Design Optimization of Annular Fins on an Air-Cooled 100CC Hero Honda Engine using Genetic Algorithm

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Abstract - *The main aim of this study is to develop a Genetic Algorithm based heuristic technique which can give optimal values for fin thickness, fin length, number of fins and air velocity, for engine cylinder fins, which will maximize the total heat flux from the cylinder fin array. Genetic Algorithms are robust, stochastic search techniques which are also used for optimizing highly complex problems. In this study, the fin array is of the traditional circular fin type, which is subject to ambient convective heat transfer. The parameters (degrees of freedom) selected for the analysis include fin thickness, fin length, the number of fins, and the velocity of air. By using Genetic Algorithm (GA), the total heat flux through the fin arrays is set as the objective function to be optimized with each parameter varied within the physical ranges. Proper population size is selected and the mutations, cross-over and selection are conducted in the GA procedure to arrive at the optimal set of parameters after a certain number of generations. The GA proves to be an effective optimization method in the thermal system component designs when the number of independent variables is large. The optimal values for the input parameters were found to be 59.88 mm, 1.052 mm, 9 and 38.92 m/s for fin radius, fin thickness, number of fins and air velocity, respectively. The maximised value for heat flux average when the input parameters were at their optimum values was found to be 232114.4399 W/m^2.*

Key Words: engine cylinder fins, material, genetic algorithm, optimization, CFD analysis.

1. INTRODUCTION

Heat build-up is one of the major causes of engine failure and is responsible for several other harmful attributes ranging from the breakdown of oil to the fracture of cylinder blocks to over-expansion of pistons and other moving parts. It is of utmost importance to dissipate the heat caused by the internal combustion engine and friction heat from the moving parts inside the engine. This can be done by either liquid or air cooled engines. Liquid cooled engines use a shell and tube style radiator whereas air cooled engines use forced convection over a set of fins that are near the heat source.

Fins are extended surfaces often used to enhance the rate of heat transfer from the cylinder surface. Fins are generally used on the surface which has very low heat transfer coefficient. Straight fins are one of the most common choices for enhancing better heat transfer from the flat surfaces. The rate of heat flow per unit basis surface increase in direct proportion to the added heat conducting surface. The arrangement of fins and their geometry in an array are the most important criteria, to dissipate heat from the cylinder surface.

There are several factors which find a significant effect on the efficiency of the fin, such as geometry, shape, size, roughness, etc. By optimizing these parameters we can ensure maximum heat dissipation from the engine, thus improving engine efficiency, reducing fuel consumption and increasing engine power output.

In this study, first, the shape of fins was selected. Shapes considered for comparison included angular fins, curved fins, rectangular and circular fins, as shown in figures given below.

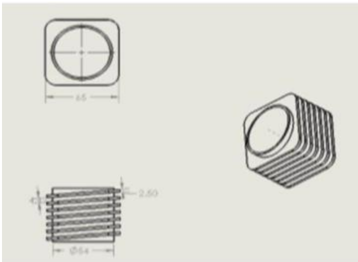


Fig 1.1 Angular fins

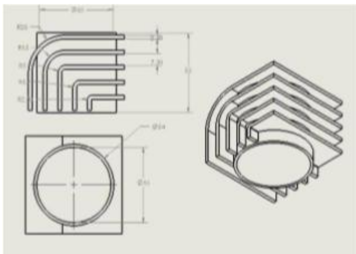


Fig 1.2 Curved fins

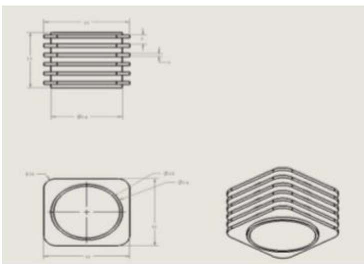


Fig 1.3 Rectangular fins

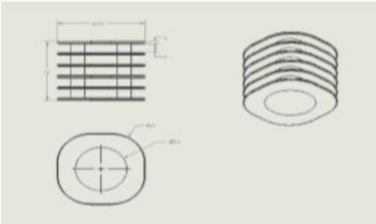


Fig 1.4 Circular fins

On thermal analysis alone, it was found that compared to the other three types, circular fins dissipated maximum amount of heat. Hence, circular fins were considered for this study. Based on the parameters that most affect the heat transfer rate from the engine cylinder fins, input parameters for the optimization procedure were identified. They were found to be fin radius, fin thickness, the number of fins and the velocity of air passing through the fin array. Other parameters reviewed included amount of material used, cost of manufacture, roughness, aesthetic design variations, etc. The material of the engine cylinder was also chosen from several alternatives. The material selected for the analysis in this study is Aluminium Alloy 6061. Alternatives considered include Aluminium Alloy 2014, Aluminium Alloy 204, Aluminium Alloy C443 and Magnesium.

Operational ranges for each of the input parameters were obtained from other research works. These are mentioned in detail in the literature review.

For the optimization procedure, three optimization techniques were compared and studied. These were the Taguchi method, Particle Swarm Optimization (PSO) and optimization using Genetic Algorithms (GAs). Among these Genetic Algorithm proved to be more dependable and evolved compared to the other two.

GAs are adaptive heuristic search algorithms that belong to the larger part of evolutionary algorithms. Genetic algorithms are based on the ideas of natural selection and genetics. These are intelligent exploitation of random search provided with historical data to direct the search into the region of better performance in solution space. They have been commonly used to generate high-quality solutions for optimization problems and search problems and hence seemed best suited for the optimization requirements of the present study.

1.1 Literature survey

G. Babu and M. Lavakumar (2013) analysed the thermal properties of cylinder fins by varying geometry, material and thickness. Parametric models of cylinder with fins were developed to predict the transient thermal behaviour. The models were created by varying the geometry, rectangular, circular and curved shaped fins and also by varying thickness of the fins. The 3D modelling software used was Pro/Engineer and the analysis was done using ANSYS software. The study revealed that circular fins made of Aluminium Alloy 6061 and having thickness of fins as 2.5 mm dissipated maximum amount of heat.

Pulkit Sagar et al. (2017) investigated the effect of geometry, different shape and the surface roughness of the fins on the heat transfer. They also analysed the heat transfer rate by varying the shape and surface roughness of fins. The model was created by varying the shape and roughness of the fin in AUTODESK INVENTER 2015 and simulated in AUTODESK NASTRAN 2015. The main aim of this paper was to study the following effects on the heat transfer through fins in motorcycle and other motor power vehicles by changing the geometry. It was found that using convex geometry increased the heat transfer rate and reduced amount of material used. The material used in this study was also Aluminium Alloy 6061.

Pulkit Sagar et al. (2017) analysed the heat transfer rate by varying the surface roughness (250 micron, 300 micro and 400 micron). An attempt was made to simulate heat transfer rate by using Thermal Analysis for different surface roughness. Parametric model was developed to study the heat transfer rate of the body. They concluded that as surface roughness increased, heat transfer rate also increases.

Balanagar Samant et al. (2017) also investigated thermal properties of engine cylinder fins by varying material and thickness of fins. He found that as thickness decreased heat transfer rate increased hyperbolically.

A. Sathishkumar et al. (2016) investigated the thermal properties by varying geometry, material and angle of cylinder fins using ANSYS Workbench and the models were created by changing the geometry like rectangular, circular, angular and curved shaped fins. Transient thermal analysis showed the deviation of temperature over time and the precise thermal simulation was very useful to identify the design parameters for improved life. The observations from the present investigation work, Aluminium Alloy 2014 showing 17 % higher temperature distribution compared to Aluminium Alloy 204. All the materials are showing linear distribution of temperature alongside the length of fins. Also, the circular fins increase the efficiency of the engine by reducing the weight of the engine..

Yaddanapudi Sai Saranya et al. (2016) analysed the thermal behaviour of different models with varying materials. Four types of cylinders were modelled in modelling software CATIA, and analysis was performed in ANSYS 16.0 software. Analysis results were taken as input of Taguchi technique. L16 array model was performed and an optimum model was found.

Du Juan et al. (2014) considered a plate fin-and-tube heat exchanger (PFTHE) for optimization with air and water as working fluid, four geometric variables were taken as parameters for optimization, a Genetic Algorithm (GA) was used to search for the optimal structure sizes of the PFTHE, the maximum total heat transfer rate and the minimum total pressure drop were taken as objective functions in GA, respectively. Performance of the optimized result was evaluated and correspondingly the total heat transfer rate, the total pressure drop, the heat transfer coefficient and the local Nusselt number, j-factor and friction factor ξ were calculated respectively. Results show that the total heat transfer rate of the optimized heat exchanger increased by about 2.1–9.2% comparing with the original one, the heat transfer coefficient increased by about 8.2–14.7% and the total pressure drop decreased by about 4.4–8% in the range of Re = 1200–14000.

Farzaneh Hajabdollahi et al. (2012) studied, one dimensional heat transfer in a pin fin. Bezier curves was used to determine the best geometry of the fin. The model equations were solved to analyze the heat transfer. Total heat transfer rate and fin efficiency factor were considered as two objective functions and multi-objective optimization carried out to maximize heat transfer rate and fin efficiency simultaneously. Fast and elitist non-dominated sorting genetic algorithm (NSGA-II) was used to determine a set of multiple optimum solutions, called 'Pareto' optimal solutions. The optimized results were presented with Pareto front which demonstrated conflict between two objective functions in the optimized point. Both energy conservation and thermal analysis were carried out to verify the solution method and the results showed good precision.

Hamidreza Najafi et. al (2011) considered a plate and fin heat exchanger and air, as an ideal gas, and defined in both sides of the heat exchanger as the working fluid. Several geometric variables within the logical constraints were considered as optimization parameters. Two different objective functions including the total rate of heat transfer and the total annual cost of the system were defined. Since mentioned objectives were conflicting, no single solution could well-satisfy both objective functions simultaneously. Therefore, multi-objective optimization using genetic algorithm was utilized in order to achieve a set of optimal solutions, each of which was a trade-off between objectives and could satisfy both objective functions in an appropriate level. The main advantage of this work was providing a set of optimal solutions each of which could be selected by the designer based on the project's limits and the available investment. A sensitivity analysis was also presented in order to investigate the effect of some geometric parameters on each objective functions.

1.2 Problem definition

The objective of this project was to develop a Genetic Algorithm based heuristic technique which can give optimal values for fin thickness, fin length, number of fins and air velocity, which will maximize the total heat flux. This was achieved by coupling a Python computer program with ANSYS. The program was responsible for implementing the genetic algorithm procedure to the set of randomly generated (within user defined ranges), input data. ANSYS 19.2 software was used to find the fitness function or the output parameter i.e. total heat flux. The program flow alternated between the computer program and ANSYS, till convergence was reached. For the purpose of this project, about 10000 simulations were carried out to arrive at the solution.

2. NUMERICAL SIMULATION

2.1 Geometric model

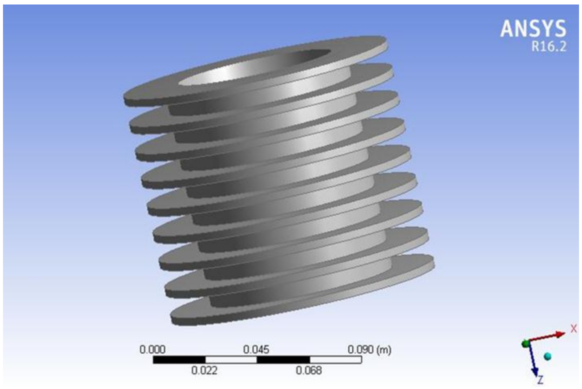


Fig 2.1: Geometric model of engine cylinder and fin array

The engine cylinder considered for analysis is that of a 100 cc Hero Honda motorcycle. The fins considered are uniformly thick, annular fins. The material used for analysis of engine cylinder as well as the fins is Aluminium Alloy 6061 having thermal conductivity 180 $Wm^{-1}K^{-1}$, specific heat 896 $Jkg^{-1}K^{-1}$ and density 2700 kgm^{-3}. The dimensions of the engine cylinder are: engine cylinder length is 100 mm, outer radius of cylinder is 40 mm and inner cylinder radius is 34 mm. Four input parameters are considered for the optimization. These are fin radius, fin thickness, number of fins and air velocity (which gives the film co-efficient on the fin surface). These four design parameters are varied between certain ranges. The fin radius is varied between 50 mm and 60 mm. Fin thickness is considered between 1 mm and 4 mm. Number of fins is considered between 9 and 14. Velocity of air ranges between 10 ms^{-1} and 40 ms^{-1}. The basic geometry of the engine cylinder and fin array is shown in the figure 2.1 above.

2.2 Assumptions

There are 4 main assumptions made while doing the thermal analysis of the engine cylinder fins.

The inner cylinder wall is uniformly kept at constant temperature, i.e. at 558 K or 285°C.

The thermal model considered here is the steady state thermal model.

Heat transfer due to radiation has not been considered in this study.

And, the ambient temperature is taken as 298 K. Hence all physical properties of air are considered at 298 K or 25°C.

2.3 Boundary Conditions

The thermal model is defined by the boundary conditions that are applied to the geometry under analysis. For this particular problem, we apply two specific boundary conditions. They are:

- Constant temperature boundary condition
- Convection boundary condition

The constant temperature boundary condition is applied on the inner cylinder wall. A constant temperature is specified throughout the inner surface of the engine cylinder. This temperature is chosen based on the high temperature produced in the engine cylinder during combustion. Based on literature review, this temperature is here, taken as 558 K.

The convection boundary condition is specified on the outer surface of the engine cylinder as well as the surface of the fins. The convection boundary condition is specified by defining the film co-efficient on the selected surfaces. The film co-efficient of a particular surface can be found out from the velocity of air in direct contact with the surface. The empirical relation to find the film co-efficient in this case is taken from *Introduction to Heat Transfer* by Incropera F.P. and Dewitt D.P.

Equation 1: Heat transfer co-efficient for air

$$h = \frac{k.Nu}{2.r}$$

In order to find the Nusselt number, the Reynolds number is used, which is dependent on the free stream velocity found in Table 2.1. The Nusselt number was calculated using the following formula.

Equation 2: Nusselt Number

$$Nu = c.Re^{m}.Pr^{1/3}$$

Equation 3: Reynold's Number

$$Re = \frac{\rho.v.d}{\mu}$$

Equation 4: Prandtl Number

$$Pr = \frac{\mu.cp}{k}$$

Re	c	m
0.4 - 4	0.989	0.330
4 - 40	0.911	0.385
40 - 4000	0.683	0.466
4000 - 40000	0.193	0.618
40000 - 400000	0.027	0.805

Table 2.1 Constants for circular cylinder in cross flow

As shown in figure 2.2, for this particular design, the constant temperature boundary condition is applied by specifying the inner cylinder temperature of the engine as a constant at 285 °C. Also, the convection boundary condition is applied by defining the film co-efficient on the surface corresponding to air velocity 25 ms^{-1}. The boundary conditions applied to the control regions are graphically shown in the figure below.

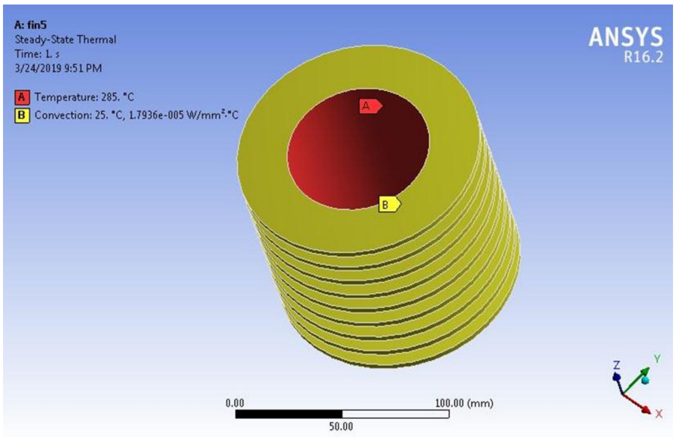


Fig 2.2 Boundary conditions applied to control volume

2.4 Grid Independence Study

Grid independence was established considering five different mesh sizes for discretizing the domain of the engine cylinder and fins. In each case total heat flux values were obtained and tabulated. Based on the results it was concluded that the grid independence was achieved for mesh-4 and this mesh was considered for further computations. The grid layout of the model is shown in figure 2.3. The grid independency study details are shown in table 2.2 and figure 2.4, below. The grid independence study was conducted on the basis of total heat flux.

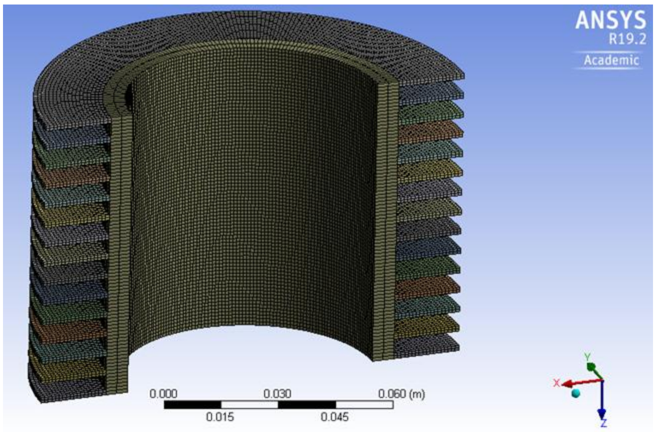


Fig-2.3: Grid layout of the model

Mesh No.	No. of elements	Total Heat flux W/m²
1	128588	29525.9
2	173257	29489.3
3	209444	29479.4
4	254790	29477.2
5	316495	29477.1

Table-2.2 Grid Independence Study

2.5 Validation of the CFD model

For validation, the study of the experimental work done by Devendra J. Waghulde, et al. [10] was chosen. The experimental setup they developed consisted of a cylinder with rectangular geometry fins by using Al 6061. Six fins are manufactured on the cylinder so that temperature at the end of fin tip is found out. Besides experimental analysis, numerical model was created and then computational analysis was conducted. For the purpose of the analysis of this project work, the same thermal model has been used. The experimental setup used in their study consisted of a set of two cylinders manufactured with fin thickness of 2.5 mm and 3.0 mm. The cylinder with fins was enclosed in a box made of cardboard to avoid external wind disturbances. The enclosure helped in developing a pure natural convection transfer through the set of fins by isolating the cylinder from the surrounding effects. The experimental setup implemented, consists of cylinder with fins, digital temperature indicator, dimmer stat (voltage regulator) and thermocouple sensor cables.

The numerical analysis was done using the Ansys software and the thermal model considered was the steady state thermal model with the loads as the inner cylinder temperature at 285 °C and the film co-efficient on surface of fins as 25 $Wmm^{-2}°C^{-1}$. The same loads and design specifications were recreated for the numerical analysis conducted in my study for the purpose of validation. The output parameter taken for comparison was the fin tip temperature.

The temperature contour of fin thickness 2.5mm, of the current study is shown in figure 2.4 below. Also shown are the temperature contour of fin thickness 3mm, as shown in figure 2.5. The fin tip temperature obtained from the experimental study and the numerical analysis conducted by Waghulde is compared to the fin tip temperature obtained from numerical analysis of the current study. The comparison is carried out for two thickness values – 2.5 mm and 3 mm. The comparison is showed in tabular form in table 2.3 given below. The slight variations in the values can be explained due to unideal conditions in experimental analysis, like heat loss due to radiation, etc.

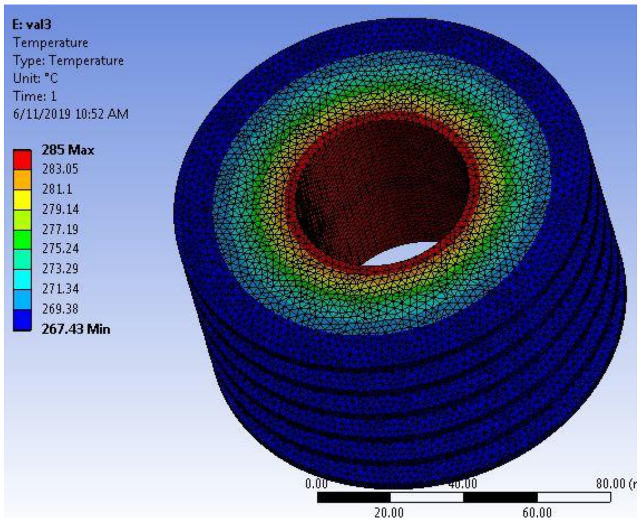
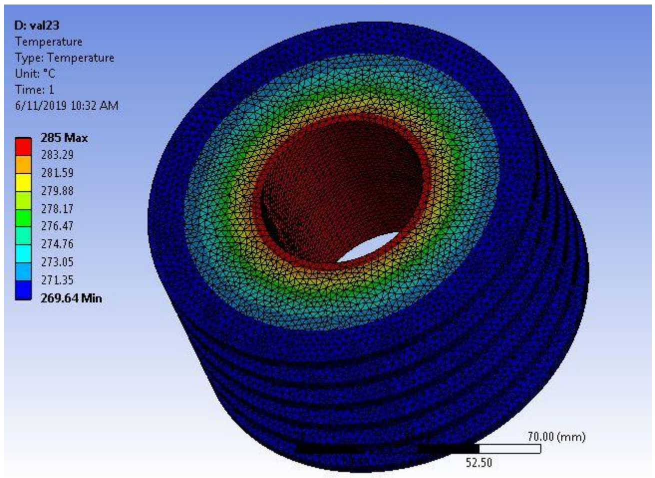


Fig 2.4 Temperature contour of fin thickness 2.5mm, of the current study



Number of fins	Thickness of fins	Fin radius	Air velocity

Fig-2.5: temperature contour of fin thickness 3mm, of the current study

Fin Thickness (mm)	Waghulde's experimental analysis (°C)	Waghulde's numerical analysis (°C)	Current numerical analysis (°C)
2.5	265.33	267.27	267.11
3	266.83	269.5	269.31

Table-2.3 Results comparison

3. GENETIC ALGORITHM

Optimization of engine fins is done in this project using Genetic Algorithm (GA). GA is applied by means of a program code written using the programming language, Python 3.7. The working of the code follows a specific flow of control (shown in figure 3.1, below), involving several processes, each of which are explained in the subsequent sections.

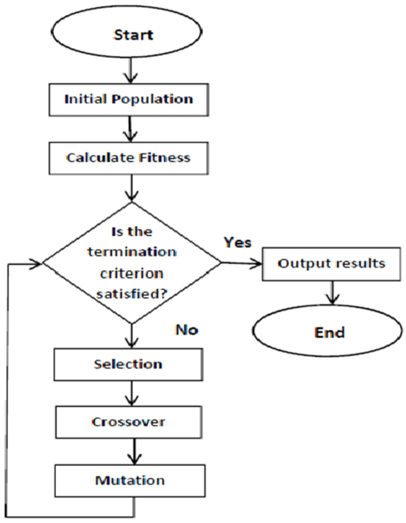


Fig-3.1 Flowchart of Genetic algorithm

3.1 Chromosome Design

Each individual in a population is termed a chromosome in GA terminology. In other words, a chromosome (also sometimes called a genotype) is a set of parameters which define a proposed solution to the problem that the genetic algorithm is trying to solve and the set of all such solutions is known as the population. Each individual parameter that make up a chromosome is called a gene. A particular gene of a particular chromosome represents a unique characteristic of that chromosome. While programming genetic algorithms, these are usually coded in binary form of 0s and 1s, however other encodings are also possible; almost any representation which allows the solution to be represented as a finite-length string can be used. Finding a suitable representation of the problem domain for a chromosome is an important consideration, as a good representation will make the search easier by limiting the search space; similarly, a poorer representation will allow a larger search space. The chromosome of this particular problem is defined with four characteristic genes, they are: number of fins, fin thickness, fin radius and air velocity. A model of the chromosome is shown below.

3.2 Population initialization

Based on literature review [14], the population size is selected as 20, as there are 4 genes per chromosome. The initial population is selected by randomly assigning values (within the specified operational ranges) to the genes of these 20 chromosomes. The values that are selected randomly are generated uniformly within the sample space. The program code is attached in appendix 1. The operational ranges of input parameters within which initial population is randomly assigned are shown in table 3.1 below

Input parameter	**Operational range**
Fin radius	50 – 60 (mm)
Fin thickness	1 – 4 (mm)
Number of fins	9 – 14
Air velocity	10 – 40 (m/s)

Table-3.1: Operational ranges of input parameters

3.3 Fitness Calculation

The initial population is then sent to Ansys 19.2 as a journal file. Ansys receives this journal file and executes a parametric file with the physics specified as the steady state thermal model explained above. While executing this parametric file, the fitness function, which is total heat flux, here is calculated for each individual of the population. And this new data, i.e., the chromosomes and their respective fitness is written into an output file. And this new file consisting of these individuals along with their respective fitness functions is sent back to the program to check for convergence. The maximum, minimum, average and standard deviation of the fitness function is calculated for that particular population. An example for a parametric file executed in Ansys in the current study is shown in figure 3.2.

Name	P1 - Fin_rad	P2 - Fin_Thick	P3 - Fin_offset	P4 - No_Fins	P6 - Convection Film Coefficient	P5 - Total Heat Flux Average
Units	mm	mm	mm		W m^-2 C^-1	W m^-2
DP 0 (Current)	52.6	2.02	7.5369	13	1.2982	2468.9
DP 1	56	1.45	8.2125	12	35.138	1.0829E+05
DP 2	55.1	3.04	8.08	12	16.68	28145
DP 3	52.6	2.02	7.5369	13	30.651	57159
DP 4	59.7	1.75	8.1875	12	47.059	1.5075E+05
DP 5	58.3	1.54	10.94	9	32.627	1.1534E+05
DP 6	52.9	1.75	7.5577	13	17.316	37104
DP 7	51	2.53	8.1225	12	13.229	19268
DP 8	50.8	1.66	10.927	9	27.099	54616
DP 9	50.5	3.25	9.675	10	18.738	23714
DP 10	56.9	1.75	10.917	9	18.194	54392
DP 11	59.8	2.74	8.8418	11	27.45	65507
DP 12	53.7	3.85	10.683	9	30.487	42713
DP 13	55.4	2.35	8.8773	11	26.289	55564
DP 14	59.5	2.38	8.135	12	36.077	91421
DP 15	56.6	1.66	12.293	8	17.06	51772
DP 16	55.6	2.77	10.803	9	21.064	41173
DP 17	52.8	1.21	8.2325	12	22.64	65832
DP 18	52.7	3.58	9.642	10	15.249	21237
DP 19	59.2	2.14	10.873	9	24.957	71729
DP 20	53.8	1.84	8.18	12	30.989	67705

Fig-3.2 Parametric Journal

3.4 Crossover

In genetic algorithms and evolutionary computation, crossover, also called recombination, is a genetic operator used to combine the genetic information of two parents to generate new offspring. It is one way to stochastically generate new solutions from an existing population, and analogous to the crossover that happens during sexual reproduction in biology. Solutions can also be generated by cloning an existing solution, which is analogous to asexual reproduction. An example for crossover is shown in figures 3.3, 3.4 and 3.5 given below.

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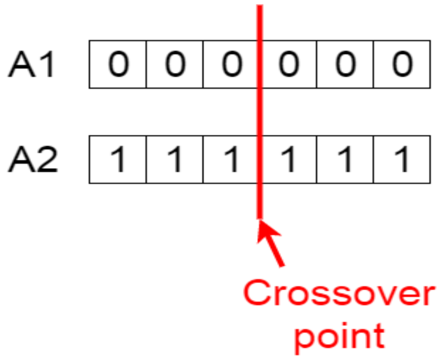

Fig-3.3 Three point crossover

Offspring are created by exchanging the genes of parents among themselves until the crossover point is reached.

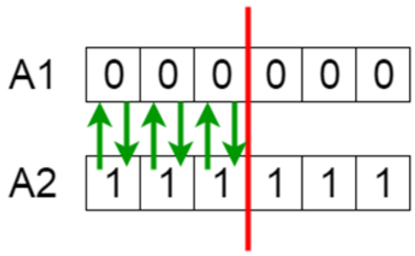

Fig-3.4 Crossover

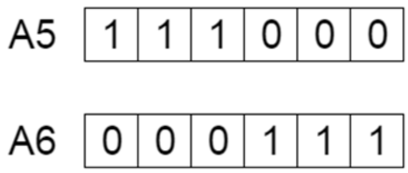

Fig-3.5 New individuals created after crossover

If the standard deviation and maximum values for successive population differ largely, then first, a selection is carried out in the current population to select the fittest individuals for crossover, in order to increase the overall strength of the population. The method of selection applied here is a tournament selection, which compares three individuals at a time. For crossover, 2-point crossover is carried out. The crossover probability is selected here as 0.8.

3.5 Mutation

Mutation is a genetic operator used to maintain genetic diversity from one generation of a population of genetic algorithm chromosomes to the next. It is analogous to biological mutation. Mutation alters one or more gene values in a chromosome from its initial state. In mutation, the solution may change entirely from the previous solution. Hence GA can come to a better solution by using mutation. Mutation occurs during evolution according to a user-definable mutation probability. The mutation operator and crossover operator employed by the genetic algorithm must also take into account the chromosome's design. This probability should be set low. If it is set too high, the search will turn into a primitive random search. An example for mutation is shown in figures 3.6 and 3.7 given below.

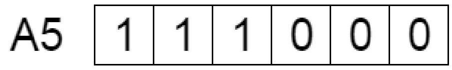

Fig-3.6 Chromosome before mutation

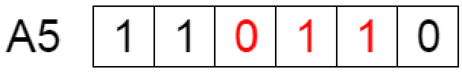

Fig-3.7 Chromosome after mutation

Mutation occurs to maintain diversity within the population and prevent premature convergence. One point mutation is carried out in this study.

3.6 Selection of individuals of next generation

For this particular study, the individuals of subsequent generation are selected by first pooling the parent population and offspring population of the current generation, and then sorting them according to their fitness, and then forming a new population of fittest individuals from that pool that are unique.

3.7 Termination

Termination signifies the end of iteration. Termination can occur either if a convergence criterion is reached, or if an absolute number of iterations is run, or if there have been no variation in fitness for an absolute amount of iterations. In this study, termination criteria was fixed as 100 generations based on a pilot study.

4. RESULTS AND DISCUSSIONS

Genetic Algorithm was implemented by means of a program code written in Python programming language. The geometrical input for the first generation was randomly generated. Seed values were used to ensure repeatability for a particular program run. Hundred generations each, for five different seeds were carried out. Each generation contained twenty simulations. The number of generations for a particular seed were taken on the basis of point of convergence observed. Here the input parameters were taken as fin radius, fin thickness, number of fins and air velocity and the output parameter was the total heat flux, from the fin array.

The final result was obtained by calculating the average value of each of the optimized input parameters from each seed and their maximized total heat flux values respectively, as shown in table 4.1.

Seed	Fin radius (mm)	Fin thickness (mm)	No. of fins	Air velocity (m/s)	Total avg. heat flux (W/m²)
1	59.9	1.06	9	39.7	234974.2299
2	59.8	1.06	9	39.1	230544.9793
3	59.9	1.02	9	38.8	235416.1168
4	59.8	1.06	9	38.5	227976.5155
5	60	1.06	9	38.5	231660.3582
Average	59.88	1.052	9	38.92	232114.4399

Table-4.1 Final Results

Hence, we can suggest that the near optimal solution of this maximization problem, after having analysed 10000 simulations as: engine fin array having fin radius of 59.88 mm, fin thickness of 1.052 mm, number of fins as 9 and air velocity of 38.92 ms^{-1}. The maximized objective, which is the total heat flux, was found to have a value of 232114.4399 Wm^{-2}.

4.1 Convergence for different seed values

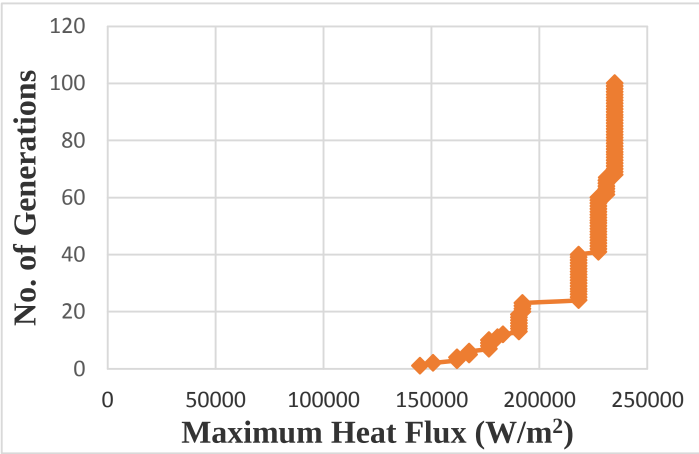

Fig-4.1 Convergence of output parameter for seed 1

For seed 1, as shown in figure 4.1, convergence occurred after: 67th generation
Optimised values for input parameters,
Fin radius = 59.9 mm
Fin thickness = 1.06 mm
Number of fins = 9
Air velocity = 39.7 ms^{-1}
Maximised Total Heat Flux = 234974.23 W/m^2

Fig. 4.2 Convergence of output parameter for seed 2
For seed 2, as seen in figure 4.2, convergence occurred after: 59th generation
Optimised values for input parameters,
Fin radius = 59.8 mm
Fin thickness = 1.06 mm
Number of fins = 9
Air velocity = 39.1 ms^{-1}
Maximised Total Heat Flux = 230544.98 W/m^2

Fig. 4.3 Convergence of output parameter for seed 3
For seed 3, as seen in figure 4.3, convergence occurred after: 69th generation
Optimised values for input parameters,
Fin radius = 59.9 mm
Fin thickness = 1.02 mm
Number of fins = 9
Air velocity = 38.8 ms^{-1}
Maximised Total Heat Flux = 235416.1168 W/m^2

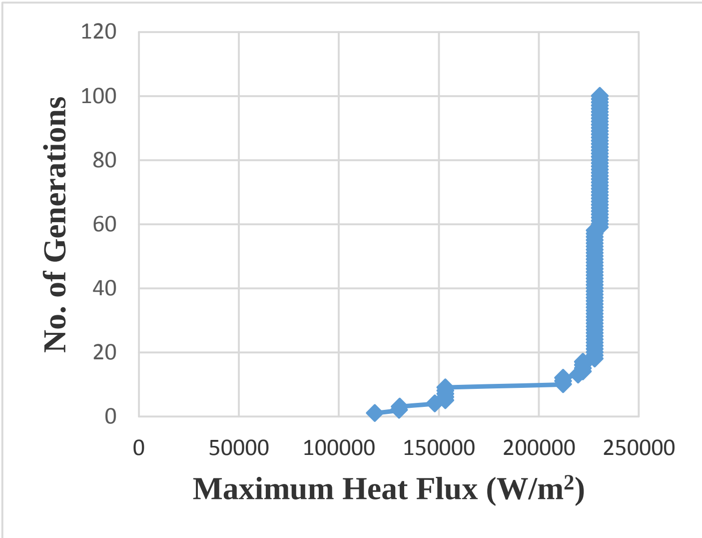

Fig. 4.2 Convergence of output parameter for seed 2

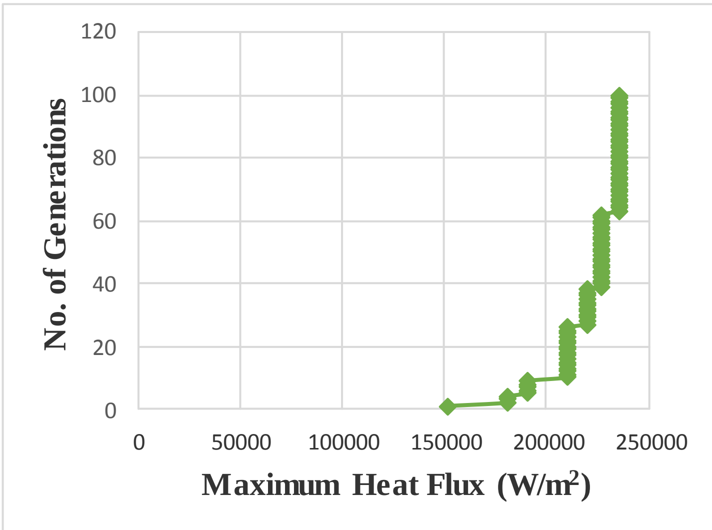

Fig. 4.3 Convergence of output parameter for seed 3

For seed 4, as seen in figure 4.4, convergence occurred after: 47th generation
Optimised values for input parameters,
Fin radius = 59.8 mm
Fin thickness = 1.06 mm
Number of fins = 9
Air velocity = 38.5 ms^{-1}
Maximised Total Heat Flux = 227976.5155 W/m^2

Fig. 4.5 Convergence of output parameter for seed 5
For seed 4, as seen in figure 4.4, convergence occurred after: 67th generation
Optimised values for input parameters,
Fin radius = 60 mm
Fin thickness = 1.06 mm
Number of fins = 9
Air velocity = 38.5 ms^{-1}
Maximised Total Heat Flux = 227976.5155 W/m^2

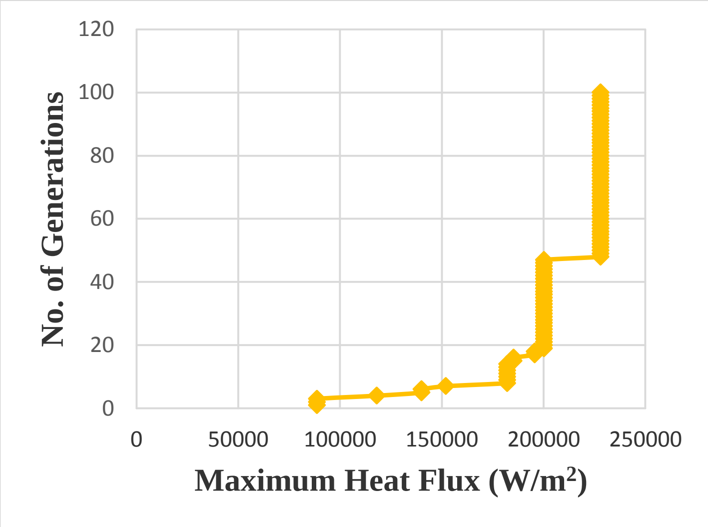

Fig-4.4 Convergence of output parameter for seed 4

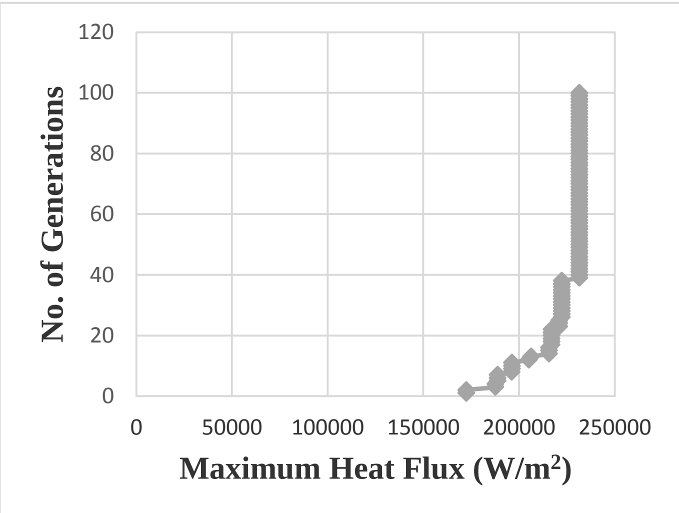

Fig-4.5 Convergence of output parameter for seed 5

5. CONCLUSIONS

In the current study, a Genetic Algorithm based heuristic technique was developed which gave optimal values for fin thickness, fin length, number of fins and air velocity of a 100 cc Hero Honda engine cylinder fin array, which maximized the total heat flux.

The optimal design was found to be the one with fin radius as 59.88 mm, the fin thickness as 1.052 mm, the number of fins as 9 and the air velocity as 38.92 ms^{-1}.

The maximized objective function, which was the total heat flux (taken as the average value of the 100th generation of each of the 5 seeds), found its maximized value as 232114.4399 Wm^{-2} , whereas the maximum value of total heat flux taken as the average value of 1st generation of each of the 5 seeds was found to be 150748.312 Wm^{-2}. Hence we can see that the maximum value has almost doubled at the end of the analysis.

It can be noted that the optimal values of fin radius and fin velocity which were 59.88 mm and 38.92 ms^{-1}, respectively are closer to the upper limits of their ranges, which were 60 mm and 40 ms^{-1}, respectively. This could suggest that these two parameters have a positive influence on the total heat flux value.

Similarly, it can be noted that the optimal values of thickness and number of fins which were 1.052 mm and 9, respectively are closer to the lower limits of their ranges, which were 1 mm and 9, respectively. This could suggest that these two parameters have a negative influence on the total heat flux value.

Genetic Algorithm has hence proved to be a reliable and accurate method of optimization when the input parameters are large, and therefore can be applied successfully to any optimization problem.

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