Chapter Four
Results and Discussion

4. Results and Discussion:

This research presents a novel approach to verify and optimize surface of V beam micro electrothermal actuator using particle swarm optimization by MATLAB. several run will carry out for parameters to Determination the optimal dimensions of beam thickness h, gap between beam & substrate g, V beam width w, V beam length L, current density J developing more effective optimization techniques to achieve maximum angular displacement & output force which was not achieve in past designs or inaccurate optimization tool. It is obvious in the simulation of the electrothermal actuator angular displacement & output force can be improved.

Constrainsin this study roughly estimated for any parameter focusing on study the (PSO) and neglected factors can effect parameters limitations.

There are some parameters in PSO algorithm that may affect its performance. For any given optimization problem, some of these parameter's values and choices have large impact on the efficiency of the PSO method, and other parameters have small or no effect **[47, 48].** The basic PSO parameters are swarm size or number of particles, number of iterations, velocity components, and acceleration coefficients In addition; PSO is also influenced by inertia weight.

We estimated 10 particles due to huge amounts of particles increase the computational complexity per iteration, and more time consuming**,**100 iteration because a too low number of iterations may stop the search process prematurely**[47],**$C_2 > C_1$to make all particles are much more influenced by the global best position, which causes all particles to run prematurely to the optima**[49,50]** and The inertia weight implemented dynamically changing values, This decreasing inertia weight has produced good results in many optimization problems **[51].** Commonly, the inertia weight decreases linearly from 0.9 to 0.4 over the entire run**[47].**

It is obvious from the results when iteration go on, if the previous velocities of particles are close to zero, all particles stop moving once and they catch up with the global best position, which can lead to premature convergence of the process. This does not even guarantee that the process has converged to a local minimum; it only means that all particles have converged to the best position in the entire swarm. This leads to stagnation of the search process **[47].**

4.1. Parameterx_1: V beam thickness (h):

Figure (4.1) shows that V beam thickness (h) decrease as the entropy generation rate will decrease; the entropy generation rate will start to decrease gradually and rate of convergence for particles increase to optimal solution location when we increase the iteration. As it is clear from the figure, the optimal solution of h is50 μm, The Optimal solution of the entropy generation rate is 6.4545W/K, the particles entersstagnation zone in iteration number97. The variation due to particles may occasionally fly to a position beyond the defined search space which generateseither 1 when it cross overthe limit and 0 if it is under the limit during search the space.

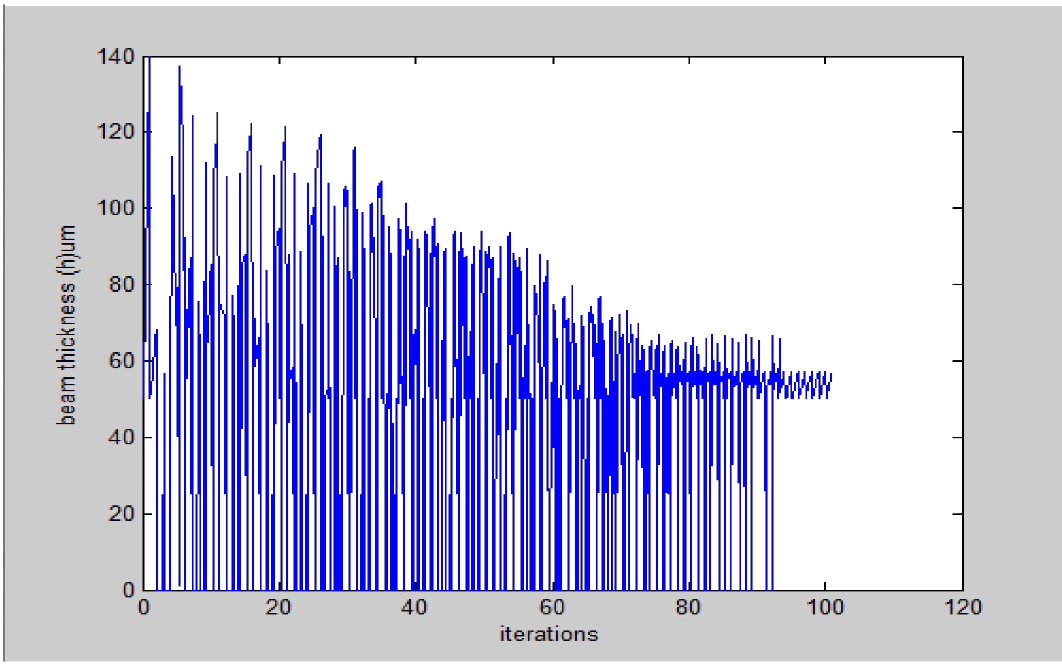

Figure (4.1) shows Variation of the optimum entropy generation rate and optimum V beam thickness (h) during iterations.

4.2. Parameterx_2:gap between beam & substrate (g):

Figure (4.2) shows that gap between beam & substrate (g)decrease as the entropy generation rate will decrease, the entropy generation rate will start to decrease gradually and rate of convergence for particles increase fast to optimal solution location when we increase the iteration. As it is clear from the figure, Less interaction occurs when the neighborhoods in the swarm are small **[49].**the optimal solution of g is 1 μm, The Optimal solution of the entropy generation rate is 9.8182 W/K, the particles enters stagnation zone in iteration number 3,most particles set to 0 which change the global solution position to became under the limit by making velocity very low. Limited Variation due tosmall search and all particles pass under the limit set to 0.

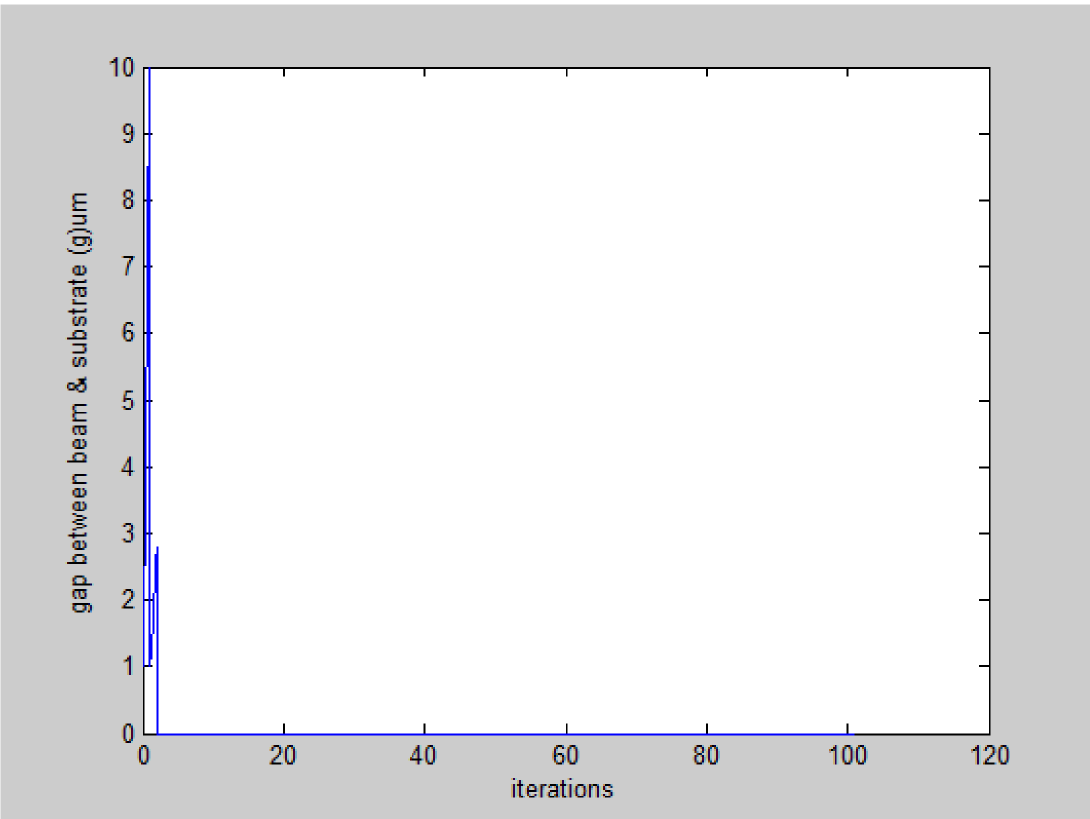

Figure (4.2) shows Variation of the optimum entropy generation rate and optimum gap between beam & substrate (g) during iterations.

4.3. Parameter x_3:V beam width (w):

Figure (4.3) shows that V beam width (w) increase as the entropy generation rate will decrease; the entropy generation rate will start to decrease gradually and rate of convergence for particles increase very fast to optimal solution location when we increase the iteration. As it is clear from the figure, particle velocities build up too fast and the maximum of the objective function is passed over**[47]**. For larger neighborhood, the convergence will be faster but the risk that sometimes convergence occurs earlier **[52].**

the optimal solution of w is 20 μm, The Optimal solution of the entropy generation rate is 6.25W/K, the particles enters stagnation zone in iteration number 2.less variation occurs due to all particles that cross over the limit set to 1 during search the space .

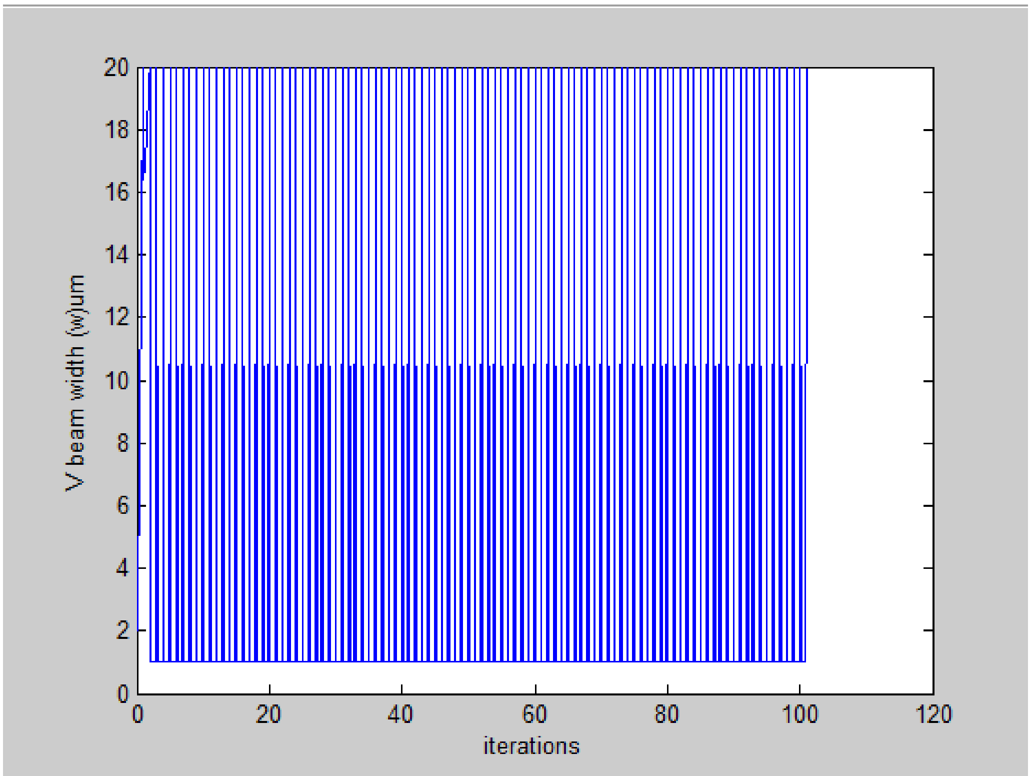

Figure (4.3) shows Variation of the optimum entropy generation rate and optimum V beam width (w) during iterations.

4.4. Parameterx_4: V beam length (L):

Figure (4.4) shows that V beam length (L) decrease as the entropy generation rate will decrease, the entropy generation rate will start to decrease gradually and rate of convergence for particles increase to optimal solution location when we increase the iteration. As it is clear from the figure, the optimal solution of L is 500 μm, The Optimal solution of the entropy generation rate is 10.5455 W/K, the particles enters stagnation zone in iteration number 74. The variation due to particles may occasionally fly to a position beyond the defined search space which generates either 1 when it cross over the limit and 0 if it is under the limit during search the space.

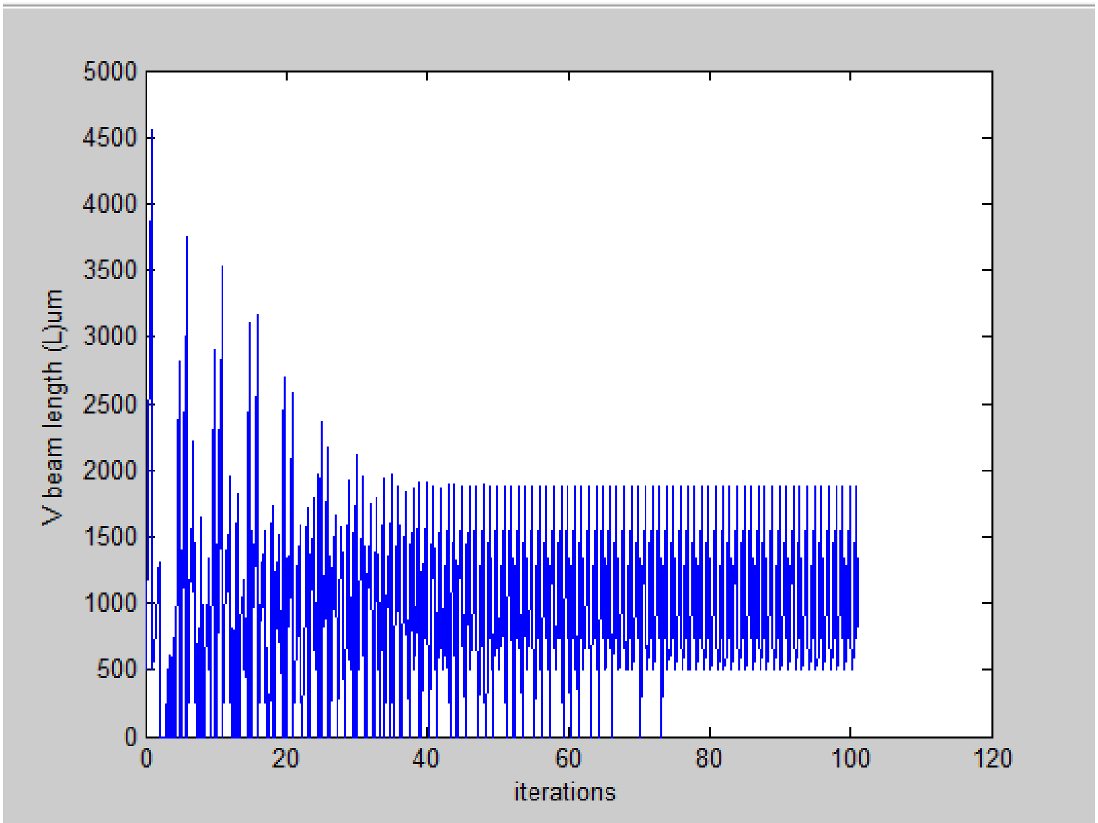

Figure (4.4) shows Variation of the optimum entropy generation rate and optimum V beam Length (L) during iterations.

4.5. Parameterx_5:V beam current density (J):

Figure (4.5) shows that V beam current density (J) decrease as the entropy generation rate will decrease, the entropy generation rate will start to decrease gradually and rate of convergence for particles increase to optimal solution location when we increase the iteration. As it is clear from the figure, the optimal solution of J is 0.1A/μm^2, The Optimal solution of the entropy generation rate is 10.5455 W/K, the particles enters stagnation zone in iteration number 65. The variation due to particles may occasionally fly to a position beyond the defined search space which generates either 1 when it cross over the limit and 0 if it is under the limit during search the space.

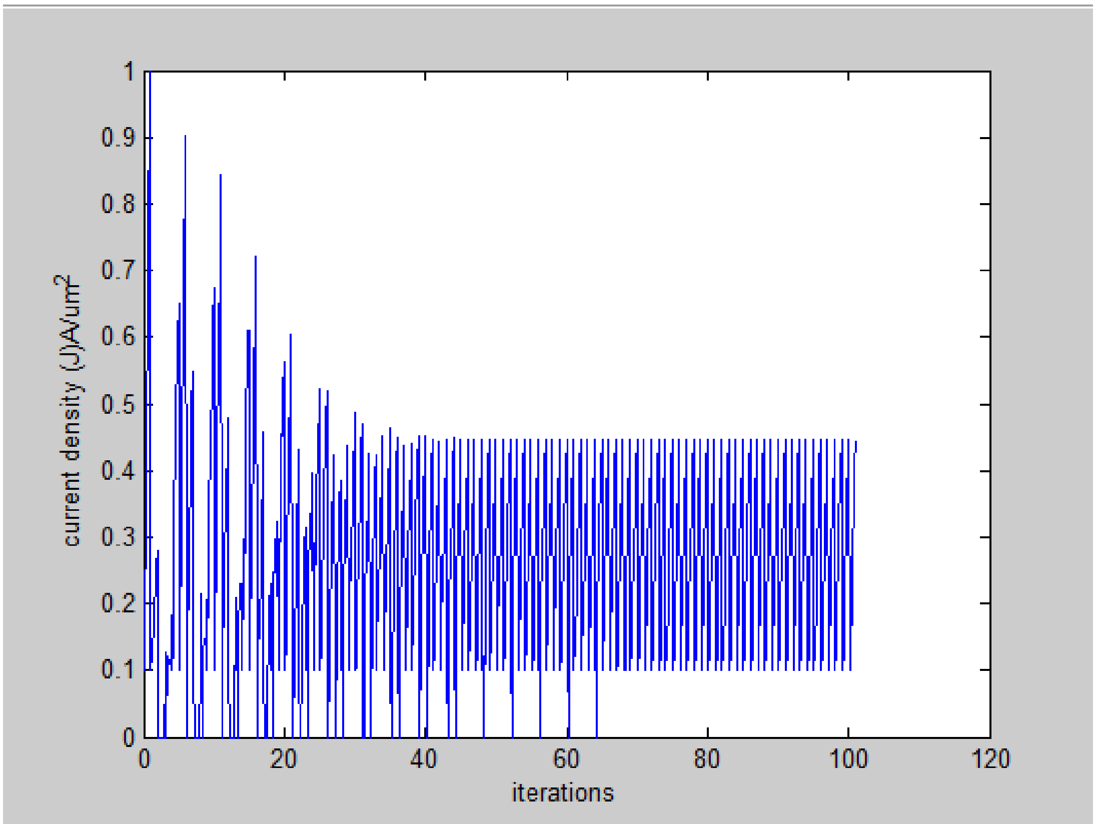

Figure (4.5) shows Variation of the optimum entropy generation rate and optimum V beam current density (J) during iterations.

Table 4.1 gives the summarized results for parameters and obtained values by applying PSO method:

h(μm)	$g(\mu m)$	w(μm)	L(μm)	J(A /µm²)	$S(\frac{W}{K})$	$F_t(\mu N)$	$U(\theta)(\frac{degree}{\mu m})$
50	1	20	500	0.1	3.6	6259.6	8.75*10^{-8}

4.6. Example of PSO implementation for parameter x_1 :

Step1: Choose the number of particles:

$$x_1 = 50, x_2 = 60, x_3 = 70, x_4 = 80, x_5 = 90, x_6 = 100,$$
$$x_7 = 110, x_8 = 120, x_9 = 130, x_{10} = 140.$$

The initial population (i.e. the iteration number t = 0) can be represented as:
x_i^0, i=1, 2,3,4,5,6,7,8,9,10.

$x_1^0 = 50, x_2^0 = 60, x_3^0 = 70, x_4^0 = 80, x_5^0 = 90, x_6^0 = 100, x_7^0 = 110, x_8^0 = 120, x_9^0 = 130,$
$x_{10}^0 = 140.$

Evaluate the objective function equation (3.10) & (3.11) values as

$$s = \frac{2.39875x_1 + 0.239875x_1^2 + p}{p} \qquad (3.10)$$

$$p = 2.638625x_1 \qquad (3.11)$$

$$p_1^0 = 2.638625 * 50 = 131.93$$

$$S_1^0 = \frac{2.39875 * 50 + 0.239875 * 50^2 + 131.93}{131.93} = 6.4545$$

$$p_2^0 = 2.638625 * 60 = 158.3175$$

$$S_2^0 = \frac{2.39875 * 60 + 0.239875 * 60^2 + 158.3175}{158.3175} = 7.3636$$

$$p_3^0 = 2.638625 * 70 = 184.7037$$

$$S_3^0 = \frac{2.39875 * 70 + 0.239875 * 70^2 + 184.7037}{184.7037} = 8.2727$$

$$p_4^0 = 2.638625 * 80 = 211.09$$

$$S_4^0 = \frac{2.39875 * 80 + 0.239875 * 80^2 + 211.09}{211.09} = 9.1818$$

$$p_5^0 = 2.638625 * 90 = 237.74625$$

$$S_5^0 = \frac{2.39875 * 90 + 0.239875 * 90^2 + 237.74625}{237.74625} = 10.0909$$

$$p_6^0 = 2.638625 * 100 = 263.8625$$

$$S_6^0 = \frac{2.39875 * 100 + 0.239875 * 100^2 + 263.8625}{263.8625} = 11.0000$$

$$p_7^0 = 2.638625 * 110 = 290.2487$$

$$S_7^0 = \frac{2.39875 * 110 + 0.239875 * 110^2 + 290.2487}{290.2487} = 11.9091$$

$$p_8^0 = 2.638625 * 120 = 316.635$$

$$S_8^0 = \frac{2.39875 * 120 + 0.239875 * 120^2 + 316.635}{316.635} = 12.8182$$

$$p_9^0 = 2.638625 * 130 = 343.0212$$

$$S_9^0 = \frac{2.39875 * 130 + 0.239875 * 130^2 + 343.0212}{343.0212} = 13.7273$$

$$p_{10}^0 = 2.638625 * 140 = 369.4075$$

$$S_{10}^0 = \frac{2.39875 * 140 + 0.239875 * 140^2 + 369.4075}{369.4075} = 14.6364$$

Assume random numbers: rand1r_1=0.5, rand2 , r_2=0.4

Cognitive learning factor c_1=1

Social learning factor c_2 = 2

Set the initial velocities of each particle to zero:

$$V_i^0 = 0, V_1^0 = V_2^0 = V_3^0 = V_4^0 = V_5^0 = V_6^0 = V_7^0 = V_8^0 = V_9^0 = V_{10}^0 = 0$$

Step2: Set the iteration number as and go to step 3.

Iterations =100

Step3: Find the personal best for each particle by:

$$P_{pest,i}^{t+1} = \begin{cases} P_{pest,i}^{t} \ if \ S_i^{t+1} > P_{pest,i}^{t} \\ x_i^{t+1} \ if \ S_i^{t+1} \leq P_{pest,i}^{t} \end{cases}$$

So

$$P_{pest,1}^1 = 50, P_{pest,2}^1 = 60, P_{pest,3}^1 = 70.$$
$$P_{pest,4}^1 = 80, P_{pest,5}^1 = 90, P_{pest,6}^1 = 100.$$
$$P_{pest,7}^1 = 110, P_{pest,8}^1 = 120, P_{pest,9}^1 = 130, P_{pest,10}^1 = 140.$$

Step4: Find the global best by:

$$G_{pest} = \min\{P_{pest,i}^t\} \quad where \ i = 1,2,3,4,5,6,7,8,9,10$$

Since, the minimum personal best is $P_{pest,1}^1 = 50$ then $G_{pest} = 50$

Step5: find the new velocities of the particles by:

$$V_i^{t+1} = \mathrm{W} * V_i^t + \sigma_1 * \mathrm{rand}_1\left[P_{pest,i}^t - X_i^t\right] + \sigma_2 \mathrm{rand}_2\left[G_{pest}^t - X_i^t\right] \quad (2.1)$$

$V_1^1 = 0.9 * 0 + 1 * 0.5[50 - 50] + 2 * 0.4[50 - 50] = 0$

$V_2^1 = 0.9 * 0 + 1 * 0.5[60 - 60] + 2 * 0.4[50 - 60] = -8$

$V_3^1 = 0.9 * 0 + 1 * 0.5[70 - 70] + 2 * 0.4[50 - 70] = -16$

$V_4^1 = 0.9 * 0 + 1 * 0.5[80 - 80] + 2 * 0.4[50 - 80] = -24$

$V_5^1 = 0.9 * 0 + 1 * 0.5[90 - 90] + 2 * 0.4[50 - 90] = -32$

$V_6^1 = 0.9 * 0 + 1 * 0.5[100 - 100] + 2 * 0.4[50 - 100] = -40$

$V_7^1 = 0.9 * 0 + 1 * 0.5[110 - 110] + 2 * 0.4[50 - 110] = -48$

$V_8^1 = 0.9 * 0 + 1 * 0.5[120 - 120] + 2 * 0.4[50 - 120] = -56$

$V_9^1 = 0.9 * 0 + 1 * 0.5[130 - 130] + 2 * 0.4[50 - 130] = -64$

$$V_{10}^1 = 0.9 * 0 + 1 * 0.5[140 - 140] + 2 * 0.4[50 - 140] = -72$$

Step6: Find the new values of X_i^{t+1} by:

$$X_i^{t+1} = X_i^t + V_i^{t+1} \qquad (2.2)$$

So

$X_1^1 = 50 + 0 = 50$

$X_2^1 = 60 - 8 = 52$

$X_3^1 = 70 - 16 = 54$

$X_4^1 = 80 - 24 = 56$

$X_5^1 = 90 - 32 = 58$

$X_6^1 = 100 - 40 = 60$

$X_7^1 = 110 - 48 = 62$

$X_8^1 = 120 - 56 = 64$

$X_9^1 = 130 - 64 = 66$

$X_{10}^1 = 140 - 72 = 68$

Step7: Find the objective function values of X_i^1, i=1,2,3,4,5,6,7,8,9,10:

$S_1^1 = 6.4545$, $S_2^1 = 6.6363$, $S_3^1 = 6.8181$, $S_4^1 = 7.0000$

$S_5^1 = 7.1818$, $S_6^1 = 7.3636$, $S_7^1 = 7.4545$.

$S_8^1 = 7.7272$, $S_9^1 = 7.9090$, $S_{10}^1 = 8.0909$.

Step 8: Stopping criterion:

If the terminal rule is satisfied, go to step 2, otherwise stop the iteration and output the results.

Table 4.2 gives the summarized results of PSO method compared to Chengkuo Lee results:

	h(μm)	g(μm)	w(μm)	L(μm)	$J(A/\mu m^2)$	$S(\frac{W}{K})$	$F_t(\mu N)$	$U(\theta)(\frac{degree}{\mu m})$
Current work	50	1	20	500	0.1	3.6	6259.6	$8.75*10^{-8}$
Chengkuo Lee	85	NA	6	3200	NA	NA	3750	NA

The research take five parameter while in other study take three parameters to optimized V-beam, the length(L) of V-beam in current study reduced 84% That Implies less material is needed and cost compared, the V-beam width (w) is increase by 70% to maintain good thermal necessity with more structure and cost, V-beam thickness (h) reduced by 37.5% in current work and the force output(F_t) is increase by 40% compared to Chengkuo Lee.