order to solve optimal mechanical design problems and proposed an optimal design for a four-bar linkage using mathematical modeling and analysis. The design and optimization of the four-bar mechanism were realized through the MATLAB optimization toolbox. The dynamic analysis of a parallel kinematic mechanism (PKM) was carried out by Liu *et al.* (2010) [13]. In this study, a PKM with four degrees of freedom (DOFs) was defined using the Denavit-Hartenberg method, and the mechanism's dynamic model was developed via the Newton-Euler approach. The computation process was also demonstrated, and the dynamic model was simulated using MATLAB.

Function generation has been carried out by Hitesh *et al.* (2019) [14] for two loops in a four-bar planar mechanism. For high flexibility and precision in function generation, two connected loops of the four-bar mechanism were considered, where the output of the first loop is the input of the second, and the output of the second loop is the final desired output. Moreover, the function generation error is reduced to two steps. Subsequently, equations have been used to construct mathematical models for both loops. Ultimately, the authors concluded that the double-loop four-bar mechanism can generate functions in two steps compared to single-loop four-bar mechanisms, making it possible to generate the optimal function. A novel approach has been proposed by Neider *et al.* (2019) [15] for the optimization analysis of path-generator links. Optimization has also been performed using mathematical formulation. In this research, natural coordinates were combined with a Hermitian analysis to solve the kinematic position of the four-bar mechanism and were used to define an objective function. Also, a training-based optimization algorithm has been implemented to test the robustness of the proposed formulation. Moreover, the authors concluded that it is possible to extend this method to other types of mechanisms.

The approach presented in this paper uses the genetic algorithm for synthesizing the mechanism. Genetic algorithms were first introduced by Holland [16] and then implemented widely and successfully for various optimization problems. Fang [17] and Kunjur [18] presented mechanism synthesis results obtained from evolutionary techniques. In these methods, a starting population is defined and improved through objective function approximation using natural selection mechanisms and genetic rules. The main benefits of these methods include their simple implementation and low computational costs. Three types of analytical synthesis were defined by Sandor *et al.* (1984) [19]: function generation synthesis, motion generation synthesis, and path synthesis. This paper is based on the last type although the method can be applied to any one of the types.

In the present paper, the genetic algorithm is used to optimize the geometry of a six-bar shaper mechanism, which is a continuous model, in such a way that the speed function of the slider is almost constant within a specific interval of rotational motion of the input link, i.e., it follows a predetermined function with a gentle slope. To this end, four accuracy points are selected within a certain range of the input link. Subsequently, the distances between the points on the velocity function of the slider and the predetermined function are calculated at these four points. The goal is to minimize these four distances. Hence, a cost function is defined in the form of the squares of the sums of these distances and is minimized using the genetic algorithm. The significance of this research lies in the fact that, as far as the authors know, no study has ever optimized the geometry of a shaper mechanism to maintain the slider speed constant for a given rotational interval of the input link. Hence, the present study can be considered an innovation in this field. Moreover, the results of this research can be used to define other similar functions in the future and extend the velocity function of the slider to them.

II. Mathematical Model

The model in the present paper is a 1-DOF six-bar mechanism used in shaper machines as presented in Fig. 1. The slider, i.e., the shaper blade (slider), moves back and forth as input link (link with the length b) rotates. As seen in this figure, a is the distance between the supports of the mechanism, b is the length of the input link, c denotes the length of the follower link, d represents the length of the link guiding the blade, θ is the angle of the input link relative to the horizon, α expresses the angle of the follower link relative to the horizon, and β represents the angle of the link guiding the blade relative to the horizon.

In order to optimize this mechanism so that the slider's velocity follows a desired function, the function representing this speed must be specified first. Hence, the kinematics of the mechanism must be determined.

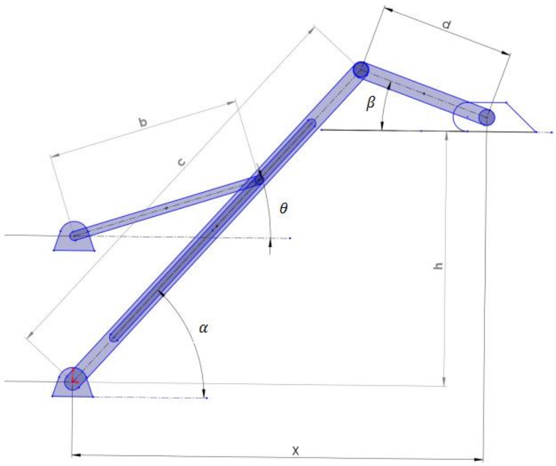

Figure 1. Schematic of the six-bar shaper mechanism

The slider's equation of motion, expressed by X, is defined by Eq. (1) based on the geometry of the mechanism:

$$X = c cos\alpha + d cos\beta \tag{1}$$

where $cos\alpha$ and $cos\beta$ are defined by Eq. (2) and Eq. (3), respectively:

$$cos\alpha = \frac{b cos\theta}{a^2 + 2ab sin\theta + b^2} \tag{2}$$

$$cos\beta = \sqrt{1 - \left(\frac{c}{d}\sqrt{1 - \frac{b^2 cos^2\theta}{a^2 + 2ab sin\theta + b^2}} - \frac{h}{d}\right)^2} \tag{3}$$

Furthermore, Eq. (4) and Eq. (5) can be used to determine $sin\alpha$ and $\sin\beta$:

$$sin\alpha = \sqrt{1 - \frac{b^2 cos^2\theta}{a^2 + 2ab sin\theta + b^2}} \tag{4}$$

$$sin\beta = \frac{c}{d}\sqrt{1 - \frac{b^2 cos^2\theta}{a^2 + 2ab sin\theta + b^2}} - \frac{h}{d} \tag{5}$$

By substituting Eq. (2) to Eq. (5) in Eq. (1), Eq. (6) is obtained:

$$X = \frac{cb cos\theta}{a^2 + 2ab sin\theta + b^2} + d\sqrt{1 - \left(\frac{c}{d}\sqrt{1 - \frac{b^2 cos^2\theta}{a^2 + 2ab sin\theta + b^2}} - \frac{h}{d}\right)^2} \tag{6}$$

If the two sides of Eq. (6) are differentiated with respect to time, the equation representing the speed of the slider is determined as follows:

$$V = \frac{\frac{2ab^3 c\omega \cos^3(\theta) + 2b^2 c\omega\cos(\theta)\sin(\theta)}{\#1}(\#2)}{2\sqrt{\left(1 - \frac{b^2\cos^2(\theta)}{\#1}\right)(1 - \#2^2)}} - \frac{ab^2 c\omega\cos^2(\theta)}{(\#1)^{\frac{3}{2}}} - \frac{bc\omega\sin(\theta)}{(\#1)^{\frac{1}{2}}} - \tag{7}$$

where $\omega = \frac{d\theta}{dt} = \dot{\theta}$ is the angular input speed of the mechanism, and the other parameters are as follows:

$$\#1 = a^2 + 2ab\, sin(\theta) + b^2$$

$$\#2 = \frac{h}{d} - \frac{c}{d}\sqrt{1 - \frac{b^2\cos^2(\theta)}{a^2 + 2ab\sin(\theta) + b^2}}$$

The equations are usually made dimensionless in order to reduce the number of iterations in the numerical solution. As a result, Eq. (7) is made dimensionless in the subsequent step by dividing its two sides by bω. The dimensionless speed (V^*) is expressed by Eq. (8):

$$V^* = \frac{\left(\frac{2ab^2 c\ \cos^3(\theta) + 2bc\cos(\theta)\sin(\theta)}{a^2 + 2ab\sin(\theta) + b^2}\right)\left(\frac{h}{d} - \frac{c}{d}\sqrt{1 - \frac{b^2\cos^2(\theta)}{a^2 + 2ab\sin(\theta) + b^2}}\right)}{2\sqrt{1 - \frac{b^2\cos^2(\theta)}{a^2 + 2ab\sin(\theta) + b^2}}\left(1 - \left(\frac{h}{d} - \frac{c}{d}\sqrt{1 - \frac{b^2\cos^2(\theta)}{a^2 + 2ab\sin(\theta) + b^2}}\right)^2\right)^{\frac{1}{2}}} - \frac{abc\ cos(\theta + \varphi)^2}{(a^2 + 2ab\ sin(\theta) + b^2)^{\frac{3}{2}}} - \frac{c sin(\theta)}{(a^2 + 2ab\sin(\theta) + b^2)^{\frac{1}{2}}} \tag{8}$$

If the dimensionless parameters K_1, K_2, K_3, and K_4 are defined as follows:

$$K_1 = \frac{a}{b} \tag{9}$$

$$K_2 = \frac{c}{b}$$

$$K_3 = \frac{h}{d}$$

$$K_4 = \frac{c}{d}$$

Eq. (8) becomes Eq. (10):

$$V^* = \frac{\left(\frac{2K_1K_2\cos^3(\theta) + 2K_2\cos(\theta)\sin(\theta)}{{K_1}^2 + 2K_1\sin(\theta) + 1}\right)\left(K_3 - K_4\sqrt{1 - \frac{\cos^2(\theta)}{{K_1}^2 + 2K_1\sin(\theta) + 1}}\right)}{2\sqrt{1 - \frac{\cos^2(\theta)}{{K_1}^2 + 2K_1\sin(\theta) + 1}}\left(1 - \left(K_3 - K_4\sqrt{1 - \frac{\cos^2(\theta)}{{K_1}^2 + 2K_1\sin(\theta) + 1}}\right)^2\right)^{\frac{1}{2}}} - \frac{K_1K_2\cos^2(\theta)}{\left({K_1}^2 + 2K_1\sin(\theta) + 1\right)^{\frac{3}{2}}} - \frac{K_2\sin(\theta)}{\left({K_1}^2 + 2K_1\sin(\theta) + 1\right)^{\frac{1}{2}}} \quad (10)$$

Eq. (10) represents the dimensionless speed of the slider, which can be considered as Eq. (11):

$$V^* = f(K_1, K_2, K_3, K_4, \theta) = f(\vec{\boldsymbol{K}}, \theta) \quad (11)$$

where $\vec{\boldsymbol{K}}$ is the vector of the parameters that must be optimized.

$$\vec{\boldsymbol{K}} = \begin{bmatrix} K_1 \\ K_2 \\ K_3 \\ K_4 \end{bmatrix} \quad (12)$$

A. *Objective Function*

It must be noted that, in the present shaper mechanism, the objective is to have a specified and almost constant blade speed function for a specific motion interval of the input link. This profile should be as linear as possible since the goal is to keep it constant; therefore, the ideal function is defined as a linear function. To this end, a linear function termed f_{ideal} with a slope close to zero has been considered as the objective function. The purpose of the optimization is to linearize the function V^* in the interval $0 \ll \theta \leq 4$ of the input link, such that the function f becomes close to the function f_{ideal} by satisfying the problem's constraints in this interval. The function f_{ideal} is defined using Eq. (13):

$$f_{ideal}(\theta) = 0.001\theta \quad (13)$$

B. *Cost Function*

In order for the function f to be close to the function f_{ideal} in the specified interval θ, four accuracy points are selected in the interval $0 \ll \theta \leq 4$ and named $\theta_i, i = 1,2,3,4$. The difference between the dimensionless speed $f(\theta_i)$ and the function $f_{ideal}(\theta_i)$ at these points is calculated for a given $\vec{\boldsymbol{K}}$ (a specific geometry). Since these differences must be minimal, a cost function is defined that must be minimized by the optimization algorithms. The cost function is the square root of the sum of the squares of these differences. In other words, the cost function can be expressed by Eq. (14):

$$Cost\ function = \sqrt{\sum_{i=1}^{5} \left(f(\vec{\boldsymbol{K}}, \theta_i) - f_{ideal}(\theta_i)\right)^2} \quad (14)$$

C. *Constraints*

In order to ensure the existence of the optimal mechanism, certain constraints are defined. These constraints expressed by Eq. (15) and Eq. (16), govern the problem:

$$a > b \quad (15)$$

$$a + b < c \quad (16)$$

It is worth noting that the above constraints were defined according to the Grashof condition. This condition ensures that at least one of the links can perform a full revolution. Using the dimensionless coefficients K_1 and K_2, the above equations are rewritten as follows:

$$K_1 - 1 > 0 \quad (17)$$

$$K_1 - K_2 < 0 \quad (18)$$

The other constraints have been defined as in Table I.

TABLE I. THE RANGE OF THE DESIGN PARAMETERS

The range of the design parameters
$\boldsymbol{1 \leq K(1) = K_1 \leq 1.5}$
$\boldsymbol{1 \leq K(2) = K_2 \leq 10}$
$\boldsymbol{1 \leq K(3) = K_3 \leq 4}$
$\boldsymbol{1 \leq K(4) = K_4 \leq 15}$

III. OPTIMIZATION

The optimization problem of this paper is defined by Eq. (19):

$$\min F(\vec{\boldsymbol{K}}, \theta_i)$$

$$subject\ to: g_j(\vec{\boldsymbol{K}}) \leq 0\ , \quad j = 1, 2, \ldots 10 \quad (19)$$

in which F is the cost function defined according to Eq. (14), $\vec{\boldsymbol{K}}$ represents the dimensionless parameters (K_i), and g is the matrix of the problem's constraints. $\vec{\boldsymbol{K}}$ must be selected in such a way that the cost function defined for the four accuracy points is minimized while the problem constraints are observed.

The optimization is carried out using the genetic algorithm, which is an evolutionary optimization method. Since the genetic algorithm is meta-heuristic, it may not produce an accurate and rational output via a single solution, and the graph plotted for the blade speed may not be acceptable. Thus, at this step, an acceptance criterion may be defined after the plot of the speed with the obtained coefficients is viewed. In this work, the acceptance criterion is defined to be the difference between $V^*_{\text{optimized}}$ and f_{ideal} corresponding to the interval $0 \ll \theta \leq 4$, which must not exceed 10%. Hence, if the acceptance criterion fails, the problem is solved once more, the optimal coefficients are obtained again, and the speed graph is redrawn with the newly obtained coefficients. This will be repeated until the plotted graph is acceptable and the acceptance criterion is satisfied. In this case, the obtained coefficients represent the optimal solution to the problem.

The procedure of evolutionary methods for optimization problems begins with generating the initial population. For the synthesis of mechanisms, the initial population consists of a set of design variables the values of which are randomly generated in the search space. Therefore, in the present problem, the algorithm begins by selecting several sets of values for $\vec{\boldsymbol{K}}$, which is the initial population. Each individual (chromosome) in the population is a possible solution to the problem and is formed by the parameters (genes) that determine the design variables of the problem.

Genes can be introduced into the problem in a variety of ways. In the first approach, defined by Holland [16] , they are in the form of binary chains. Hence, each gene y_i is expressed using a binary code with a size of P, which is limited to an interval defined with integer or real values. Another method for defining genes is the use of real numbers, which is the method of choice in this paper. In this method, all the genes are placed in a vector that represents the chromosome.

$$Y = [y_1\ y_2 \dots\ y_n\ ]\ \ \forall y \in R \qquad (20)$$

In the next step, the initial population must be converted to one that provides a better solution. This can be done via natural selection, reproduction, mutation, or other genetic operators. All three processes are used in this paper. Hence, a brief explanation is provided about each one.

A. Natural Selection

In this process, two individuals (solutions) are randomly selected from the population in order to form a couple for reproduction. Selection can be based on different probabilistic distributions, such as uniform distribution or random selection from the population. A weight is assigned to each member depending on its fitness, such that the most fitted individual is the most likely to be selected.

In this paper, the best individual (solution) and two individuals have been randomly selected with a uniform distribution for reproduction, and one individual from the new generation, named s, which is a differential evolution [20], is formed based on Eq. (21):

$$y_i : i \in [1, P] \qquad (21)$$

$$s = y_{best} + W(y_{r1} - y_{r2})$$

where y_{best} is the best individual from the population P, y_{r1} and y_{r2} are two individuals randomly selected from the population, and W represents a real number that controls the disturbance of the best individual.

B. Reproduction

In the next step, S is crossed with the i-th individual from the current population to produce the i-th individual from the next population. This operator is called the crossover operator.

Reproduction occurs in two ways. As shown in Fig. 2, in the first case, parents y_i and S produce their descendent (y_i^N) via a piecewise multi-point crossover [21]: the crossover points $(j, j+k)$ are selected randomly from the parent genes for reproducing the next generation (with a uniform probability distribution). This group of genes crossed from two parents can be placed together.

In the second case, shown in Fig. 3, discrete multi-point crossover can be used to produce y_i^N. Parent y_i produces its descendent using a set of N genes randomly selected from the entire corresponding chromosome. Parent S provides the rest of the genes. If Child y_i^N is better than its previous generation, it will replace y_i. Otherwise, y_i will remain in the population, and y_i^N will be removed. As a result, the population will neither decrease nor increase.

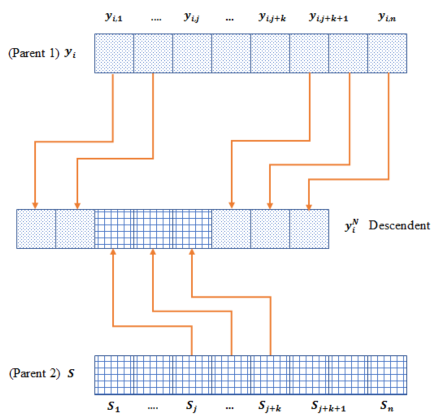

Figure 2. Piecewise multi-point crossover for reproduction

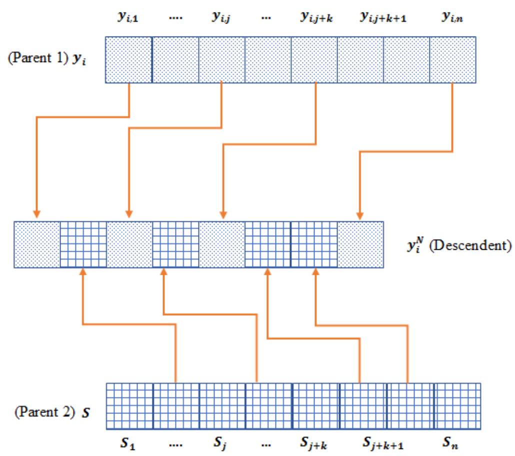

Figure 3. Discrete multi-point crossover for reproduction

It should be noted that multi point crossover is a generalized one-point crossover wherein new off-springs are born by swapping the alternating segments.

C. Mutation

The mutation operator refers to a random change in a gene during reproduction. Mutation is defined as follows: when Gene y_i mutates, the operator randomly selects a value in the set of real numbers $(y_i, y_i \pm range)$ and adds it to or subtracts it from y_i.

IV. Numerical Example

To evaluate the performance of the optimization process for a mechanism using the genetic algorithm, the dimensionless parameters $\mathrm{K_i}$ are considered according to Table II.

TABLE II. The Range of the Design Parameters

The Dimensionless Parameters $\mathrm{K_i}$				
i	**1**	**2**	**3**	4
$\boldsymbol{K_i}$	3	4	1.3	1.3

With these values, the dimensionless speed curve of the mechanism in (10) will correspond to the range $0 \ll \theta \leq 2\pi$, and the target speed curve ($\mathrm{f_{ideal}}$) will be as shown in Fig. 4.

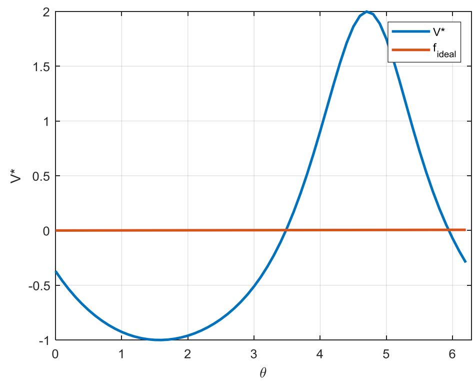

Figure 4. Graph of the dimensionless speed of the shaper mechanism

Now four accuracy points in the interval $0 \ll \theta \leq 4$ are selected in the form of a vector $\Theta = [1\ 2\ 3\ 4]$. The cost function is formed by substituting these four accuracy points into (14). Using the genetic algorithm to minimize the defined cost function, the four unknowns (dimensionless coefficients $\mathrm{K_i}$) are determined. The variation of the cost function with relation to the iteration number has been demonstrated in Fig. 5.

The parameters for the Genetic Algorithm are listed in Table III.

TABLE III. The Parameters for the Genetic Algorithm

Initial Population	Crossover probability	Mutation probability
100	0.6	0.001

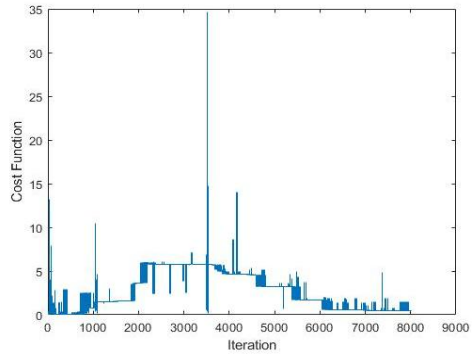

Figure 5. The variation of the cost function with relation to the iteration number

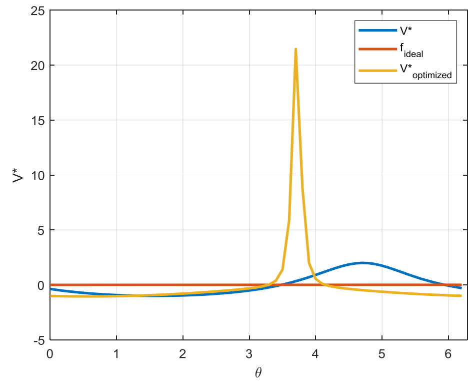

Figure 6. Graph of the dimensionless speed of the mechanism before and after optimization

As could be seen from this figure, the cost function first increases but as the number of iterations passes 4000, the cost function starts to decrease and it finally converges to the acceptance criteria. In addition, Table IV also demonstrates that how the acceptance criterion converges to its acceptance level as the number of iterations increases in the Genetic Algorithm. As could be inferred from this table, it could be concluded that after the iteration No. 7000, the acceptance criterion approaches to its required value and for the iteration No. 8000, it has already been reached and the optimization algorithm stops.

TABLE IV. Convergence of the Acceptance Criterion to Its Acceptance Level as the Number of Iterations Increases

No. Iteration	*1000*	*2000*	*3000*	*4000*	*5000*	*6000*	*7000*
Acceptance Criterion (%)	17	**21**	27	25	23	12	*11*

Finally, the graph of the slider's speed is plotted with the coefficients calculated for minimizing the objective function. In this study, the graph of the dimensionless speed function ($\mathrm{V^*_{optimized}}$) corresponds to $\mathrm{K_1} = 1.1$, $\mathrm{K_2} = 2.2$, $\mathrm{K_3} = 3.17$, $\mathrm{K_4} = 11.04$ as shown in Fig. 6.

According to the speed plot with the obtained coefficients, the acceptance criterion has not yet been met. Hence, the problem is solved again, and the optimal coefficients are obtained again until the acceptance criterion is satisfied. Once this happens, the obtained coefficients will represent the optimal solution to the problem. In the end, one of the several values obtained in different solutions is selected as the optimal solution to the problem.

One of the graphs meeting the acceptance criterion is shown in Fig. 7. For this chart, the dimensions are as follows: $K_1 = 1.23$, $K_2 = 2.65$, $K_3 = 3.98$, $K_4 = 12.05$.

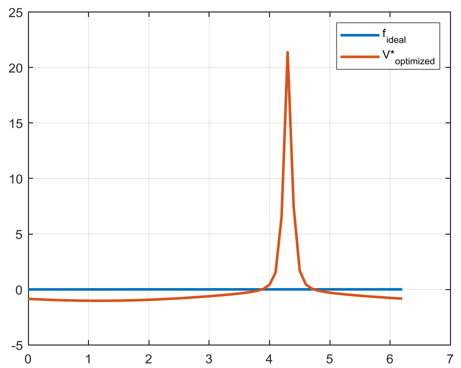

Figure 7. Dimensionless speed graph satisfying the acceptance criterion

If one of the dimensions a, b, c, d, h is known, the other parameters can be determined using these coefficients, which represent the dimensional ratios between the links in the mechanism, and the resulting mechanism will exhibit optimal performance in terms of having an almost linear slider speed function in the interval $0 \ll \theta \leq 4$.

The six-bar shaper mechanism corresponding to the generated optimal solution has been sketched in Fig. 8 using simple lines with correct length ratios of optimal design results.

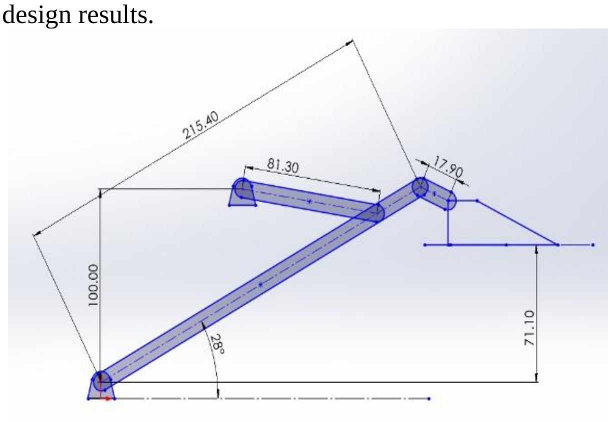

Figure 8. The six-bar shaper mechanism corresponding to one of the generated optimal solutions

V. CONCLUSION

The optimization of mechanisms designed for shapers is one of the issues considered by their designers so that the best results can be achieved under any given set of circumstances. As mentioned previously, different methods have been used in various papers to optimize shaper mechanisms, including graphical and analytical methods for the dimensional synthesis of mechanism.

In this paper, a genetic algorithm was used to optimize and synthesize a six-bar shaper mechanism such that the slider moves at a nearly constant dimensionless speed for a specified interval of the input link's angle. The error between the speed function generated by the mechanism and the objective function was minimized by selecting four accuracy points. The distances between the corresponding points on the speed function of the slider and the objective function were calculated at these four accuracy points, and a suitable cost function was defined for the optimization. Moreover, the optimization was carried out while satisfying different geometric constraints. A numerical example was also considered as a case study. The results of this example generated various configurations for the mechanism such that the desired speed function was formed. The optimization algorithm was observed to converge to the solution rapidly, and its error was within the specified range.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

All authors have contributed to the paper equally. They both conducted the research; analyzed the data; and wrote the paper. All authors had approved the final version.

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