Science Publications

Online Journal of Mechanical Engineering, 2023, 1, 596
www.scipublications.org/journal/index.php/ojme
DOI: 10.31586/ojme.2022.596

Article

Balancing of Planar Eight –Bar Mechanism using Genetic Algorithm

Basayya K. Belleri[1,*],Dayanand M. Goudar[1], Shravankumar B. Kerur[2]

[1]Department of Mechanical Engineering, Tontadarya College of Engineering, Gadag, India
[2]Department of Mechanical Engineering, Basaveshwar Engineering College, Bagalkot, India

*Correspondence: Basayya K. Belleri (basayyakb@gmail.com)

Abstract: In the current study, the eight-bar planar mechanism is balanced by reducing variations in shaking force and moments using Minitab and a genetic algorithm. The objective function and constraint equations are taken into consideration, the mathematical model was developed to optimize the balancing of the planar eight-bar mechanism.A set of weighting factors were taken into consideration in order to determine the ideal values for the design parameters based on the contributions of the X and Y components of the shaking force and the shaking moment. A genetic algorithm was used to find the best design parameters. The results showed that the shaking force and moments decreased by 34.5 and 61% from the initial values, respectively.

Keywords: Shaking force, Shaking moment, Dynamic balancing, Eight-bar mechanism, Genetic Algorithm

How to cite this paper:
K. Belleri, B., M. Goudar, D., & B. Kerur, S. (2023). Balancing of Planar Eight –Bar Mechanism using Genetic Algorithm. *Online Journal of Mechanical Engineering*, *1*(1), 42–52. Retrieved from https://www.scipublications.com/journal/index.php/ojme/article/view/596

Received: December 9, 2022
Accepted: February 5, 2023
Published: February 7, 2023

1. Introduction

The dynamics of mechanisms is the study of balanced and unbalanced forces acting on the parts and also accounting for the masses, accelerations. The dynamic performance characteristics of mechanisms, such as shaking force, shaking moment, and input torque are influenced by the masses and locations of the mass centres of each moving link. The link masses must be distributed as evenly as possible in order to reduce the shaking force and shaking moment. Reduced variations in shaking force and moment are necessary for dynamic balancing, which prolongs the mechanism's fatigue life. Cheng-HO Li and Pei-Lum TSO [1] suggested linkage balance and counterweight discs as a method for reducing shaking force and moment. S. The method of linearly independent mass vectors was used by Balasubramanian et al. [2] to present the design equations for the complete shaking force balancing of planar Stephenson's and Watt's type 6R 6-bar slider-crank regular force transmission mechanisms. In comparison to using external loads, Design equations and procedures were created by Gao Feng et al. [3] for perfectly balancing the shaking force and shaking moments of linear and rotary inertia of various six-bar linkage types. For servo mechanical presses with high mechanical advantage, Jianguo Hu et al. [4] developed the two-phase design scheme of Stephenson's six-bar working mechanisms. Using simulations built on the ADAMS software, the transmission properties of the symmetrical toggle mechanism, the slider-crank mechanism, and the optimised working mechanism were compared. Using computer simulation and experimental techniques, From both a kinematic and dynamic perspective, Dewen Jin et al[5] .'s investigation looked at the benefits of the mechanism used in prosthetic knees. Comparing the outcomes of the six-bar and four-bar mechanisms' predictions of the ankle joint trajectory during the swing phase. KailashChoudhary et al. [6] used HyperWorks to determine the shaking force and shaking moment for a complete rotation of motion. For Stephenson's six-bar mechanism, an MBD simulation was run using Motion Solve [6]. Sebastian Briot et al. [7] used a coupler link and a class-two assur group with predetermined geometrical and mass parameters to perfectly balance the shaking force and shaking moment. P. Nehemiah et al. [8] presented a technique for balancing the rotary inertia-driven shaking force and moments of three different kinds of four-bar linkages. MATLAB was used to calculate the dynamic force analysis of the four-bar mechanism, and variable topology was used to add the six-bar mechanism [9]. F. C. Chen et al. [10] used the Taguchi method to examine the effects of manufacturing tolerance and joint clearance on the quality of the dual-purpose six-bar mechanism. Erkaya et al. [11] investigated a 2D articulated mechanism to minimise the shaking force and shaking moment fluctuations by selecting weighing factors.

Using Minitab and a genetic algorithm approach, a set of weighing factors were considered in the present study to optimise the dynamic balancing of an eight-bar mechanism.

2. Methodology

2.1. Determination of joint forces

The eight-bar mechanism as shown in Figure 1 consists of three loops of four-bar mechanisms, ABCD (Loop-1), DCEF (Loop-2) and FEGH (Loop-3). Input torque required on the crank and forces at the joints were calculated using variable topology [9]. The outputs of the first loop were taken as an inputs for the second loop 2 and outputs of the second were considered as inputs for the third loop of four-bar mechanism. The position, velocity, acceleration and forces were calculated. Combining loops 1 and 2 allowed us to determine the joint forces that resulted at joints C and D. Combining loops 2 and 3 allowed us to determine the joint forces at joints E and F.

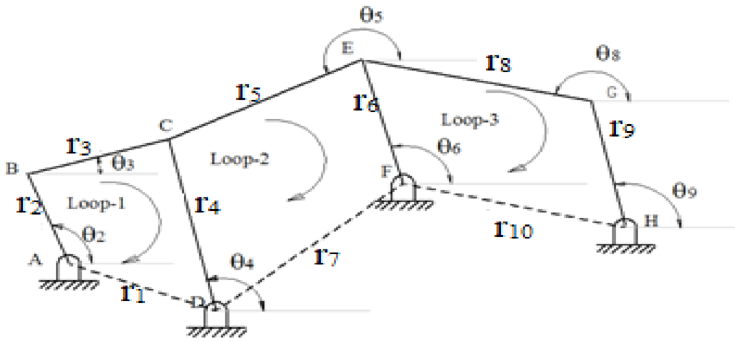

Figure 1. Eight-bar mechanism

2.2. Shaking force and shaking moment

The equations 1 and 2 were used to calculate shaking force and shaking moment at fixed joints A, D and F

$$F_{sh} = F_{21} + F_{41} + F_{47} + F_{67} + F_{610} + F_{910} \tag{1}$$

$$M_{sh} = T_{21} + (r_1 * F_{41}) + T_{47} + (r_7 * F_{67}) + T_{610} + (r_{10} * F_{910}) \tag{2}$$

2.3. Optimization Process

Both the shaking force and shaking moment must be removed or decreased for the mechanism to be dynamically balanced completely. The mechanism's shaking force can be greatly reduced by adding counterweights to its moving links, while doing so increases the mechanism's overall mass and inertia, which enlarges the shaking moment. In the current study, the design parameters listed in Table 1 were optimised using a genetic algorithm approach to reduce the shaking force and shaking moment for balancing an eight-bar mechanism.

MINITAB was used to obtain the regression equation for the 38 design variables. The obtained regression equation served as the fitness function, and a genetic algorithm was used to optimise all 38 design parameters. For optimization, the following objective function was taken into account.

Minimize

$$F(x) = \sum_{n=1}^{\infty}[(\mathrm{W_1(F_{21x_n}) + W_2(F_{21y_n}) + W_3(F_{41x_n} + F_{47x_n}) + W_4(F_{41y_n} + F_{47y_n})} \\ \mathrm{+ W_5(F_{67x_n} + F_{610x_n}) + W_6(F_{67y_n} + F_{610y_n}) + W_7(F_{910x_n}) + W_8(F_{910y_n})} \\ \mathrm{+ W_9(M_{sh_n})}]$$

Subject to

$$\mathrm{x_r^{min} \leq x_r \leq x_r^{max};\ \ x_r \epsilon X;\ \ g_k(X) \leq 0} \tag{3}$$

Weighting factors (Wh) and number of the points (s) considered during the one revolution of the crank. X is the vector consisting of 38 independent design variables (xr).

X=[Li δi mi Igirgi]T

The link lengths, structural angles, masses, moment of inertia of moving links, and position vectors, respectively, are Li, δi, mi, Igi and rgi. The lower and upper limits of the design parameters are Li-0.1xLi and Li+0.1xLi respectively are set as the lower and upper bounds for link lengths. The minimum and maximum structural angles (δi) are taken to be 00 and 3600, respectively. The link geometries were taken into consideration when arranging the lower and upper bounds for ‘mi’, ‘Igi’, ‘rg2’, ‘rg3’ and ‘ rg4’. The following requirement must be met by each weighting factor [11].

$$0 \leq \mathrm{W_h} \leq 1 \mathrm{and} \textstyle\sum_{h=1}^{9} \mathrm{W_h} = 1$$

The selected weighting factors are W1=0.14, W2=0.09, W3=0.111, W4=0.031, W5=0.262, W6=0.09, W7=0.15, W8=0.065, W9=0.061

3. Results and Discussion

The pin forces and input driving torque of the mechanism for the original value were calculated using MATLAB. A Genetic algorithm was used to determine the optimum design parameters by assuming an objective function which was based on the subcomponents of shaking force and shaking moments. Table 1 displays 38 parameters' initial values and the mechanism's constant operating speed of 300 rpm. The X and Y components of the forces acting on the ground, as well as their moment, were used to determine the weighting factors. The obtained optimum design variables were shown in the table1.

Table1. Original and optimized parameters of eight-bar mechanism

Sl. No.	Parameter	Description	Original Value	Optimized Value
1	r_1(mm)	Length of fixed link	600	540
2	r_2(mm)	Length of crank	100	90
3	r_3(mm)	Length of coupler	400	450
4	r_4(mm)	Length of follower	320	270
5	r_7(mm)	Length of fixed link	500	450
6	r_5(mm)	Length of coupler	500	450

7	r_6(mm)	Length of follower	330	330
8	r_{10}(mm)	Length of fixed link	600	540
9	r_8(mm)	Length of coupler	550	500
10	r_9(mm)	Length of follower	400	360
11	m_2 (kg)	Mass of crank	0.36	0.36
12	m_3(kg)	Mass of coupler	1.296	0.75
13	m_4 (kg)	Mass of follower	1.046	0.75
14	m_5 (kg)	Mass of coupler	0.36	0.36
15	m_6 (kg)	Mass of follower	1.046	0.75
16	m_8 (kg)	Mass of coupler	0.36	0.36
17	m_9 (kg)	Mass of follower	1.046	1.046
18	δ_2 (degree)	Structural angle of crank	0	0
19	δ_3 (degree)	Structural angle of coupler	0	329
20	δ_4 (degree)	Structural angle of follower	0	0.016
21	δ_5 (degree)	Structural angle of coupler	0	0
22	δ_6 (degree)	Structural angle of follower	0	355
23	δ_8 (degree)	Structural angle of coupler	0	0
24	δ_9 (degree)	Structural angle of follower	0	0355
25	Ig_2 (kg m2)	Inertia moment of crank	4.13 x 10-4	2.0 x10-4
26	Ig_3 (kg m2)	Inertia moment of coupler	1.87 x 10-2	0.008
27	Ig_4 (kg m2)	Inertia moment of follower	9.87 x 10-3	0.02
28	Ig_5 (kg m2)	Inertia moment of coupler	1.87 x 10-2	0.0187
29	Ig_6(kg m2)	Inertia moment of follower	9.87 x 10-3	9.85 x 10-3
30	Ig_8 (kg m2)	Inertia moment of coupler	1.87 x 10-2	0.018
31	Ig_9 (kg m2)	Inertia moment of follower	9.87 x 10-3	0.00985
32	rg_2(mm)	Position vector of crank	50	50
33	rg_3(mm)	Position vector of coupler	200	200
34	rg_4(mm)	Position vector of follower	160	160
35	rg_5(mm)	Position vector of coupler	200	200
36	rg_6(mm)	Position vector of follower	160	145
37	rg_8(mm)	Position vector of coupler	200	180
38	rg_9(mm)	Position vector of follower	160	162

The variation of force at joint-A with a crank angle before and after optimization is shown in Figure 2. Before optimization, a maximum value of 398.6 N occurred at a crank angle of 180^0, and that was reduced to 134.45 N after optimization. For one rotation of the crank, 45% of the forces at joint-A are reduced. It is also observed from the figure that the erratic forces are eliminated after optimization.

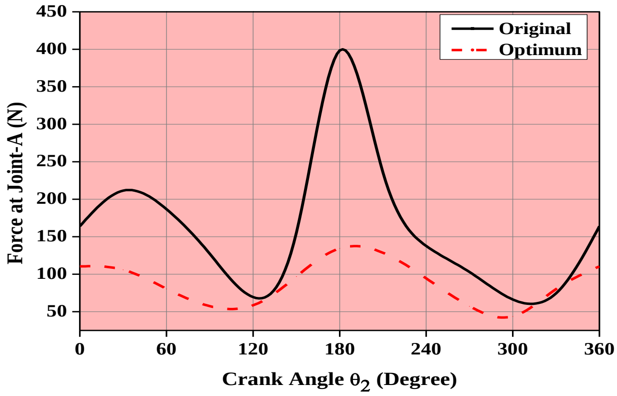

Figure 2. Variation of Force at joint-A with Crank angle (θ_2)

The forces at joint-B against crank positions before and after optimization are plotted in Figure 3. Before optimization, the maximum force of 381.5 N was acting at a crank angle of 180^0 as the acceleration of the link-3 is maximum at the same crank position. After optimization, that force is reduced to 117 N due to the reduction in the angular acceleration of the link-3 at the same angular position after optimization. The forces at joint-B were decreased by 50% after optimization.

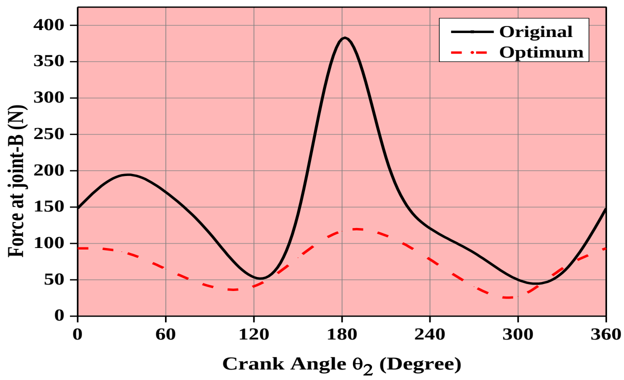

Figure 3. Variation of Force at joint-B with Crank angle (θ_2)

Before and after optimizing the design parameters, the force acting at joint-C for one rotation of the crank is shown in Figure 4. The angular accelerations of CG's of link-3, link-4, and link-5 reach their maximum value at a crank angle of 180^0, which results in obtaining the maximum force of 376.25 N before optimization and that is reduced to 71.37 N after optimization. The forces at joint-C are reduced by 53.1% after optimization. It is also observed from the figure that, after optimization, the graph obtained for the force at joint-C is smooth.

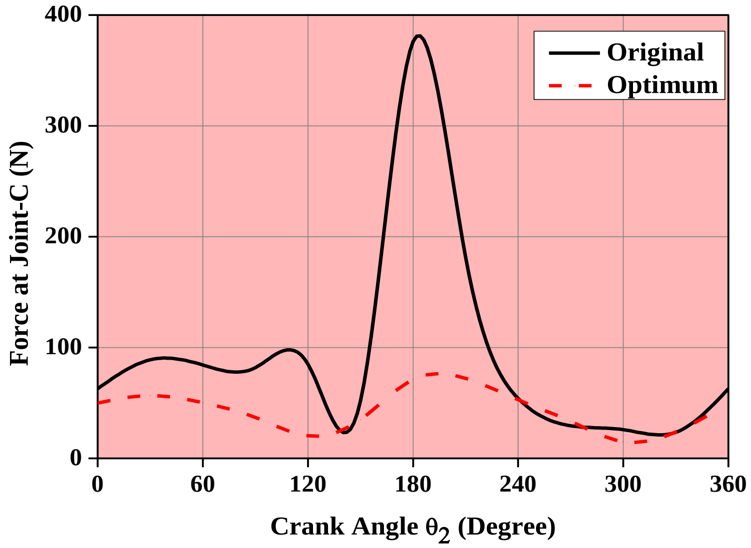

Figure 4. Variation of Force at joint-C with Crank angle (θ_2)

Loop-I and loop-II are connected at joint-D at the frame. Figure 5 illustrates the force acting at joint-D for one rotation of the crank before and after optimization. It is noted from the figure that the maximum force of 443.9 N is acting because of the maximum angular acceleration of CG of the link-4 at a crank angle of 180^0 and reduced to 69 N after optimization. It is also observed from the figure that, 65% of the forces are reduced and erratic forces are eliminated by the optimization process.

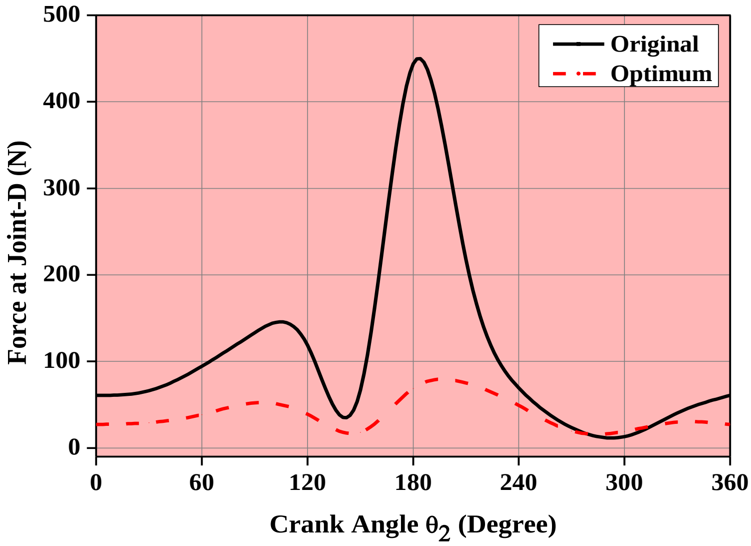

Figure 5. Variation of Force at joint-D with Crank angle (θ_2)

The forces before and after optimization at joints E, F, G, and H against the crank angle are shown in Figs. 6 to Figure 9, respectively. It is observed from all the figures that the maximum forces are obtained for a crank angle of 180^0 because the maximum accelerations of links 5, 6, 8, and 9 are acting at the same crank angle, and after optimization, the forces at these joints are drastically reduced.

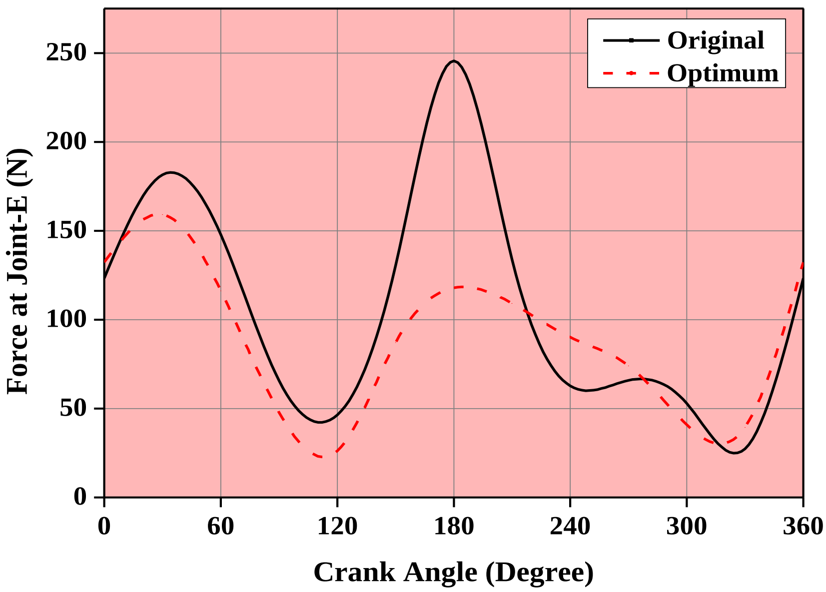

Figure 6. Variation of Force at joint-E with Crank angle (θ_2)

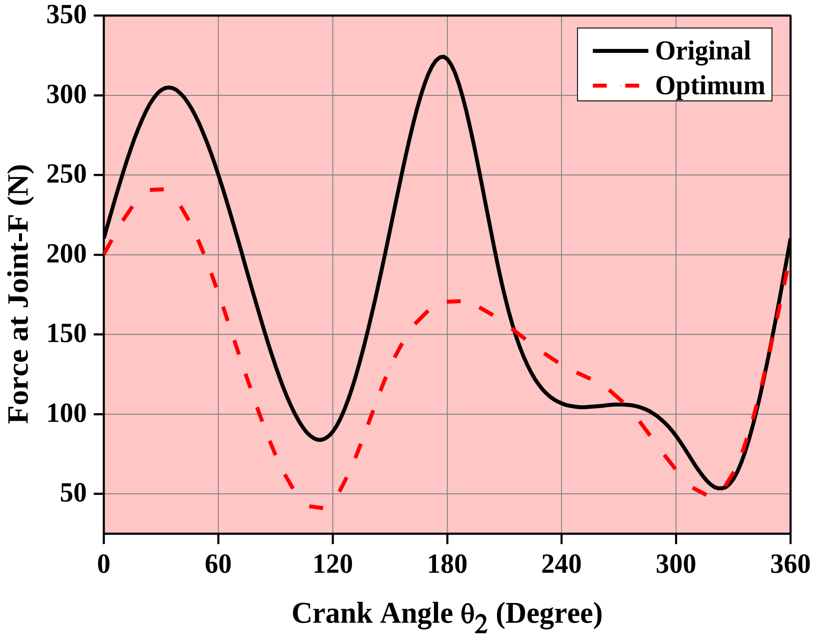

Figure 7. Variation of Force at joint-F with Crank angle (θ_2)

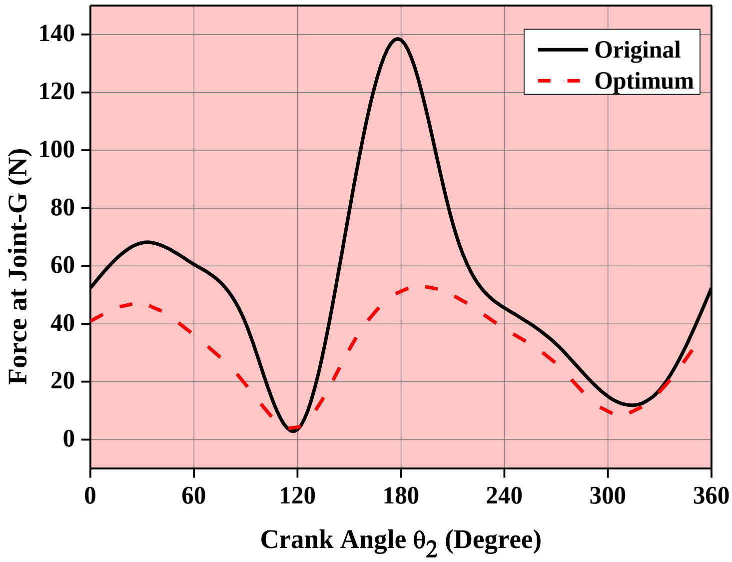

Figure 8. Variation of Force at joint-G with Crank angle (θ_2)

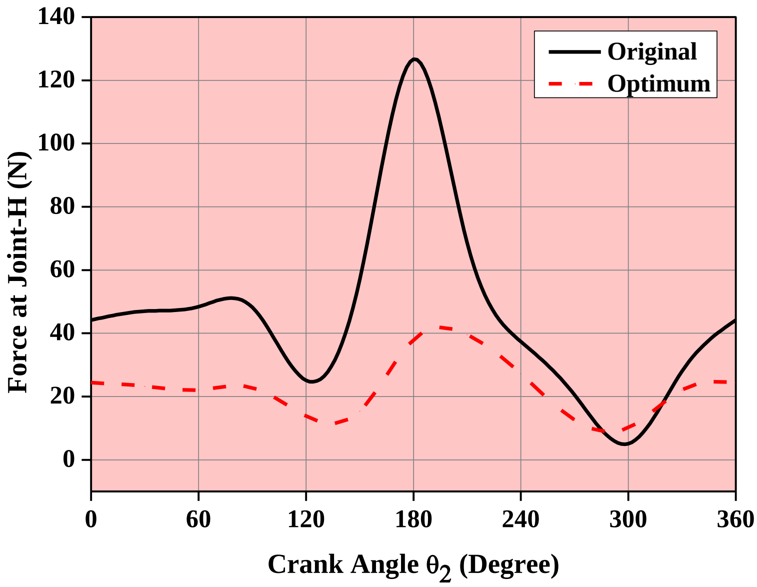

Figure 9. Variation of Force at joint-H with Crank angle (θ_2)

Figure 10 illustrates the shaking force acting on the frame before and after optimization for one rotation of the crank. It is observed from the figure that the maximum shaking forces of 693.6N and 584N are acting at crank angles of 180^0 and 30^0, and these forces are reduced to 302N and 392.8N, respectively, after the optimization process. It is also observed that the shaking forces are reduced by 34.5% after optimization.

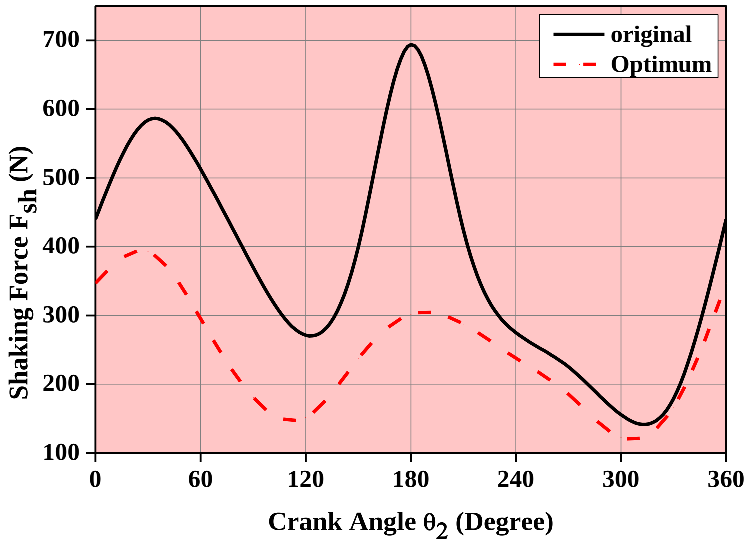

Figure 10. Variation of Shaking Force (F_{sh}) with Crank angle (θ_2)

The variation of the shaking moments before and after optimization for one crank rotation is shown in Figure 11. It is observed from the figure that the shaking moment is maximum (-149.8Nm) at a crank angle of 180^0 and decreases to -18.26Nm after optimization. 61% of the shaking moment is reduced during one rotation of the crank. During one rotation of the crank, the shaking moments varied between -42.9Nm and 34.1Nm, whereas before optimization, the shaking moments vary between -149.8Nm and 84.4Nm.

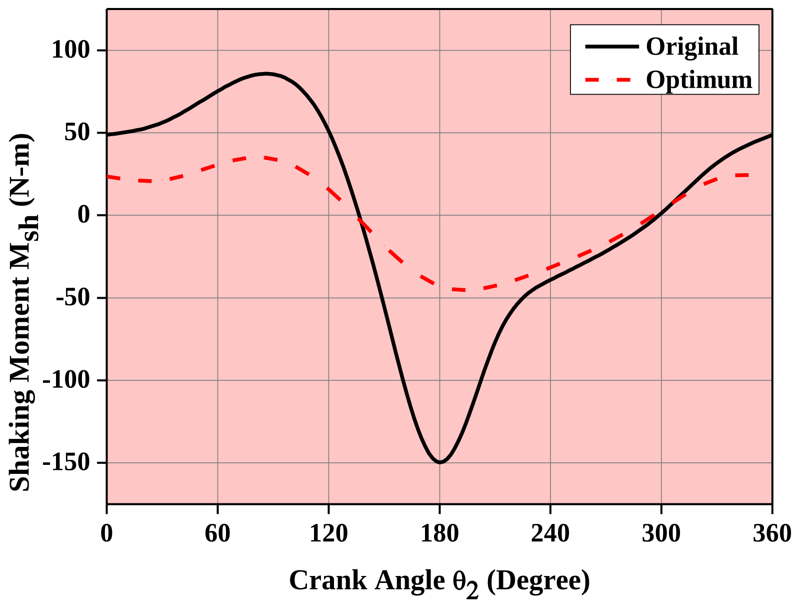

Figure 11. Variation of Shaking Moment (M_{sh}) with Crank angle (θ_2)

The torque required on the crank (link-2) against the crank angle before and after optimization is shown in Figure 12. Before optimization, the torque required on the crank varies from 7.77 Nm to 12.74 Nm, whereas after optimization, varies from 4.45 Nm to 5.83 Nm.

The value of the objective function against crank angle before and after optimization is shown in Figure 13. It is observed from the figure that, after optimization, the objective values are drastically reduced, which shows the obtained design parameters are well optimized

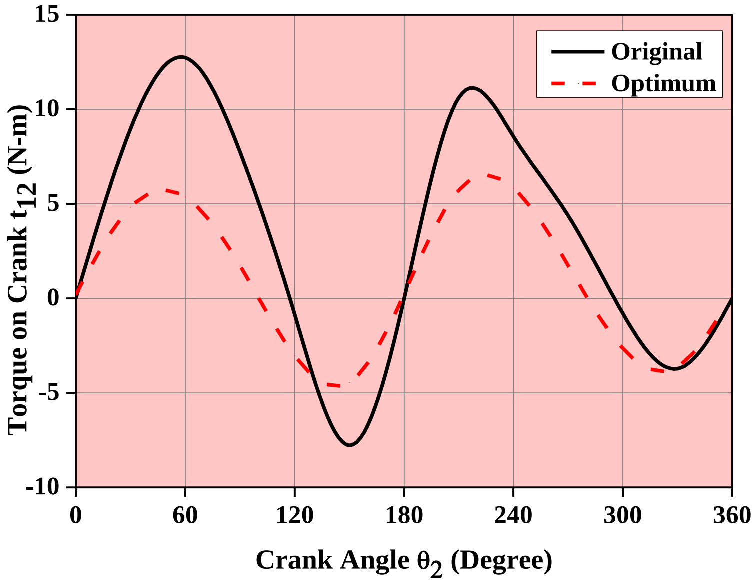

Figure 12. Variation of Torque (t12) with Crank angle (θ2)

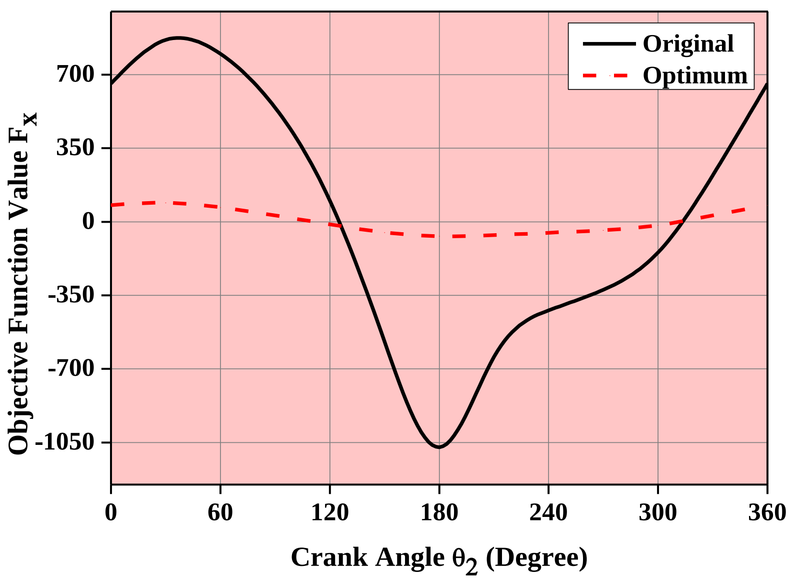

Figure 13. Variation of value of Objective Function (Fx) with Crank angle (θ2)

4. Conclusion

In this study, an optimization technique called a genetic algorithm was used to investigate the shaking force and shaking moment for balancing the eight-bar mechanism by taking a set of weighing factors. The regression equation was generated using Minitab software and used as a fitness function in a genetic algorithm. By adjusting the weighting factors, the investigation's findings show what design variables are best.

Shaking force and moment were decreased by 34.53% and 61%, respectively, after optimization. The four joint forces at the frame (joints-A, D, F, and H) are reduced by 44.64%, 65%, 22.1%, and 50.7%, respectively, resulting in a 69.68% reduction in the torque required on the crank. Additionally, there was a significant decrease in the forces at other joints as well as an 89.3% reduction in the objective function value.

References

[1] Cheng-Ho Li and Pei-Lum Tso, The study of Dynamic balancing for High-Speed Presses, JSME International Journal, Series C, Vol 49, No. 3, 2006.

[2] S. Balasubramanian and CemilBagci., Design Equations for the Complete Shaking Force Balancing of 6R 6-Bar Slider-Crank Mechanisms, Mechanism and Machine Theory, volume 13, pp 659-674, Pergamon Press Ltd, 1978.

[3] GAO FENG, Complete Shaking Force and Shaking Moment Balancing of Four types of Six-bar Linkages, Mechanism and Machine Theory, Vol. 24, No. 4, pp. 275-287, printed in Great Britain, 1989.

[4] Jianguo Hu, Yousong and Yongqi Cheng (2016), High Mechanical Advantage Design of Six-bar Stephenson Mechanism for Servo Mechanical Presses, Advances in Mechanical Engineering, Vo8(7),

[5] Dewen Jin, Ruibong Zhang, Rencheng Wang, Jichuan Zhang, Kinematic and Dynamic Performanceof Prosthetic Knee joint using Six-bar Mechanism, Journal of Rehabilitation Research and Development, vol.40, No. 1, pp. 39-48, 2003.

[6] Kailash Chaudhary and Himanshu Chaudhary, Kinematic and Dynamic Analysis of Stephenson Six-bar Mechanism using Hyper Works, Altair Technology Conference, 2013.

[7] SébastienBriot and VigenArakelian, Complete Shaking Force and Shaking Moment Balancing of in-line Four-bar Linkages by adding a Class-two RRR or RRP Assure Group, Mechanism and Machine Theory, Elsevier, 2012, 57, pp.13-26. HAL-00683213.

[8] P.Nehemiah, Complete Shaking Force and Shaking moment Balancing of 3 Types of Four-bar Linkages, International Journal of Current Engineering and Technology, E-ISSN 2277 – 4106, P-ISSN 2347 – 5161.

[9] Basayya K. Belleri and Shravankumar B. Kerur, Dynamic Analysis of Four bar Planar Mechanism extended to Six-bar Planar Mechanism with Variable Topology, AIP Conference Proceedings, 020094 (2018); DOI: 10.1063/1.5029670

[10] F C Chaen., Y F Tzeng., W R Chen nad M H Hsu, The use of the Taguchi Method and Principal Component Analysis for the Sensitivity Analysis of a Dual-purpose Six-bar Mechanism, IMechE Vol.223, J. Mechanical Engineering Science.

[11] SelcukErkaya, Minimization of Shaking Force and Moment on a Four-bar Mechanism Using Genetic Algorithm, Springer International Publishing Switzerland 2016, Dynamic Balancing of Mechanisms and Synthesizing of Parallel Robots.