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ORIGINAL STUDY

Minimizing the Production Cost of the Cam-follower Profile Using Shape Optimization Techniques

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Abstract

The study of shape optimization techniques in structural products helps in reducing mechanical stresses and vibrations in related mechanical elements, such as cam follower mechanisms. This, in turn, has a positive impact on cost savings in the manufacturing process and enhances production quality and reliability. The point of view in this research depends on the idea of minimizing the total production cost while ensuring good functional performance of the cam profile during the shape-manufacturing optimization problem-solving process. The investigation of the impact of changing the motion type of a cam, such as uniform velocity motion and simple harmonic motion, on the profile shape, manufacturing costs, and cam stresses is studied. The design variables of the optimization problem include the shape design variables (coordinates of B-spline control points) and manufacturing design variables (cutting parameters such as cutting speed, tool diameter, and feed rate). These variables are optimized by applying an integration of MATLAB 2021a and ANSYS 20. The problem solvers used are the interior point method and the sequential quadratic programming method. The minimum production cost is found, and an optimum shape of the cam profile is achieved when the cutting speed is 30 m/min, the feed rate is 0.17 mm/flute, and the cutter diameter is 25.4 mm. The best reduction in total cost while using the SHM motion type is about 32.74%, and the stress reduction is about 9.44% (return motion) using the interior point method algorithm after 40 iterations.

Keywords: B-spline, Cam Mechanism, Cam Profile, Manufacturing cost optimization, Shape optimization

1. Introduction

The cam-follower mechanism plays a crucial role in various mechanical systems and machinery. It is designed to follow the profile of a cam, translating rotary motion into linear motion through direct contact. Careful consideration of the cam profile is necessary to achieve the desired movement and performance. Optimizing the cam profile aims to result in smooth motion for the follower, ensuring that the velocity and acceleration curves remain continuous, thereby reducing vibrations and wear in the system, as discussed by Rothbart (Rothbart, 1956).

In recent decades, researchers such as Rao and Pawar (2022) have studied various numerical techniques to optimize the design of cam-follower mechanisms. Chew and Chuang (1995) applied the Generalized Lagrange Multiplier Technique and the Generalized Reduced Gradient Algorithm to optimize the residual vibrations of a high-speed cam-follower. Shape optimization of cam profiles is not a new concept and has been investigated by several researchers. Lampinen (2003) explored the shape optimization of a cam using the Genetic Algorithm (GA). Polynomial curves and B-splines are common methods for representing cam profiles in cam design. Qiu et al. (2005) developed a universal optimal approach using a complex search algorithm for cam curve design. N. Sateesh, Rao, and Janardhan Reddy (Sateesh et al., 2009) designed the follower velocity curve using B-spline polynomials and

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established a CAD/CAM system to improve the motion characteristics in cam-follower mechanisms. Mandal and Naskar (2009) attempted to minimize the acceleration and jerk of the cam-follower by manipulating the knots in a classical B-spline. Xiao and Zu (2009) aimed to determine optimal cam profiles by manipulating various combinations of cam profile representations, with the output torque selected as the objective function in the optimization problem. Xia et al. (2017) optimized a cam profile design model for a single-dwell cam mechanism using a 6th-order classical spline and a single-degree-of-freedom dynamic model. Ouyang et al. (2017) achieved the optimal cam profile by combining a single-objective optimization procedure with a dynamic model using Sequential Quadratic Programming (SQP).

The production of cams is highly precise work. Specific cam profiles can be readily established using graphical methods, envelope methods, and the instant center method. Cams are commonly manufactured using a CNC-End Milling machine. Good design and proper execution of production steps for the cam profile are primary considerations for achieving the mechanical efficiency required for the desired movement. Additionally, minimizing costs while adhering to constraints and maintaining optimal functional performance is one of the most crucial factors during the early stages of production and design. Optimizing the manufacturing process parameters of a cam-follower mechanism leads to improved efficiency, cost reduction, and the assurance of high-quality production. Various mathematical techniques, including integer programming, nonlinear programming, and Genetic Algorithms (GA), have been utilized to reduce production costs and pinpoint optimal values for diverse cutting parameters, as noted by Chang and Tang (2001), Norton (2002), Mostafa (2016), and Dain Lint and Ben Chut (1994). Hsieh (2007) aimed to design and machine a Cylindrical-Cam with a meshing indexing disc by establishing a kinematic model for the designed cam profile and determining the configuration of the cutting tool based on the cam blank. Al-Ahmari and Aalam (2015) applied Design of Experiment methods to optimize the process parameters of surface reconstruction for freeform surfaces through the utilization of reverse engineering technology. Veera Ajay et al. (Veera et al., 2020) compared the surface finish and accuracy of cam profiles machined using both CNC milling and wire cut EDM processes, utilizing a surface roughness tester and a Coordinate Measuring Machine (CMM). Erwinski et al., 2021 presented an approach to solve the feed-rate non-linear constrained optimization problem in CNC machines based on the nature-inspired Particle Swarm Optimization algorithm.

Despite the crucial role of manufacturability in reducing the total production cost of engineering products, there appears to be a significant gap in the literature regarding its integration into structural shape optimization. In my extensive literature review, it was found that very few studies address the combined approach of manufacturing optimization and shape optimization, especially for cam profiles.

In this study, the focus revolves around the concept of reducing the production cost associated with the disk−cam profile. The authors strive to attain the global minimum product cost by considering both design and manufacturing perspectives. They intend to examine how different cam motion types impact the range of influence on the cam profile, considering realistic design and manufacturing conditions. The objective is to reduce the overall cost function, which includes the expenses for raw materials and production, of the cam profile during manufacturing while adhering to efficient production methods and shape constraints through the utilization of two mathematical optimization algorithms (Interior Point (IP) and SQP). The recommended method for manufacturing the cam profile is the End-Milling machining process.

2. Materials and methods

The objective of this section is to offer a concise overview of the adapted method for calculating the time of machining and minimum total cost of the selected manufacturing process (End-Milling) for producing the disc cam profile. Additionally, the section outlines the procedures for profile shape representation using nonuniform rational B-Splines and describes the simultaneous manufacturing shape optimization problem for the suggested case studies, involving two types of cam follower motion. The chosen material for the cam is AISI 4140, which belongs to the category of higher-performance steel alloys. Tables 1 and 2, respectively, show the chemical composition and mechanical properties of the materials used for producing cams.

As is well-known, the total production cost is calculated based on material cost, labor cost, tooling cost, and expenses. Machining time plays a crucial

Table 1. Chemical composition of AISI 4140 (Mechanical properties and Chemical Composition).

Element	C	P	Mn	S	Si
Wt.%	0.380−0.430	≤0.035	0.75−1.0	≤0.040	0.15−0.30

Table 2. Mechanical properties of AISI 4140 (Mechanical properties and Chemical Composition).

Element	Modulus of elasticity (MPa)	Poisson ratio	UTS (MPa)
Value	2.1×10^5	0.27	690

role in cost calculation as it directly affects labor costs. Material cost and expenses are classified as fixed costs. In this study, a Feature-Based Approach technique is utilized to estimate the machining time of process (Creese et al., 1992). This approach allows the inclusion of the generated cam area and the length of the cam profile in each iteration of the optimization problem. To estimate tool cost, Taylor's Tool Life Equation ($V \times T^n = C$) is adapted.

The shape optimization problem presents challenges and requires additional computational time and resources. In recent times, B-splines have seen increased application in designing cam profiles due to their adaptability, versatility, locally control, and ease of integration into optimization models. The goal of the proposed shape problem is to enhance the optimization of the cam profile (Mostafa, 2016), Tarczewski (2021)). In our work, nonuniform rational B-splines of the cubic degree are utilized. In shape modeling because of their capacity to incorporate knots and control points is illustrated in Fig. 1.

By adjusting the control points in the x and y directions, the cam profile undergoes modifications to meet the specified objective. The cost function is constructed and optimized using the 'MATLAB R2021a' software. The MATLAB spline toolbox is applied for creating the B-splines, with the control points influencing the profile shape used as design variables in polynomial functions to achieve optimal performance. The B-spline control points have two degrees of freedom in the x and y-directions. There is a total of 30 control points, distributed as follows: 12 control points represent the cam profile at the rise stage, another 12 control points represent the cam profile at the return stage, and the remaining 6 points complete the profile as a closed contour.

The IP and SQP algorithms in MATLAB (R2021a), recognized as mathematical optimization techniques,

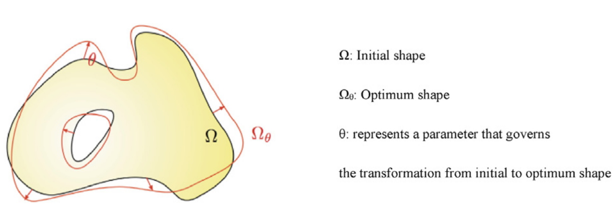


Fig. 1. Shape optimization involves improving a particular shape. Paris et al., 2016.

are established tools for addressing inequality-constrained nonlinear optimization problems. Both algorithms will be employed to solve the proposed problem of manufacturing shape optimization in the research. A comparison will be conducted between the results for each of the two assumed types of motion of the cam mechanism.

The optimization problem is handled by employing finite element analysis using ANSYS20 with a Lagrangian approach for precise and sensitivity analysis. The collaboration between MATLAB (R2021a) and ANSYS20 is crucial for the success of our study. A robust MATLAB function is created to interact with the ANSYS environment and generate a comprehensive finite element model of the geometric solid for the cam-part in ANSYS. A solid model is built and meshed with nodes and elements. After completing the creation of a robust model, configuring element attributes and establishing meshing controls triggers the ANSYS program to generate the mesh. In this study, the PLANE82 element type was utilized. The meshing type employed for the cam is FREE mesh, which is governed by two parameters assigned to each mesh surface, influencing the size of the generated elements. The structural stresses and compliance are computed within ANSYS and then transferred back to MATLAB to verify the fulfillment of the design constraint function.

2.1. Description of the proposed optimization problem

The proposed optimization problem simultaneously considers both the performance of the structural shape and the cost of manufacturing. It investigates the manufacturing cost by incorporating the use of end-milling processes for machining a cam profile. Simultaneously optimizing the manufacturing and shape of the product enables the attainment of the global minimum product cost. This study concentrates on the optimal design of a cam profile with eccentric roller follower translation, particularly taking into account a specific type of follower motion law. In this work, the presented cam-follower mechanism undergoes two types of motion: SHM and UVM. The schematic view of the mechanism is illustrated in Fig. 2. It is assumed that the cam rotates with a constant angular velocity ω. To ensure the follower's return motion, it is assumed that the spring has a constant elastic ratio k and an initial compression δ.

The design parameters considered in this study include the base circle radius of the cam (Rb), the roller radius (Rg), the follower eccentricity (e), the

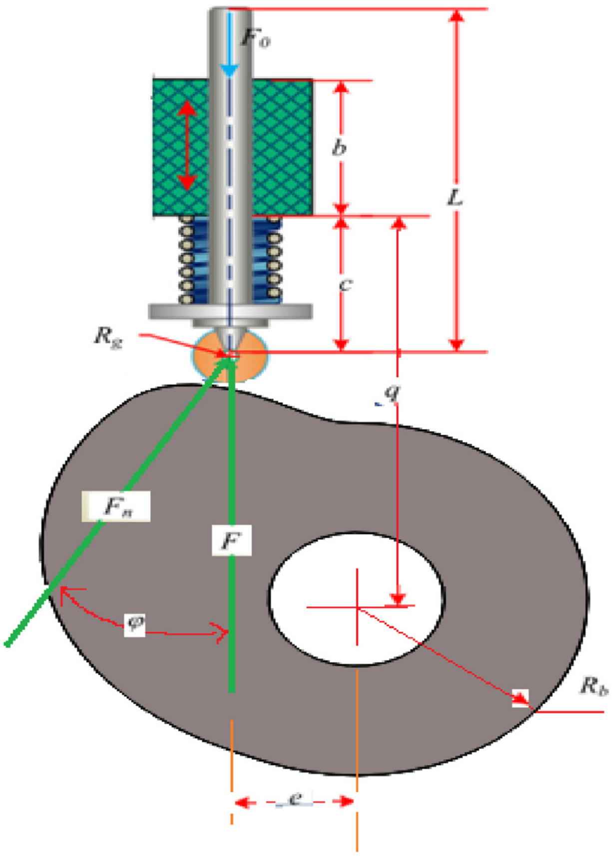


Fig. 2. Cam mechanism featuring a translating roller follower with an offset.

distance between the follower bearing and the center of the cam (q), and the length of the follower bearing (b). The optimization model is intricate, involving nonlinearity, multiple variables, and constraints. The process entails machining a plate to create the cam profile by removing unwanted material to achieve the desired shape. The dimensions of the workpiece are specified as '20 × 10 × 2 cm^3'. The cutting conditions involve categorizing machine tools and selecting suitable cutting parameters for end-milling to achieve the desired profile. The optimization program developed incorporates fixed cutting parameters, such as material properties, machine type (3-axis CNC mill), machine and labor rates, and related information. For the rough cut, an uncoated 'HSS 2-flute single end 30° RH Spiral Ball Nose End Mill' is chosen, and the finishing end-mill has the same characteristics but with four flutes. The machining parameters, including the axial depth of cut (l), radial depth of cut (Rdoc), cutter diameter (Dc), rough-cut feed per flute (ft), and cutting speed (V), are considered as manufacturing design variables in the proposed nested optimization problem.

2.2. Formulation of manufacturing-shape optimization problem

This study proposes a novel nested optimization approach with two loops: one for optimizing the cam profile shape and the other for minimizing the cost of manufacturing. During every iteration of parametric profile optimization, the loop of manufacturing determines the minimum total cost, considering both material and manufacturing costs in the objective cost function. The flowchart in Fig. 3 illustrates the integrated optimization problem steps and sequence of operations undertaken during the research using the applicable technique.

2.2.1. Objective function formulation

The objective function of total production cost (TCost) is designed to minimize the overall manufacturing cost for the end-milling process employed in the production of a profiled cam. So, it is vital to compute the direct material cost and the operating time of the proposed machining process. Material cost encompasses the expense of all materials used in a specific batch size. This cost is considered fixed because it doesn't depend on the product's shape. Labor cost is determined by the

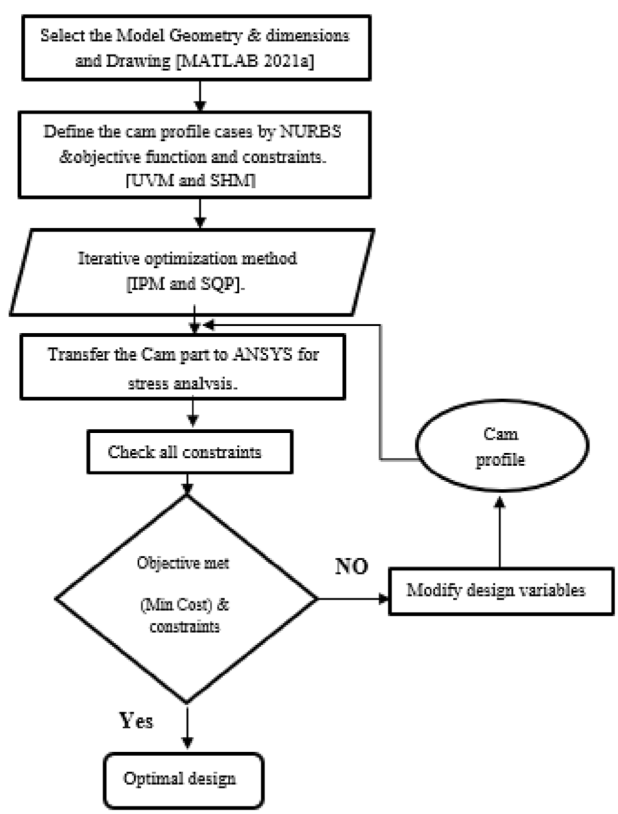


Fig. 3. The flowchart illustrates the integrated optimization problem steps.

total machining time, and tooling cost includes the expenses for tools and tool changes (Kaung-Hua (Chang, 2013)). The problem variables (DVs) in the optimization loops include two types: design variables and manufacturing variables. Design variables encompass the distance between the follower bearing and the center of the cam (q), the length of the follower bearing (b), and the control point coordinates of the B-spline profile along the x and y directions. Manufacturing variables include the speed of rough cutting (V), feed (ft), and the diameter of end-mill (Dc) for the machining process. The cost function and its constraints in the proposed optimization problem are formulated as non-linear functions of the design and manufacturing variables.

Minimize

$$TCost = labor\ cost + tooling\ cost + material\ cost \tag{1}$$

Where:

Labor Cost = total labor rate
* total cutting time (1-1)
Tooling Cost = Cutter price
* cutting time/tool life (1–2)
Material Cost = unit material Cost
* w.p volume * material density (1–3)

Subjected to

$$g_i(x) \leq 0 \quad i: the\ number\ of\ constraints \tag{2}$$

2.2.2. The manufacturing constraints

These factors are influenced by the maximum cutting power available, the maximum feed rate of the machining equipment, the highest spindle speed, the allowable cutting force, and the designated surface roughness for both rough and finish cuts in End-Milling.

2.2.3. The design constraints

In the nested optimization problem, it is necessary to constrain the relative positions of the control points of B-splines to ensure the correction of the profile shaping during the optimization iterations. To facilitate the assembly of the mechanism parts, constructive constraints pertaining to the base circle radius of the cam, the radius of roller, and the eccentricity of the follower are assumed. Furthermore, constraints must be applied to ensure the proper functioning of the mechanism during the high dwell of the follower, preventing contact between the roller and the bearing of the follower., Hence, to avoid such contact, the constraint (1) should be incorporated where h and q denote the follower lift & the distance between the center of cam and the bearing of the follower, respectively. The (α) parameter is determined as ($\alpha = \sqrt{(\mathrm{Rg}+\mathrm{Rb})^2 - e^2}$). During the low dwell phase, it is crucial to keep the follower level above the bearing level to prevent contact between the external mass and the bearing. This constraint can be expressed as in constraint (2), where L and b represent the lengths of the follower and the follower bearing, respectively.

(α+h+Rg - q $\leq$ 0) constraint (1)

(q - α +b - L $\leq$ 0) constraint (2)

The pressure angle plays a significant role in determining the power transmission efficiency between the cam and the follower. To prevent jamming in the guide mechanism, it is important to set a maximum limit on the pressure angle for both the rise and return phases. The pressure angle is calculated as expressed in equation (3) and restricted by constraint (3–1, 3–2)

$$\phi = tan^{-1}\left(\frac{y' - e}{y + a}\right) \tag{3}$$

$$\phi_{\mathrm{Max\_rise}} - 30 \leq \text{constraint } 0 \tag{3–1}$$

$$\phi_{\mathrm{Max\ \_return}} - 45 \leq \text{constraint } 0 \tag{3–2}$$

Here, y represents the displacement of the follower, y′ is the second derivative of the follower displacement concerning the cam angle, e is the offset of the follower, and (a) is the sum of the base circle radius and roller radius.

To guarantee the mechanical integrity of the cam, it is necessary to ensure that the maximum stress (σ_{max}) is less than or equal to the permissible stress (σ_P) as shown in constraint (4–1). The normal force (F_n) exerted between the surface of cam and the roller follower is calculated as the formula:

$$Fn = \frac{P}{\left[1 - \mu\left(\frac{2C+b}{b}\right)tan\ \varphi\right]cos\ \varphi} \tag{4}$$

$$\sigma_{max}\text{-}\sigma_P \leq \text{constraint } 0 \tag{4-1}$$

Here, P represents the overall force acting on the follower, μ is the coefficient of friction, and the constant C is equal to (q - (a+y)).

3. Results and discussion

The aim of this section is to provide a concise indication of the results of the proposed optimization problem, which simultaneously considers both the performance of the structural shape and the manufacturing cost. The examination of cost reduction in producing the cam profile involves the application of two types of motion (UVM and SHM) for the proposed cam mechanism. Two mathematical algorithms (IP and SQP) are employed to solve the optimization problem, and the results are subsequently compared.

In this study, the cam-follower mechanism is assumed to be of the rise-dwell-return type. The design parameters and the input data for the suggested optimization problem are depicted in Table 3, and this table is applicable to both case studies. The data range of the problem design variables (manufacturing and design) are presented in Table 4. As mentioned, the control points, which influence the cam profile, are utilized as shape-design variables (SDVs) to achieve optimal performance. The thirty control points used in the proposed problem have two degrees of freedom along the x and y directions. Fig. 4 shows the B-spline representation of the Initial Cam Profile according to the control points.

3.1. Case (1): optimization problem of disk−cam profile according to UVM using SQP and IP algorithms

The cam and follower exhibit a motion characterized by constant or uniform velocity, signifying consistent speed throughout their movement. The kinematics of the motion can be described by equation (5)

$$y = h\left(\frac{\theta}{\theta_R}\right) \tag{5}$$

When using the ***IP algorithm***, the optimal solution for the problem is attained after 55 iterations without any breaches of the constraints. A reduction of approximately 30.98%. In the objective function is observed, the cam area reduction is about 3.23%, and the optimization of cutting parameters namely cutting speed, feed, and tool diameter results in values of 30 m/min, 0.14 mm/flute, and 25.4 mm (1 inch), respectively. The contact stress contours were determined using ANSYS software. Von Mises stresses experience reductions of about 4.89% during rise motion, 4.29% during high dwell, and 6.12% during return motion, so, an average stress reduction in the cam profile at three stages of about 5.1%. All contact stress values are expressed in units of MPa. Maximum reduction in contact stress during return motion. Fig. 5a visually presents the initial and optimal representations of the cam profile. Upon comparing the pre-shape with the optimized one, it is evident that the optimized cam shape exhibits a deviation from the initial configuration.

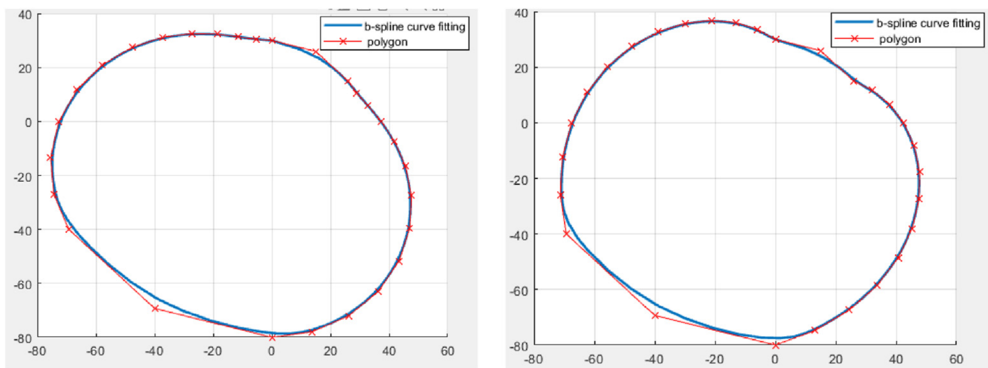
In the case of using the ***SQP algorithm***, after 26 iterations, the optimal problem solution is achieved without any violations of the constraints. It is observed that the reduction in the cam area is about 2.44%, and the reduction in the total cost (obj. fn.) is approximately 29.11%, while the cutting parameters such as cutting speed, feed, and tool diameter are optimized to 30 m/min, 0.14 mm/flute, and 25.4 mm (1 inch), respectively. The contact stress contours were determined using ANSYS software. The Von Mises stresses are reduced by about 4.30% during the rise motion, 4.18% during the high dwell, and 3.42% during the return motion, so, an average

Table 3. Design parameters and input data for manufacturing-shape optimizing problem.

Design Parameter	Value	Design parameter	Value
Follower lift (h)	50 mm	Applied force on the follower (F0)	30 N
Rise Angle (Θ_R)	120°	Modulus of elasticity (E)	2.1×10^5 MPa
High dwell angle (Θ_{DH})	60°	Permissible tensile strength (σ_p)	690 MPa
Return angle (Θ_T)	120°	Coefficient of friction (μ)	0.1
Low dwell angle (Θ_{DL})	60°	Base circle radius of the cam (Rb)	30 mm
Angular velocity (ω)	3 rad/s	Poisson ratio (υ_1)	0.27
Initial spring compression (δ)	5 mm	Spring rate (k)	1.2 N/mm
Roller circle radius (Rg)	10 mm	Offset of the follower (e)	15 mm
Follower length (L)	130 mm	Cam material	Alloy steel (AISI 4140)

Table 4. Data range of design variables of the manufacturing-shape optimization problem.

Manufacturing design variables (MDVs)	Data range	Shape design variables (SDVs)	Data range
Cutter dia.	(3.175−25.4) mm	Follower-bearing length	(30−70) mm
Cutting speed	(30−90) m/min	Distance between the center of cam and the bearing of the follower	(70−150) mm
Feed/flute	(0.05−0.2) mm/flute		



a) SHM

b) UVM

Fig. 4. B-spline representation of Initial Cam Profile according to the control points. UVM, uniform velocity motion; SHM, simple harmonic motion.

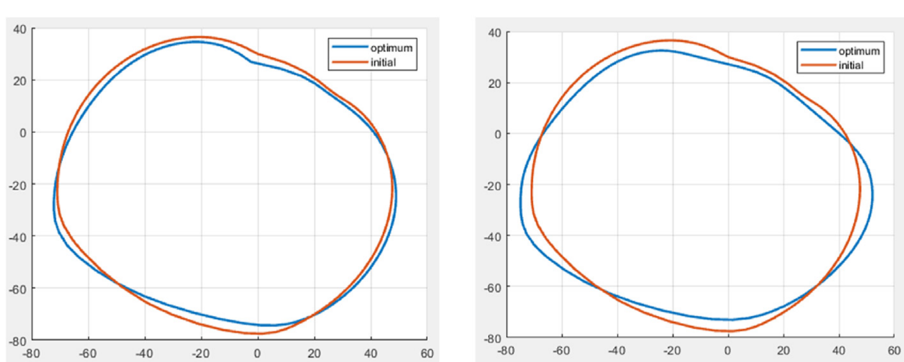
stress reduction in the cam profile at three stages of about 3.9%. All contact stress values are expressed in units of MPa. Maximum reduction in contact stress during rise motion. Fig. 5b illustrates the representation of the initial and the optimal cam profile. When comparing the pre-shaped cam and the optimized cam, it becomes apparent that the optimized cam shape exhibits slight variations from the initial shape.

3.2. Case (2): optimization problem of disk—cam profile according to SHM using SQP and IP algorithms

The movement of a follower exhibits (SHM) when its acceleration directed towards a specific point is directly proportional to its distance from that point. The kinematics of the motion can be expressed by equation (6). Fig. 6 illustrates the diagrams of SHM according to the supposed case.

$$y=\frac{h}{2}\left(1-\cos\left(\pi\frac{\theta}{\theta_R}\right)\right) \tag{6}$$

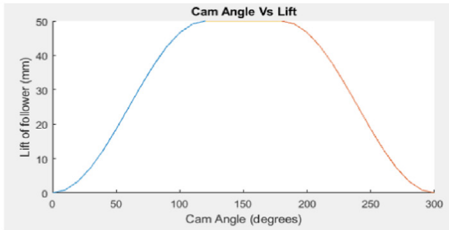
When using the ***IP algorithm***, the optimal solution for the problem is attained after 40 iterations without any breaches of the constraints. A reduction of approximately 2.47% in the cam area and 32.74% in the objective function is observed. The optimized cutting parameters namely cutting speed, feed, and diameter of tool results are in values of 30 m/min, 0.17 mm/flute, and 25.4 mm (1 inch), respectively. The contact stress contours were determined using ANSYS software. Von Mises stresses experience reductions of about 3.42% during rise motion, 3.70% during high dwell, and 9.44% during return motion, so, an average stress reduction at three stages of about 5.52%. All contact stress values are expressed in units of MPa. Maximum reduction in contact stress during return motion. Fig. 7a visually presents the initial and optimal representations of the cam profile.



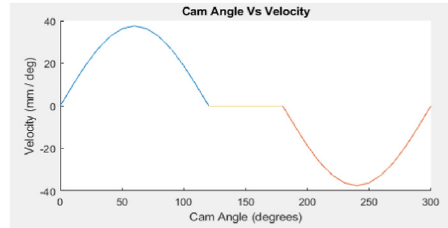
a) The initial and optimal profile shape by using (IP) Algorithm

b) The initial and optimal profile shape by using (SQP)Algorithm

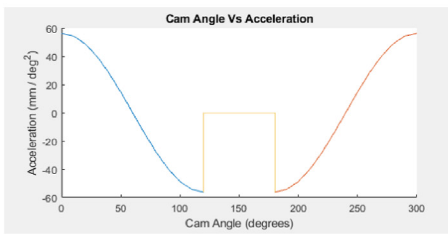
Fig. 5. The initial and optimal cam profile according to uniform velocity motion-type.



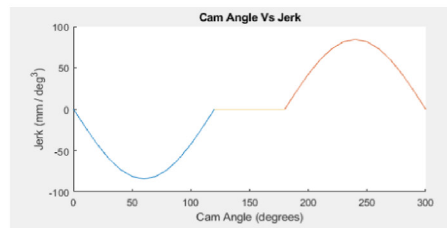
a) SHM displacement



b) SHM velocity



c) SHM acceleration



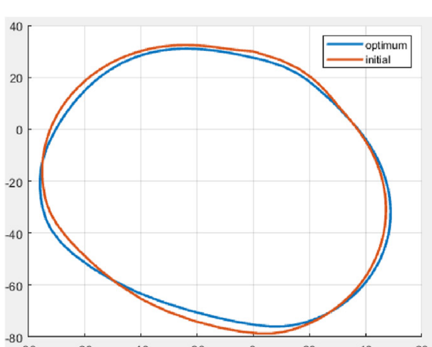
d) SHM jerk

Fig. 6. Simple harmonic motion diagrams for the supposed Case.

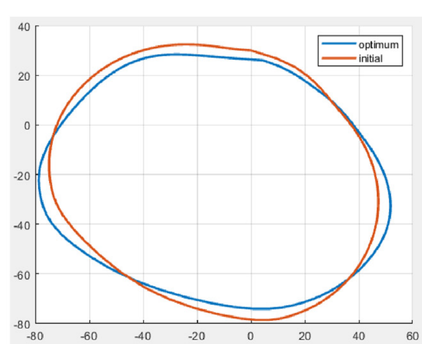
Upon comparing the pre-shape with the optimized one, it is evident that the optimized cam shape exhibits a deviation from the initial configuration.

In the case of using the *SQP algorithm*, after 20 iterations, the optimal problem solution is achieved without any violations of the constraints. It is observed that the cam area reduction is about 2.16% and the reduction in the total cost (obj. fn.) is approximately 29.63%, while the cutting parameters such as cutting speed, feed, and diameter of tool are optimized to 30 m/min, 0.14 mm/flute, and 25.4 mm (1 inch), respectively. The contact stress contours were determined using ANSYS software. The Von Mises stresses are reduced by about 6.94% during the rise motion, 1.54% during the high dwell, and 7.69% during the return motion, an average stress reduction in the cam profile at three stages of about 5.3%. All contact stress values are expressed in units of MPa. Maximum reduction in contact stress during return motion. Fig. 7b illustrates the representation of the initial and the optimal cam profile. When comparing the pre-shaped cam and the optimized cam, it becomes apparent that the optimized cam shape exhibits slight variations from the initial shape.

Fig. 8 represents the stress distributions in the case of optimal cam profile according to the IP algorithms



a) The initial and optimal profile shape by using (IP) Algorithm



b) The initial and optimal profile shape by using (SQP)Algorithm

Fig. 7. The initial and optimal cam profile according to simple harmonic motion -type.

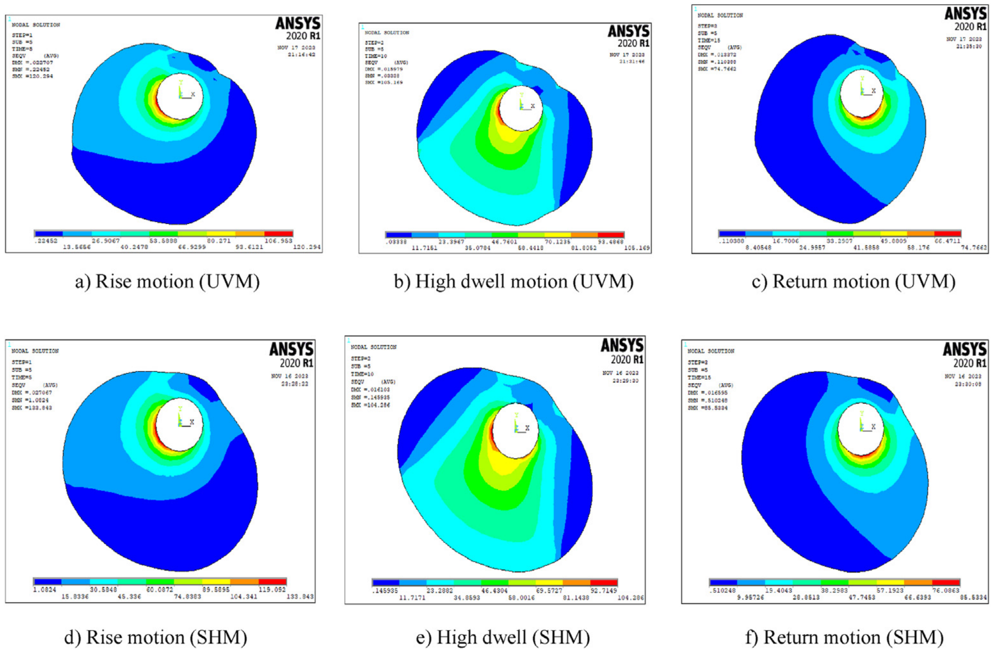


Fig. 8. Von Mises stresses Distribution in uniform velocity motion and simple harmonic motion in optimal case according to interior point Algorithm.

for two types of motion, respectively. The contact stress shows variation with the compression load at different positions of the follower at rise, high dwell, and return motion with the cam. The contact stress exhibits a linear increase as the compression load is progressively increased. The contact stress is maximum during rise motion, while the contact stress is minimal during return motion.

The final optimized shapes are influenced by the motion type of the cam mechanism and the algorithm employed. It is also evident that there is a variation in the percentage reduction of the objective function and the cam area. Fig. 9 represents the effect of the motion types on the initial and optimal total cost while using the two different algorithms. Fig. 10 represents the effect of the motion types on the initial and optimal cam area while using the two different algorithms. When comparing the findings from the two cases, it is observed that the second case has the best objective function in terms of total cost and stress reduction when using the interior point method (IPM), even though the area reduction is lower than in case 1. There is closeness between the values of cutting conditions, with almost the same values in cutting speed, feed, and depth of cut in both cases. There is closeness between the optimal values of Shape Design Variables (SDVs) in two cases when using SQP: q = 110.4 mm and b = 55.13 mm, and when using IPM: q = 119.67 mm and b = 47.3 mm. Figs. 11 and 12 represent the effect of the motion types on the initial and optimal stresses while using the two

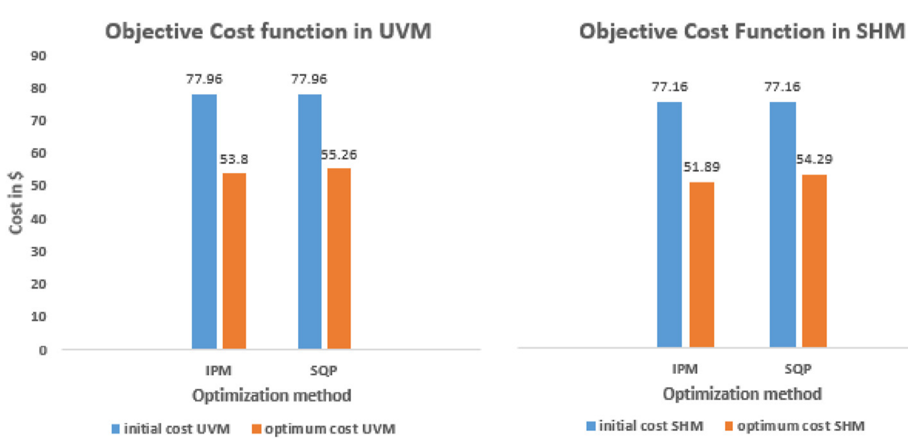


Fig. 9. Effect of motion types on the initial and optimal objective cost function under two Algorithms.

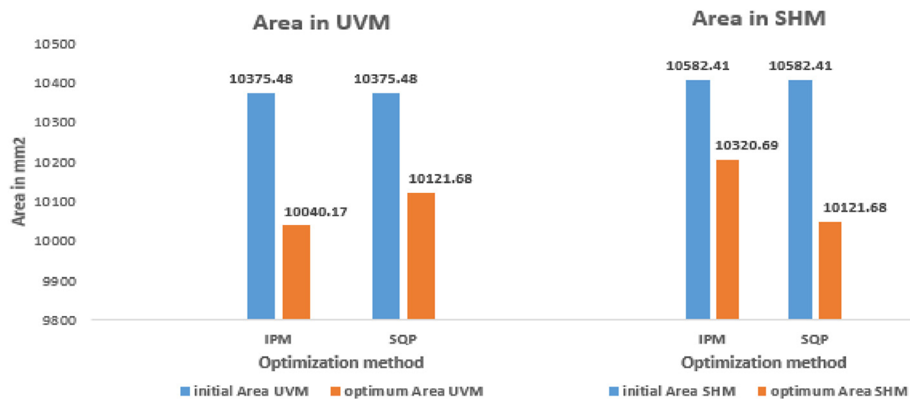


Fig. 10. Effect of motion types on the initial and optimal cam area under two Algorithms.

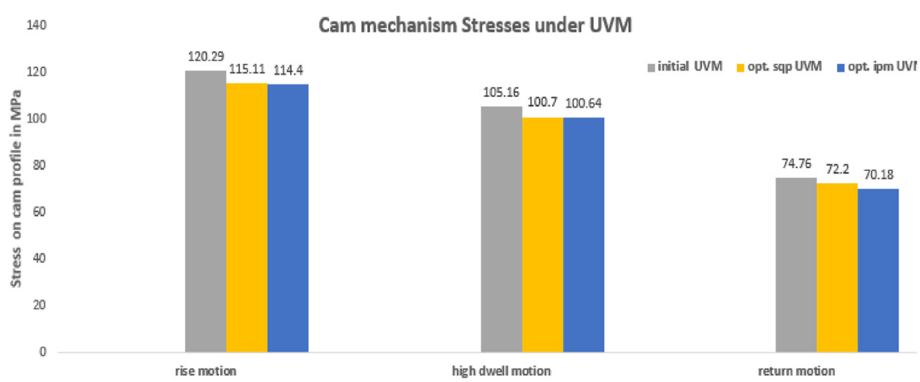


Fig. 11. Effect of two optimization algorithms on the initial and optimal distribution stress under uniform velocity motion type.

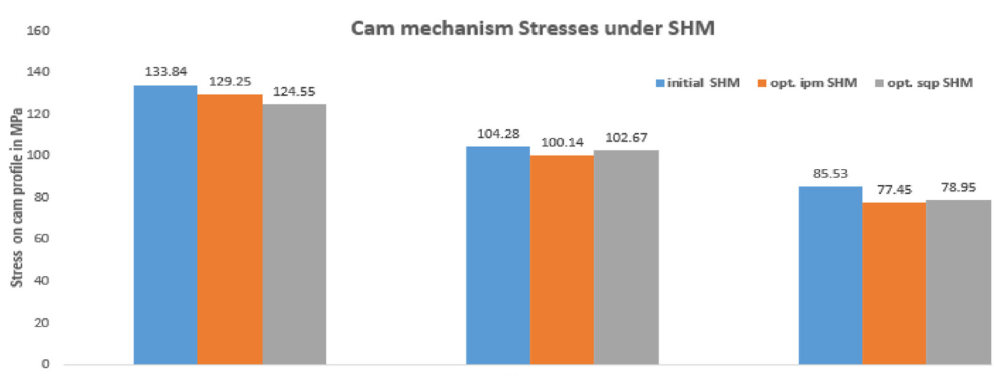


Fig. 12. Effect of two optimization algorithms on the initial and optimal distribution stress under simple harmonic motion type.

different algorithms. By comparing the outcomes with the stress distributions in the two cases of cam profile generation, it is observed that the maximum reduction in contact stress during return motion occurs in all algorithms in both cases, except for the SQP algorithm at UVM.

The main point of the research is that the total cost reduction rate is influenced by changing the shape of the cam profile. This change affects the resulting stress and manufacturing parameter values, which were calculated through the integration of MATLAB and ANSYS at each iteration of the optimization problem. This was achieved by simultaneously adjusting the cutting design variables and the shape design conditions to obtain the optimal solution to the problem.

4. Conclusion

The global minimum production cost for cam profile generation is achieved by simultaneously optimizing both the structural shape and the manufacturing parameters using the IPM and SQP optimization algorithms under two different types of follower motion; UVM and SHM. A successful integration of MATLAB and ANSYS programs facilitates the optimization process, enabling the variation of B-Spline control points coordinates in two dimensions (X, Y) simultaneously with finite element analysis of the cam mechanism model at each iteration of problem-solving. Both algorithms effectively optimize the cam profile under (UVM), but the IP algorithm shows a slightly higher reduction in the objective function (~30.98%) and contact stresses during return motion (~6.12%), while the SQP algorithm achieves faster convergence. Comparing the two algorithms, the IP algorithm with SHM provides the most significant reduction in machining cost (~32.74%) and Von Mises stress (~9.44%), particularly after 40 iterations, making it the more effective approach for this optimization problem. In both case studies, the optimal manufacturing design variables are a cutting speed of 30 m/min, a feed rate 0.17 mm/flute and a tool diameter of 25.4 mm.

4.1. Suggestion of future work

Another approaches for optimization might be applied to achieve better results. Additionally, changing the inputs and design variables and studying the reduction of the total cost of die manufacturing for producing the specific cam, instead of producing the cam profile by machining, can be considered.

Authors contributions

The trio of researchers could engage in suggesting the research concept, outlining the procedural steps, and subsequently gathering and analyzing the data. Additionally, they were involved in establishing the research methodology, sourcing materials, deliberating over, and interpreting the results. Initially, K.A. drafted the research, with M.S. and R.M. subsequently scrutinizing and refining it to its ultimate version, poised for publication.

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Conflicts of interest

There are no conflicts of interest.

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