Optimization of the Thread Take-up Lever Mechanism in Lockstitch Sewing Machine Using the Imperialistic Competitive Algorithm

Pedram Payvandy and Saeed Ebrahimi

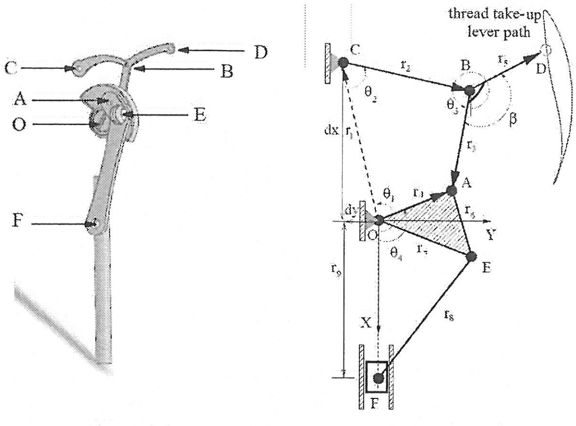
***Abstract*—Lockstitch sewing machine is one of the most common apparel industrial machines. The thread take-up lever mechanism of a sewing machine has an important role for proper stitch forming and smooth working of the machine. Acquiring a mechanism with optimized geometry is of great importance to reach this goal. Therefore, in this study the optimization of the thread take-up lever mechanism with respect to some important features such as the optimal path of the coupler point and variation of coupler point acceleration (jerk) is presented. Modification of the objective function with respect to the jerk is applied to assure smooth movement of the thread take-up lever during sewing process. For this purpose, the imperialistic competitive algorithm is used to find the optimal link lengths of the take-up lever mechanism. The analysis results present further verify that the coupler point jerk in the optimized mechanism in the horizontal direction has been decreased about 52 percent without any conflict in the consistent operation of different parts of the sewing machine.**

Keywords: Optimization, imperialistic competitive algorithm, thread take-up lever mechanism, coupler point, jerk

I. INTRODUCTION

Todays, industrial sewing machines operate more than 1500 stitches per minute. Lockstitch sewing machine is one of the most common apparel industrial machines. Stitch formation process in lockstitch sewing machine is complex, since some linkages operate simultaneously in each rotation of the machine main shaft [1]. Among these linkages, the thread take-up lever with an optimized coupler point path has an important role for proper stitch forming [2]. Despite the importance of this issue from practical point of view, very few publications have particularly focused on the optimization of thread take-up lever mechanism.

The thread take-up lever mechanism of the lock-stitch sewing machine is considered as a path generator mechanism [3]. Therefore, the studies which directly deal with the optimization of path generator four-bar mechanism are reviewed in this paper. As one of the earliest works in this context, in 1976, the dimensional synthesis of a skew four-bar linkage for the approximate generation of a given coupler path was investigated by Alizade and his co-workers [4]. Using a non-linear programming approach, the structural-error and transmission characteristics were optimized. Stochastic models of the four-bar, path-generating linkage have been made in References [5 to 7]. Tolerances and clearances have been assumed to be random variables. The optimum synthesis of planar four-bar linkages for path generation was presented in References [8 and 9]. The method allows the formulation of the problem as an unconstrained nonlinear least-square optimization. Yao and Angeles [10] studied the approximate synthesis of a planar four-bar linkage for rigid-body guidance. For this purpose, all the relevant parameters of the linkage whose coupler link passes approximately through a large number of prescribed poses were defined. Vasiliu and Yonnou [11] optimized a planar mechanism to generate a desired path using a neural network method. In Reference [12], the global optimum obtaining problem in approximate path synthesis of linkages was considered. A combined gross-fine search method was suggested as optimization strategy. Sancibrian *et al.* [13] proposed a gradient-based optimization approach for path synthesis problems.



3D view schematic veiw

Fig. 1. The thread take-up lever and needle bar mechanism.

The optimal synthesis of the driven link of an adjustable four-bar linkage based on a modified genetic algorithm was performed in Reference [14] to effectively reflect the overall difference between the desired and the generated paths. Optimal synthesis of planar four-bar mechanism was also followed in Reference [15] in which a searching procedure was defined based on genetic and evolutionary

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algorithms. In Reference [16], the work presented a combined genetic algorithm–fuzzy logic method to solve the problem of path generation in mechanism synthesis. The work of Cabrera *et al.* [17] deals with solution methods to multi-objective constrained optimization of planar mechanisms using a new evolutionary algorithm. Smaili and Diab [18] studied optimum synthesis of hybrid-task mechanisms using ant-gradient search method which is a combination of ant colony optimization and gradient search methods. In Reference [19], an alternative method of linkage synthesis using the simulated annealing approach was presented. The optimization of link parameters of a four-bar path generator mechanism having revolute joints with clearance was presented in Reference [20] using the genetic algorithm. The work of Starosta [21] concerned synthesis of a path-generator four-bar linkage using the genetic algorithm and Fourier coefficients. The synthesis of a four-bar linkage in which the coupler point performs approximately rectilinear motion was studied in Reference [22] by using the method of variable controlled deviations and by applying differential evolution algorithm. Nariman-Zadeh *et al.* [23] used the hybrid multi-objective genetic algorithms for Pareto optimum synthesis of four-bar linkages considering the minimization of the tracking error and transmission angle's deviation from 90°. Acharyya and Mandal [24] studied three evolutionary algorithms namely genetic algorithm, particle swarm optimization, and differential evolution performance for designing four-bar mechanism with given curve path. They reported that the differential evolution shows fast convergence to the optimal result and very low error of adjustment to target points than other two methods. Optimal synthesis of mechanisms for path generation using Fourier descriptors and a stochastic global search method derived from simulated annealing and Powell's method was presented in Reference [25]. Rai *et al.* [26] introduced a unified procedure for the synthesis of planar linkages. The synthesis task was posed as a constrained optimization problem and was solved by a hybrid, elite-preserving genetic algorithm. Lin [27] studied a real-coded evolutionary algorithm obtained by combining differential evolution with the real-valued genetic algorithm for application to path synthesis of a four-bar linkage. In Reference [28], a novel approach to the multi-objective optimal design of four-bar linkages for path generation was proposed. A hybrid Pareto genetic algorithm with a built-in adaptive local search was employed to accelerate the search in the highly multimodal solution space. The work presented by Matekar *et al.* [29] introduced a new error function for optimum synthesis of path generating mechanisms. They used the method of differential evolution to carry out the optimization. Chanekar and Ghosal [30] investigated an optimization based method for synthesis of adjustable planar four-bar, crank-rocker mechanisms. A two stage method was used first to determine the parameters of the possible driving dyads in tracing multiple different and desired paths. Then, the remaining mechanism parameters were determined in the second stage where a least-squares based circle-fitting procedure was used.

The optimization algorithms are usually categorized within either analytical or numerical methods which the latter is further classified as deterministic methods or heuristic methods. In contrast to the deterministic methods, which can converge to a local minima or maxima, instead of the global one, heuristic algorithms can ideally converge

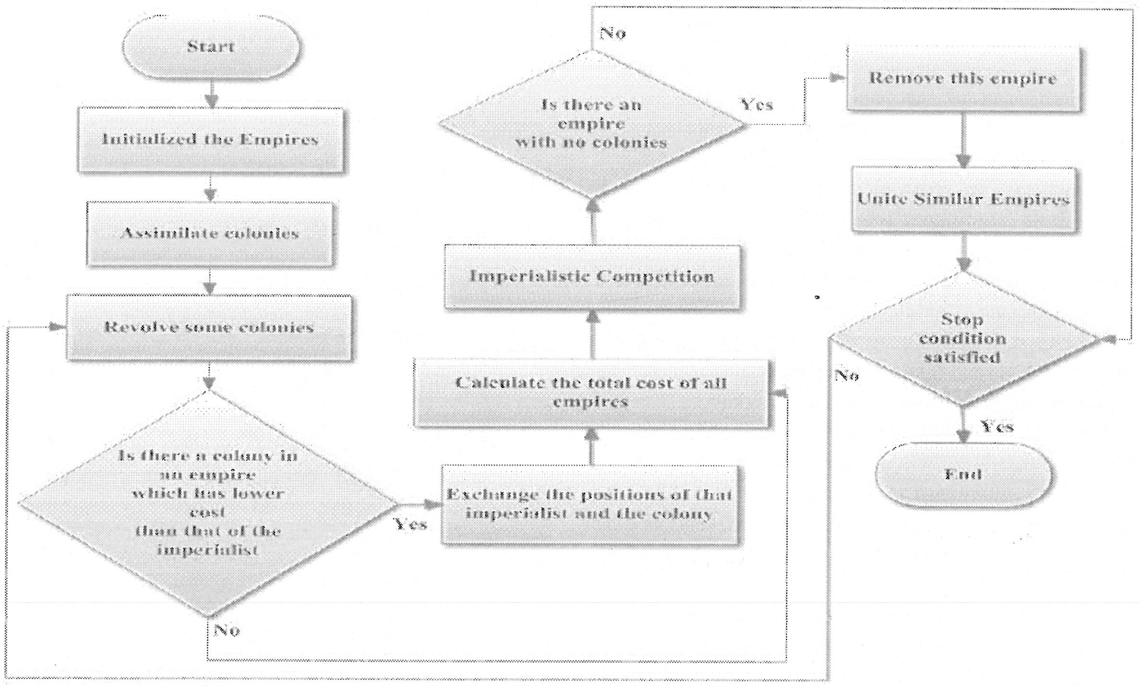


Fig. 2. The ICA flowchart.

to a global maxima or minima. Heuristic approaches have been found to be more flexible and efficient than deterministic approaches especially for problems with relatively high number of design variables.

In the next section, the thread take-up lever mechanism specifications are investigated. The optimization of this mechanism with respect to some important features such as the optimal path of the coupler point and variation of coupler point acceleration (jerk) is presented further on in this paper. Modification of the objective function with respect to the jerk is applied to assure smooth movement of the thread take-up lever during sewing process. Indeed, this is important since due to the operation of sewing machines in high speeds, decreasing the machine vibration by minimizing the jerk of its coupler point is a desired task. For this purpose, the Imperialistic Competitive Algorithm (ICA) is used as the optimization strategy to find the optimal link lengths of the take-up lever mechanism [31]. This technique is a new heuristic powerful optimization tool which is based on the innovative evolutionary optimization method. Selection of this approach lies in its clear advantages compared to other evolutionary algorithms such as genetic algorithm.

II. THREAD TAKE-UP LEVER MECHANISM

Figure 1(a) illustrates the thread take-up lever and the classical needle bar mechanism of a typical lockstitch sewing machine by focusing on the main parts which are involved in the stitch formation process. The thread is supplied through the take-up lever and needle which are driven by their associated mechanisms. The schematic view of this mechanism is shown in Fig. 1(b). The thread take-up lever mechanism is the four-bar linkage OABC. The coupler link ABD plays the fundamental role of this mechanism in controlling the thread movement. This important task is carried out based on the path of the coupler point at D. The needle bar mechanism OEF is of the classical slider-crank mechanism type in which slider F denotes the needle. Both mechanisms are driven simultaneously through the ternary link OAE [32].

The thread take-up lever mechanism of the lockstitch sewing machine completes the stitch formation process together with the needle and bobbin hook by influencing the thread control curve according to the technological requirements of the sewing machine [33]. The needle thread capacity required during stitch process is the basis for designing the thread take-up lever mechanism to secure the feeding of the thread without thread breakage.

In the first step of stitch formation, the sewing needle penetrates into the fabric. During this time, the thread take-up lever moves downward and releases thread which the needle draws down through the needle eye. The needle begins to rise after reaching its lower dead position, while the thread take-up lever continues its downward motion supplying thread to the bobbin. After rounding the thread to the lowest point of the bobbin, the thread take-up lever begins its upward motion to draw excess thread up through the needle eye. This action tightens the interlocked stitch into the fabric. During the fabric progression by the serrated dogs, the thread take-up lever approaches the top of its vertical position. This upward motion also causes a demand for thread which is supplied from the check spring reservoir [34]. As the thread take-up lever begins its downward motion, the stitch formation is completed. This process then repeats for the creation of the next stitch.

III. KINEMATICS OF THE THREAD TAKE-UP LEVER MECHANISM

For optimization of the thread take-up lever mechanism, it is mandatory first to find its kinematic relations between the input crank OA and the coupler link ABD. A detailed description of some required kinematic relations is presented in the appendix.

The angle θ, the rotational velocity $\dot{\theta}_4$ and the rotational acceleration $\ddot{\theta}_4$ of the input crank OA are supposed to be known during the operation of sewing machine. Then, according to Fig. 1(b), the position vector of the coupler point D can be written as

$$r_D = r_4 - r_3 + r_5 \quad (1)$$

which can be rewritten in the x and y directions as

$$\begin{aligned} r_{Dx} &= r_4\cos(\theta_4) + r_3\cos(\theta_3) + r_5\cos(\theta_4+\beta), \\ r_{Dy} &= r_4\sin(\theta_4) + r_3\sin(\theta_3) + r_5\sin(\theta_4+\beta), \end{aligned} \quad (2)$$

where, θ_3 is the angle of link BA of the coupler and can be obtained from the associated relation derived in appendix. Parameter β is the constant angle between BA and BD. Differentiation of Eq. (2) with respect to time leads to the coupler point velocity in terms of the crank angular velocity $\dot{\theta}_4$ and coupler angular velocity $\dot{\theta}_3$ as

$$\begin{aligned} \upsilon_{Dx} &= -r_4\dot{\theta}_4\sin(\theta_4) + r_3\dot{\theta}_3\sin(\theta_3) - r_5\dot{\theta}_3\sin(\theta_3+\beta) \\ \upsilon_{Dy} &= -r_4\dot{\theta}_4\cos(\theta_4) + r_3\dot{\theta}_3\cos(\theta_3) - r_5\dot{\theta}_3\cos(\theta_3+\beta) \end{aligned} \quad (3)$$

Further, differentiation with respect to time yields the coupler point acceleration as

$$\begin{aligned} a_{Dx} &= -r_4(\ddot{\theta}_4\sin(\theta_4) + \dot{\theta}_4^2\cos(\theta_4)) \\ &\quad + r_3(\ddot{\theta}_3\sin(\theta_3) + \dot{\theta}_3^2\cos(\theta_3)) \\ &\quad - r_5(\ddot{\theta}_3\sin(\theta_3+\beta) + \dot{\theta}_3^2\cos(\theta_3+\beta)) \\ a_{Dy} &= -r_4(\ddot{\theta}_4\cos(\theta_4) + \dot{\theta}_4^2\sin(\theta_4)) \\ &\quad + r_3(\ddot{\theta}_3\cos(\theta_3) + \dot{\theta}_3^2\sin(\theta_3)) \\ &\quad - r_5(\ddot{\theta}_3\cos(\theta_3+\beta) + \dot{\theta}_3^2\sin(\theta_3+\beta)) \end{aligned} \quad (4)$$

Calculation of the coupler point jerk (which is the acceleration derivative with respect to time) can be obtained by taking numerical derivative of D_a using three-point difference formula.

IV. IMPERIALISTIC COMPETITIVE ALGORITHM

Imperialistic Competitive Algorithm (ICA) is an innovative evolutionary optimization method which is inspired by imperialistic competition [3]. ICA starts with some random initial population that each of them called a “Country”. Some of the best countries in the population are selected as “Imperialist”, rest of them is considered as “Colony”. Imperialists can dominate colonies depending on their power. The power of each empire depends on two parts: imperialist as a main core and the colonies. In mathematical model, it is modeled by the imperialist power in addition to few percent of colonies power. With formation of initial empires, imperialist competition is started. Each of imperialist will be removed if it cannot develop its power (at least prevent to decrease its power). So survival of each empire is depended on absorbing other empires colonies. Accordingly, in imperialist competition, stronger empires gradually develop their power and weaker empires will be eliminated. The empires must develop their colonies to improve their power. Over time, colonies power will be closer to imperialist power and a convergence will be seen. When only one empire is existed, the algorithm is terminated. In this condition, power of this empires’ colony is very close to empires power. Details of the ICA approach are illustrated in flowchart of Figure 2.

A. *Initialize empires*

As the first step, some arbitrary initial population is selected. An array of optimization variables is then constructed. When solving a N_{var} dimensional optimization problem, a country is $1 \times N_{var}$ array. This country is defined as follows:

$$\text{country} = [p_1, p_2, p_3, \dots, p_i, \dots, p_{N_{var}}] \qquad (5)$$

where, $p_i (i = 1, \dots, N_{var})$ denotes the optimization variables. The optimization terminates after finding the solution with minimum cost value. Initial countries of size $N_{Country}$ are produced in the next step. Then, N_{imp} numbers of strong countries are considered as N_{imp} imperialists. The rest with the size N_{Col} will form the colonies that belong to an empire. Then, the colonies are assigned to imperialists according to their power [3].

B. *Assimilation*

According to assimilation algorithm, the imperialist states tend to draw their colonies toward themselves and make them a part of themselves. The assimilation method in the ICA is illustrated by giving a move to all the colonies toward the imperialists. Figure 3(a) illustrates such a movement in which a colony moves toward the imperialist by x which is a random variable with uniform (or any proper) distribution

$$x \sim U(0, \alpha \times d) \qquad (6)$$

where, U is the standard uniform distribution function which takes two parameters (α and d) as inputs and generates a random vector between zero and $\alpha \times d$. Parameter α is a coefficient greater than 1 to make the colonies get closer to the imperialist, and d is a vector of the same dimension as optimization variables. Its components are obtained by computing the difference between the optimization variables of a colony and its imperialist.

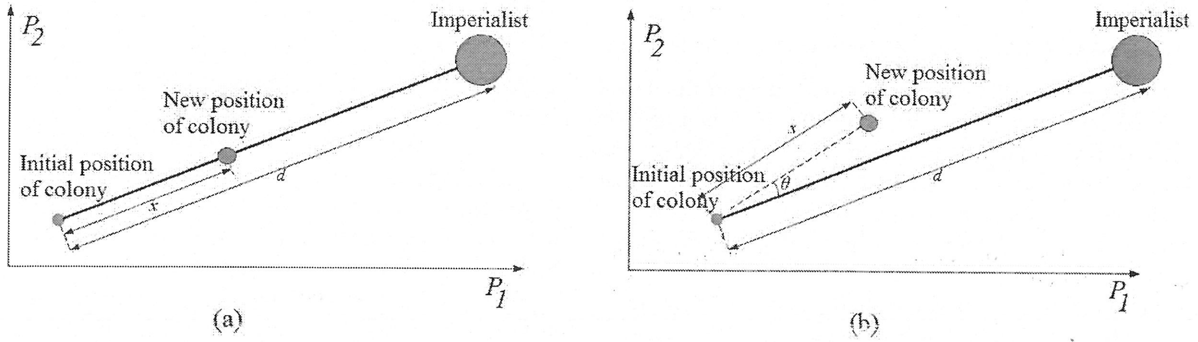
Assimilating the colonies by the imperialist states do not result in direct movement of the colonies toward the imperialist. That is, the direction of movement is not necessarily the vector from colony to the imperialist. To model this fact and to increase the ability of searching more area around the imperialist, a random amount of deviation is added to the direction of movement. Figure 3(b) shows the new direction. In this figure θ is a parameter with uniform (or any proper) distribution as

$$\theta \approx U(-\gamma, \gamma) \qquad (7)$$

where, γ is a parameter that adjusts the deviation from the original direction. Nevertheless the values of α and γ are arbitrary.

C. *Revolution*

Revolution is a basic operation in most of the heuristic algorithms which guarantees the diversity of solution space searching. Thus, revolution increases the exploration of the algorithm and avoids early convergence to local minimums. In the ICA algorithm, revolution causes a country to randomly change its characteristics.



(a) (b)

Fig. 3. (a) Direct movement of colonies toward their relevant imperialist, (b) Movement of colonies toward their relevant imperialist in a randomly deviated direction.

D. Exchanging positions of the imperialist and a colony

During the algorithm process, if a colony catches a smaller cost than it's imperialist, they will swap their position.

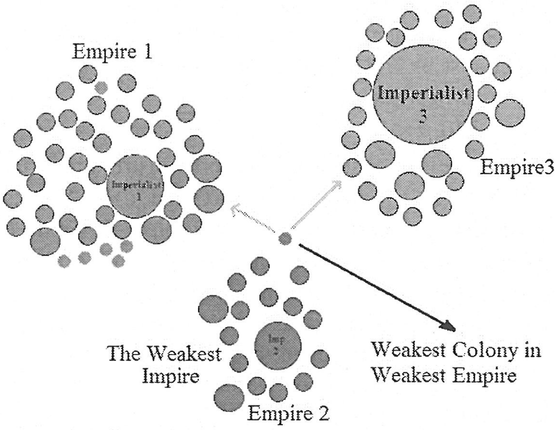


Fig. 4. Imperialistic competition.

E. Total power of an empire

The power of an empire is defined as:

$$T_n = \cos t\left(n^{th} \text{ imprialist}\right) + \left(\xi \times \frac{1}{m}\sum_{i=1}^{m}\left\{\cos t\left(i^{th} \text{ colony of } n^{th} \text{ empire}\right)\right\}\right) \quad (8)$$

where T_n is the cost of the nth empire and ξ is a positive value. Parameter m defines the number of colonies of the n^{th} empire. A small value for ξ results the power of the empire to be defined by just the imperialist, and bigger value will increase the colonies effects in determining the power of an empire.

F. Imperialistic competition

The competition between empires for possession of the colonies has to be performed to gradually eliminate weaker empires by decreasing their power. This will consequently grow the power of strong empires. The competition is started by possessing the weakest colony (or colonies) of the weakest empire by other empires. The probability of possessing that certain colony depends on the power of each empire. Figure 4 shows the mentioned competition strategy.

V. THREAD TAKE-UP LEVER MECHANISM OPTIMIZATION

In this section, the optimization procedure of the thread take-up lever mechanism based on the ICA approach is presented. The objective here is to find the mechanism link lengths for which the optimized coupler point path under some certain conditions is acquired. Figure 1(b) shows the typical thread take-up lever path during one stitch formation process in a specific sewing machine. For a proper stitch formation, the vertical position of point D on this path has to follow the prescribed path with respect to the input shaft OA rotation. This condition has to be considered when formulating the optimization algorithm. This means that position, velocity and jerk of take up lever path in vertical direction have not changed. On the other hand, the horizontal position of this point has not shown any noticeable influence on the quality of stitch in practice. Therefore, the first part of the objective function involves required tasks with respect the coupler point path. The main part of the objective function with respect to the variation of coupler point acceleration (jerk) in the horizontal direction is applied to assure smooth movement of the thread take-up lever during sewing process. Indeed, this is important since due to the operation of sewing machines in high speeds, decreasing the machine vibration by minimizing the jerk of its coupler point is a desired task. Therefore, the objective function f can be defined as

$$f = W_1 \int_0^{2\pi} \left|\mathrm{Ref}(\theta_4) - r_{Dx}(\theta_4)\right| d\theta_4 + W_2 \int_0^{2\pi} \left|\frac{d\,\ddot{r}_{Dy}(\theta_4)}{dt}\right| d\theta_4 \quad (9)$$

Weighting constants, i.e. W_1 and W_2, should be chosen in such a way that both parts of the objective function share equal effect in obtaining the optimized mechanism. In this work, the optimization was performed about 10 times to get an impression about the effect of choosing different values of W_1 and W_2. Finally, W_1=50 and W_2=1 were chosen. Parameter $\mathrm{Ref}(\theta_4)$ denotes the reference values of the vertical position of point D for a reference sewing machine as the function of θ_4. The term which is written in the second part of the objective function defines the coupler point jerk in the horizontal direction.

For introducing the objective function to the optimization procedure, the Grashof's law has to be satisfied for mechanism OABC. According to this law, sum of the shortest and the longest links of a four-bar linkage has to be lower or equal to sum of two remaining link lengths in order to be able to fully rotate the crank link. During optimization, mechanisms which would not fulfill the above mentioned condition have to be neglected. This means that, further generations of optimized mechanisms cannot include such non-acceptable mechanisms.

The sewing machine considered in this study was a Pfaff model 1122 with the specifications of the thread take-up lever mechanism shown in Table I.

TABLE I
DIMENSIONS OF THE THREAD TAKE-UP LEVER MECHANISM OF PFAFF MODEL 1122

Parameter	d_x (mm)	d_y (mm)	r_2 (mm)	r_3 (mm)	r_4 (mm)	r_5 (mm)	β (deg)
Value	22	20	32	24	15	28	135

VI. RESULTS AND DISCUSSION

According to the desired dimensions, Table II summarizes some other optimization constrains regarding mechanism geometry. These conditions were basically chosen based on some practical issues such as the construction limitations of the sewing machine, the space needed for assembling different parts of the sewing machine, the consistent operation of the take-up lever and needle driving mechanisms at each rotation of the input link, and etc.

The optimization was performed in MATLAB using a computer with Cori7, 740Qm, 1.74 GHZ, Ram 8 GB specifications. The mean execution time for optimization of the mechanism based on the ICA approach was about 20 minutes. Table III shows the ICA parameters used for initializing the optimization process in which parameter d states the current decade index.

TABLE II
OPTIMIZATION CONDITIONS

Parameter	Lower limit	Upper limit
d_x (mm)	10	45
d_y (mm)	10	45
r_2 (mm)	10	45
r_3 (mm)	10	45
r_4 (mm)	10	45
r_5 (mm)	10	50
β (deg)	103	166

TABLE III
THE ICA PARAMETERS

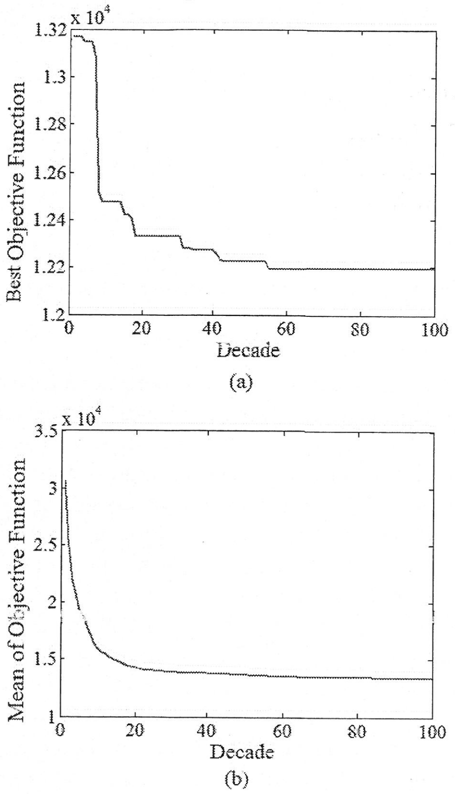
Parameter	Value
Number of decades (N_{decade})	100
Number of imperials (N_{imp})	40
Number of countries $(N_{country})$	1000
Assimilation coefficient (α)	2
Deviation coefficient (γ)	0.1
Colonies share coefficient (ξ)	0.5
Objective function (f)	Eq. (9)
Revolution rate	$0.5e^{-\frac{d}{D}}$

The optimization of the mechanism was then performed to obtain the optimized link lengths which minimize the objective function (9) by imposing the optimization conditions. Tables IV shows the optimal values of the mechanism link lengths. The reported results were selected among 50 optimization executions to guarantee obtaining reliable link lengths.

Figure 5 illustrates variation of the best cost and mean cost of the objective function for different number of decades during optimization. The results of this figure show clearly the convergence of optimization. By increasing number of decades, the mean value of the objective function shows decreasing behavior which approaches gradually to the best value. The ICA finds the best value very rapidly in early decades.

Figure 6 shows the performance of the optimization algorithm in fulfilling the first condition of the objective function. According to this figure, the coupler point position of the optimized mechanism in the horizontal direction follows the associated graph of the reference mechanism with negligible deviation. The percentage of the absolute error for the whole path is less than 1.6. It could be also observed from Fig. 7 that the coupler point jerk in the vertical direction as the second part of the objective has been decreased significantly. The performance index regarding this part is about 52 percent. This result verifies that the optimization algorithm minimizes successfully the undesired jerk.

A comparison between the coupler point path for both the reference and the optimized thread take-up lever mechanisms is presented in Fig. 8. This figure clearly illustrates the general performance of the optimization algorithm. As it is seen, the coupler point movement in the horizontal direction is performed in a narrow domain compared to the reference path, while keeping approximately the vertical movement on the desired location of the reference path.



(a)

(b)

Fig. 5. Variation of (a) the best and (b) the mean values of the objective function.

TABLE IV
OPTIMAL LINK LENGTHS

Parameter	d_x (mm)	d_y (mm)	r_2 (mm)	r_3 (mm)	r_4 (mm)	r_5 (mm)	β (deg)
Optimal value	23.2	30.7	41.9	25.3	13.6	32.7	126.05

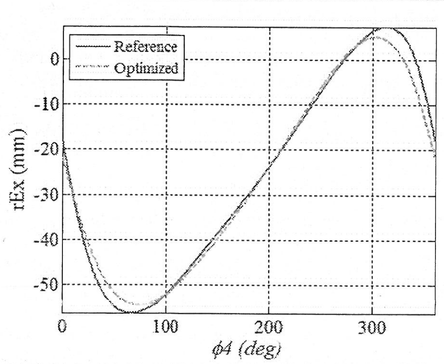


Fig. 6 Variation of the coupler point position in the horizontal direction.

Based on the above discussion, it could be concluded that the optimized mechanism has clear superiority compared to the reference mechanism with respect to the minimization of coupler jerk and reducing movement of the thread take-up lever in the horizontal direction. This achievement is directly related to the type of objective function and the ICA approach used in this study.

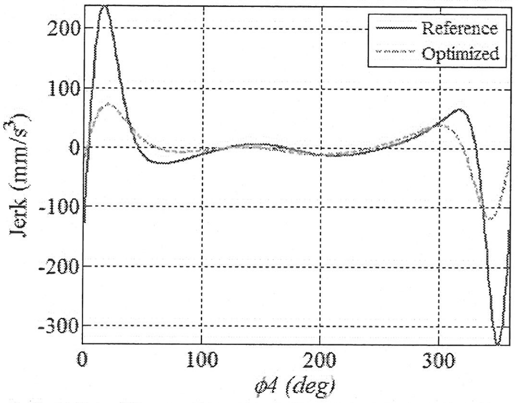


Fig. 7. Variation of the coupler point jerk in the vertical direction.

VII. CONCLUSION

The study presented here was dealing with optimization of a thread take-up lever in a typical lock stitch sewing machine. The motivation for this analysis was based on little contribution of the literature to this subject despite the inevitable role of this mechanism on the quality of the stitch formation. Therefore, the optimization problem was constructed for obtaining the optimal path of the coupler point to reducing the undesired vibration of the sewing machines by minimizing the coupler point jerk. The ICA optimization algorithm was utilized for this purpose. According to the obtained results, the optimized mechanism had clear superiority in comparison to the reference mechanism with respect to the required tasks. The results clearly justified the efficiency and reliability of suggested optimization formulation based on the ICA approach.

REFERENCES

[1] A. Chen, H. J. Zou and R. Du, "Modeling of industrial sewing machines and the balancing of thread requirement and thread supply" *J. Text. Inst.*, vol. 92, no.3, pp. 256–268, 2001.

[2] R. Krasowska, I. Frydrych and M. Rybicki, "Possibilities for modelling control conditions of the thread by disc thread take-up in the lockstitch formation zone", *Fibres Text. East. Eur.*, vol.14, no.1 pp. 68–72, 2006.

[3] R. L. Norton, *Design of Machinery: An Introduction to the Synthesis and Analysis of Mechanisms and Machines*, New York, McGraw-Hill, 2003,pp.123-128.

[4] R. A. Alizade, F. Freudenstein and P. R. Pamidi, "Optimum path generation by means of the skew four-bar linkage", *Mech. Mach. Theory*, vol. 11, no. 4, pp. 295–302, 1976.

[5] A. K. Mallik and S. G. Dhande, "Analysis and synthesis of mechanical error in path-generating linkages using a stochastic approach", *Mech. Mach. Theory*, vol. 22, no. 2, pp. 115–123, 1987.

[6] J. H. Rhyu and B. M. Kwak, "Optimal stochastic design of four-bar mechanisms for tolerance and clearance", *ASME J. Mech. Transm. Auto. Des.*, vol. 110, no 4, pp. 255–262, 1988.

[7] J. H. Choi, S. J. Lee and D. H. Choi, "Tolerance optimization for mechanisms with lubricated joints", *Multibody Syst. Dyn.*, vol 2, no. 2, pp.145–168, 1998.

[8] J. Angeles, A. Alivizatos and R. Akhras, "An unconstrained nonlinear least-square method of optimization of RRRR planar path generators", *Mech. Mach. Theory*, vol. 23, no. 5, pp. 343–353, 1988.

[9] R. Akhras and J. Angeles, "Unconstrained nonlinear least-square optimization of planar linkages for rigid-body guidance", *Mech. Mach. Theory*, vol. 25, no.1, pp. 97–118, 1990.

[10] J. Yao and J. Angeles, "Computation of all optimum dyads in the approximate synthesis of planar linkages for rigid body guidance" *Mech. Mach. Theory*, vol. 35, no. 8, pp. 1065–1078, 2000.

[11] A. Vasiliu and B. Yannou, "Dimensional synthesis of planar mechanisms using neural networks: application to path generator linkages", *Mech. Mach. Theory*, vol. 36, no. 2, pp. 299–310, 2001.

[12] F. T. Sánchez-Marín and P. González, "A global optimization in path synthesis based on design space reduction", *Mech. Mach. Theory*, vol. 38, no. 6, pp. 579–594, 2003.

[13] R. Sancibrian, F. Viadero, P. García and A. Fernández, "Gradient-based optimization of path synthesis problems in planar mechanisms", *Mech. Mach. Theory*, vol. 39, no. 8, pp. 839–856, 2004.

[14] H. Zhou and E. H. M. Cheung, "Analysis and optimal synthesis of adjustable linkages for path generation", *Mechatronics*, vol. 12, no.7, pp.949–961, 2002.

[15] J. A. Cabrera, A. Simon and M. Prado, "Optimal synthesis of mechanisms with genetic algorithms", *Mech. Mach. Theory*, vol. 37, no. 10, pp. 1165–1177, 2002.

[16] M. A. Laribi, A. Mlika, L. Romdhane and S. Zeghloul, "A combined genetic algorithm–fuzzy logic method (GA–FL) in mechanisms synthesis", *Mech. Mach. Theory*, vol. 39, no. 7, pp. 717–735, 2004.

[17] J. A. Cabrera, F. Nadal, J. P. Muñoz and A. Simon, "Multiobjective constrained optimal synthesis of planar mechanisms using a new evolutionary algorithm", *Mech. Mach. Theory*, vol. 42, no. 7, pp. 791–806, 2007.

[18] A. Smaili and N. Diab, "Optimum synthesis of hybrid-task mechanisms using ant-gradient search method", *Mech. Mach. Theory*, vol. 42, no. 1, pp. 115–130, 2007.

[19] H. Martínez-Alfaro, "Four-Bar Mechanism Synthesis for n Desired Path Points Using Simulated Annealing", in *Advances in Metaheuristics for Hard Optimization*, P. Siarry, and Z. Michalewicz Eds., Berlin: Springer, 2008, pp. 23–37.

[20] S. Erkaya and I. Uzmay, "A neural–genetic (NN–GA) approach for optimizing mechanisms having joints with clearance", *Multibody Syst. Dyn.*, vol. 20, no.1, pp. 69–83, 2008.

[21] R. Starosta, "Application of genetic algorithm and Fourier coefficients (GA-FC) in mechanism synthesis", *J. Theor. App. Mech.*, vol. 46, no. 2, pp. 395-411, 2008.

[22] R. R. Bulatović and S. R. Dordević, "On the optimum synthesis of a four-bar linkage using differential evolution and method of variable controlled deviations", *Mech. Mach. Theory.*, vol. 44, no. 1, pp.235–246, 2009.

[23] N. Nariman-Zadeh, M. Felezi, A. Jamali and M. Ganji, "Pareto optimal synthesis of four-bar mechanisms for path generation", *Mech. Mach. Theory.*, vol. 44, no. 1, pp. 180–191, 2009.

[24] S. K. Acharyya, M. Mandal, "Performance of EAS for four-bar linkage synthesis", *Mech. Mach. Theory.*, vol. 44, no.9, pp.784–1794, 2009.

[25] I. Ullah and S. Kota, "Optimal synthesis of mechanisms for path generation using Fourier descriptors and global search methods", *J. Mech. Des.*, vol. 119, no. 4, pp. 504-510, 1997.

[26] R. Ashok-Kumar, S. Anupam and N. D. Mankame, "Unified synthesis of compact planar path-generating linkages with rigid and deformable members", *Struc. Multidiscip. Optim.*, vol. 41, no. 6, pp. 863-879, 2010.

[27] W. Y. Lin, "A GA–DE hybrid evolutionary algorithm for path synthesis of four-bar linkage", *Mech. Mach. Theory*, vol. 45, no.8, pp. 1096–1107, 2010.

[28] M. Khorshidi, M. Soheilypour, M. Peyro, A. Atai and M. Shariat-Panahi, "Optimal design of four-bar mechanisms using a hybrid multi-objective GA with adaptive local search", *Mech. and Mach. Theory*, vol. 46, no. 10, pp. 1453–1465, 2010.

[29] S. B. Matekar and G. R.Gogate,"Optimum synthesis of path generating four-bar mechanisms using differential evolution and a modified error function", *Mech. Mach. Theory*, vol. 52, no.1, pp. 158-179, 2011.

[30] P. V. Chanekar and A. Ghosal, "Optimal synthesis of adjustable planar four-bar crank-rocker type mechanisms for approximate multi-path generation", *Mech. Mach. Theory*, vol. 69, pp.263–277, 2013.

[31] E. Atashpaz-Gargari and C. Lucas, "Imperialist competitive algorithm: an algorithm for optimization inspired by imperialistic competition", In: *Proceeding: IEEE congress: Evolutionary Computation International Conference*. Singapore; pp.4661–4667, 2007.

[32] Ş. Şerife, Ş. Ziya and Ö. Ziya, "Modification of the classical needle bar and thread take-up lever mechanism in sewing machines", *Fibres Text. East. Eur.*, vol. 93, no.4, pp. 108-111, 2011.

[33] R. Korycki and R. Krasowska, "Evaluation of the length distribution of needle thread within the take-up disc zone of a lockstitch machine", *Fibres Text. East. Eur.*, vol.70, no.5, pp. 94-100, 2008.

[34] S. G. Hayes, "The effects of check-spring travel on lockstitch sewing", *Res. J. Text. & Appar.*, vol.5, no. 2, pp. 54-64, 2001.

Appendix

1) Calculation of θ_3

According to Figure 1(b), the derivation process begins by writing the loop equation of the four-bar linkage as

$$r_1 + r_2 + r_3 - r_4 = 0$$

This relation equates the position of point A from two parts of the mechanism. Solving this vector equation results in the unknown angle θ_3 as

$$\theta_3 = 2\tan^{-1}\left(\frac{-B+\sqrt{B^2-4AC}}{2A}\right)$$

where, the parameters can be obtained from the following relations

$$A = K_3 - K_1;\ B = 2K_2;\ C = K_1 + K_3;$$

With

$$K_1 = \cos(\theta_4) + {dx}/{r_4};\ K_2 = \sin(\theta_4) + {dy}/{r_4}$$

$$K_3 = -\frac{(r_1^2 + r_3^2 + r_4^2 - r_2^2)}{2r_2r_3} - (d_x\cos(\theta_4) + d_j)$$

Parameters dx and dy specify the position of constant point C with respect to the origin O of the fixed coordinate frame X-Y.

2) Calculation of $\dot{\theta}_3$

The velocity analysis of the four-bar linkage results in

$$\dot{\theta}_3 = \frac{r_4\dot{\theta}_4\sin(\theta_4-\theta_2)}{r_3\sin(\theta_3-\theta_2)}$$

3) Calculation of $\ddot{\theta}_3$

By performing the acceleration analysis of the four-bar linkage one obtains

$$\ddot{\theta}_2 = \frac{K}{r_2r_3\sin(\theta_2-\theta_3)}$$

Where

$$K = \ddot{\theta}_4(A'E' - B'D') - r_3\cos(\theta_3)C' + r_3\sin(\theta_3)F'$$

And

$$A' = r_4\sin(\theta_4),\quad B' = r_3\sin(\theta_3),$$
$$D' = r_4\cos(\theta_4),\quad E' = r_3\cos(\theta_3),$$

$$C' = r_2\dot{\theta}_2^2\cos(\theta_2) + r_3\dot{\theta}_3^2\cos(\theta_3) - r_4\dot{\theta}_4^2\cos(\theta_4)$$

$$F' = -r_2\dot{\theta}_2^2\sin(\theta_2) - r_3\dot{\theta}_3^2\sin(\theta_3) + r_4\dot{\theta}_4^2\sin(\theta_4)$$

Then, after updating parameters C' and F' according to

$$C' = r_2\ddot{\theta}_2\sin(\theta_2) + C',\ \text{and}$$

$$F' = r_2\ddot{\theta}_2\cos(\theta_2) + F''$$

the rotational acceleration $\ddot{\theta}_3$ is written as

$$\ddot{\theta}_3 = \frac{C'D' - A'F'}{A'E' - E'D'}$$