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Design Formulation and Optimization of Crankshaft Diameter for Single Cylinder 4-Stroke Diesel Engine

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Abstract:
Crankshaft is large volume production component with a complex geometry. It is a component of an engine which converts the reciprocating motion of the piston into the rotary motion of crank. An attempt is made in this paper to make design formulation for crankshaft of a single cylinder 4 stroke internal combustion engine and also optimize design parameters of same crankshaft. The high performance of engines greatly depends on the overall dimension of the engine itself of which crankshaft dominates considerably and also the lightweight design, component reliability and low through cost manufacturing. Formulation of single objective function is done for the minimization of diameter of crankshaft (ds) using three design variables, 1) diameter of crankpin, 2) length of crankpin, 3) web width. A genetic algorithm has been used for the optimum design of crankshaft.

***Key words**: Crankshaft design, formulation, Crankshaft diameter, Genetic algorithm, optimization*

1. Introduction

Crankshaft is a large component with a complex geometry in the engine, which converts the reciprocating displacement of the piston to a rotary motion with a four link mechanism. Design developments have always been an important issue in the crankshaft production industry, in order to manufacture a less expensive component with the minimum weight possible and proper fatigue strength and other functional requirements. These improvements result in lighter and smaller engines with better fuel efficiency and higher power output. The crankshaft consists of the shaft parts which revolve in the main bearings, the crankpins to which the big ends of the connecting rod are connected, the crank arms or webs (also called cheeks) which connect the crankpins and the shaft parts. The crankshaft main journals rotate in a set of supporting bearings ("main bearings"), [Fig.1.1] causing the offset rod journals to rotate in a circular path around the main journal centers, the diameter of that path is the engine "stroke": the distance the piston moves up and down in its cylinder. The big ends of the connecting rods contain bearings ("rod bearings") which ride on the offset rod journals.

2. Design Optimization Method: Genetic Algorithms

Genetic algorithms (GA) are search methods that employ processes found in natural biological evolution. These algorithms search or operate on a given population of potential solutions to find those that approach some specification or criteria.

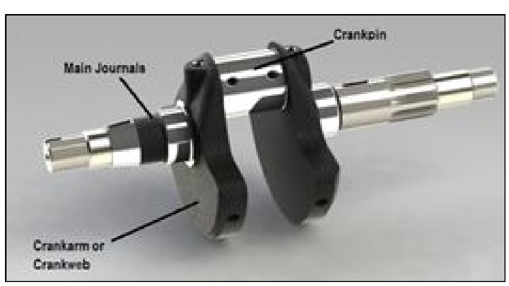

Figure 1.1: Typical Crankshaft with main journals that support the crankshaft in the engine block.[5]

To do this, the algorithm applies the principle of survival of the fittest to find better and better approximations. At each generation, a new set of approximations is created by the process of selecting individual potential solutions (individuals) according to their level of fitness in the problem domain and breeding them together using operators borrowed from natural genetics. This process leads to the evolution of populations of individuals that are better suited to their environment than the individuals that they were created from, just as in natural adaptation.[4]
The GA will generally include the three fundamental genetic operations of selection, crossover and mutation. They usually exhibit a reduced chance of converging to local minima. GAs suffer from the problem of excessive complexity if used on problems that are too large. Genetic algorithms work on populations of individuals rather than single solutions, allowing for parallel processing to be performed when finding solutions to the more large and complex problems.
Every member of a population has a certain fitness value associated with it, which represents the degree of correctness of that particular solution or the quality of solution it represents. The initial population of strings is randomly chosen. Although they do not guarantee convergence to the single best solution to the problem, the processing leverage associated with GAs make them efficient search techniques. The main advantage of a GA is that it is able to manipulate numerous strings simultaneously by parallel processing, where each string represents a different solution to a given problem. Thus, the possibility of the GA getting caught in local minima is greatly reduced because the whole space of possible solutions can be simultaneously searched.[1]

3. Formulation

Problem formulation is normally the most difficult part of the process. It is the selection of design variables, constraints, objective function(s), and models of the discipline/design. Good problem formulation is the key to success of an optimization study**.**

3.1. Objective Function

The objective function is to minimize the diameter of shaft (d_s) and ultimately reduce the weight of crankshaft under the effect of static load and so we can reduce the cost.

Let, $d_s = Diameter\ of\ shaft$

According to design of shaft, $M_s = \frac{\pi}{32} \times {d_s}^3 \times \sigma_b$

Therefore diameter of shaft,

$${d_s}^3 = \frac{M_s \times 32}{\pi \times \sigma_b} \quad \textbf{(1)}$$

Where, $M_s = Bending\ moment\ on\ the\ shaft$

$\sigma_b = Allowable\ bending\ stress$

But, $\sigma_b = \frac{M}{z}$

Where, $Max\ bending\ moment\ M = H_1 \times \left(b_2 - \frac{l_c}{2} - \frac{t}{2}\right)$

$Section\ Modulus\ Z = \frac{w \times t^2}{6}$

From equation (1),

$${d_s}^3 = (M_s \times 32)/\left(\pi \times {}^{M}/_{Z}\right) \quad \textbf{(2)}$$

Putting the value of M and Z in equation (2)

$$\therefore {d_s}^3 = \{M_s \times 32\}/\left\{\pi \times H_1 \times \left(b_2 - {}^{l_c}/_2 - {}^{t}/_2\right)/\left({}^{w \times t^2}/_6\right)\right\}$$

Now according to manual design of crankshaft, value of M_s , H_1 , b_2 and t are given below.

$M_s = 658.4\ kN \cdot m$ $\quad H_1 = 7.26\ kN$

$b_2 = 86\ mm$ $\quad t = 24\ mm$

Putting above values in equation of d_s , we get

$$F(X) = d_s = 56\ \{w/[172 - l_c - (0.65 d_c + 6.35)]\}^{\frac{1}{3}}$$

This is the required objective function in three variables when crankshaft subjected to maximum bending moment.

3.2. Formulation of Constraints

According to summary of manual design result constraints can be enlisted as follows

- $46 \le w \le 63$
- $28 \le l_c \le 33$
- $38 \le d_c \le 44$

Where,

$d_s = Diameter\ of\ crankshaft$

$w =$ Width of crank web

$l_c = Length\ of\ crankpin$

$d_c = Diameter\ of\ crankpin.$

3.3. Optimization problem in Standard format
The above optimization problem in standard format can be stated as below:
The design vector $X = \{d_c, l_c, w\}$ which minimizes

$$f(x) = d_s = 56\{w/[172 - l_c - (0.65d_c + 6.35)]\}^{\frac{1}{3}}$$

Subjected to constraints,

- $g_1(x) = 38 - d_c \leq 0$
- $g_2(x) = d_c - 44 \leq 0$
- $g_3(x) = 28 - l_c \leq 0$
- $g_4(x) = l_c - 33 \leq 0$
- $g_5(x) = 46 - w \leq 0$
- $g_6(x) = w - 63 \leq 0$

Where,

- $d_s = Diameter\ of\ crankshaft$
- w = Width of crank web
- $l_c = Length\ of\ crankpin$
- $d_c = Diameter\ of\ crankpin$

4. Results
With the use of MATLAB genetic algorithm tool the fitness function *f* (x) for the genetic algorithm is calculated with the inequality constraints and the bound limit for the three variables 1) Diameter of the crank pin, d_s 2) Length of the crank pin, l_c 3) web width of crankshaft, w.

4.1. Summary of Manual Design Results
Diameter of the Crank Pin = 44 mm
Length of the Crank Pin = 33 mm
Diameter of the shaft = 45 mm
Web Thickness (Both Left and Right Hand) = 24 mm
Web Width (Both Left and Right Hand) = 63 mm

4.2. Optimum Design Results using GA
The optimized results of the fitness function *f* (x) are shown into the Table No.1

Sr.	w	l_c	d_c	d_s
1	48.89	28.44	38.8	42.48
2	47.3	29.4	39.56	42.19
3	46.25	31.48	38.5	42.06
4	49.5	30.8	40.45	43.1
5	46	28	38	41.51
6	48.25	28.8	42.46	42.64
7	48.5	29.47	41.84	42.75
8	48.9	30.42	38.15	42.68
9	48	30.8	40.13	42.63
10	48.4	30.2	43.3	42.94

Table 1: Optimized Functional Values

Figure 4.1 shows the genetic algorithm tool from which the value of the three variables are found with the three points given at the bottom of the toolbox and the fitness function value is found in the centre of the box. Figure 4.2 shows the sample result of GA tool.

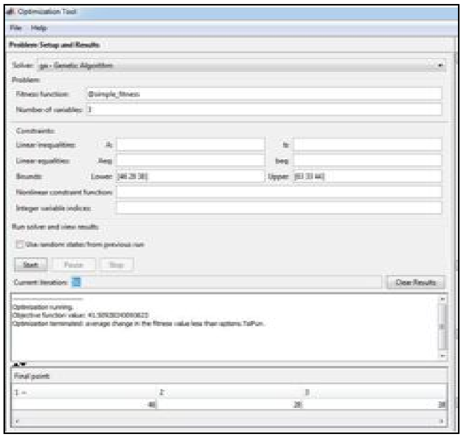

Figure 4.1 Genetic Algorithm Tool

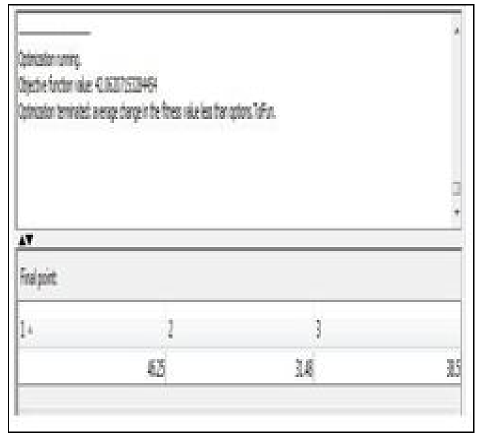

Figure 4.2 Sample Result

4.3. Surface plot for the fitness function

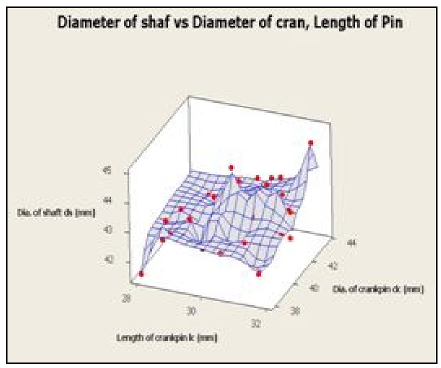

Figure 4.3: Diameter of Crankshaft to Diameter of Crankpin and Length of Crankpin

Figure 4.3 indicates that the diameter of the crankshaft decreases as the diameter of crankpin decreases and as length of crankpin decreases which is seen in figure as the valley portion. The minimum value of diameter of crankshaft 41.51 mm when the diameter of crankpin 38 mm and length of the crankpin 28 mm.

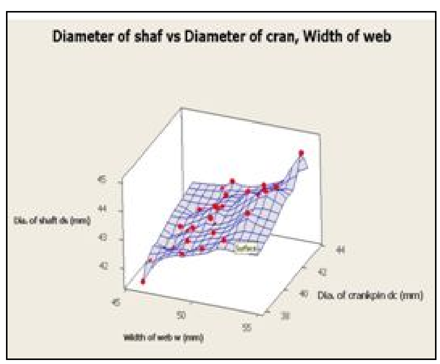

Figure 4.4: Diameter of Crankshaft to Diameter of Crankpin and Web Width

Figure 4.4 shows that the diameter of the crankshaft decreases as the diameter of crankpin decreases and as web width decreases it will generate wave form and at the end of limit it will increase but as the both value of diameter of crankpin and web width decreases and diameter of the crankshaft is decreases initially and so that it minimize the value of diameter of the crankshaft 41.51mm with diameter of crankpin 38 mm and web width 46 mm which is seen in figure as the valley portion.

Validation of Result		
Input Variable :	**Manually Design**	**Genetic Algorithm**
Diameter of crankpin (mm)	44	38
Length of crankpin (mm)	33	28
Web width (mm)	63	46
Output Variable		
Diameter of crankshaft (mm)	45	41.51

Table 2: Validation of Results

5. Conclusion

A genetic algorithm has been used for the optimum design of crankshaft. Some examples of optimum design that minimize the diameter of crankshaft under constraints are presented. The numerical results are given in graphical forms of diameter of crankpin, length of crankpin, web width. The optimized results are compared with those of exhaustive search method. All the results have the same tendency. Therefore it has a strong possibility for being used for other optimization problems.

5.1. Formulation

- Formulation of single objective function is done for the minimization of diameter of crankshaft (ds) using three design variables, 1) diameter of crankpin, 2) length of crankpin, 3) web width.

5.2. Genetic Algorithm

- The genetic algorithm only uses the function value and doesn't need derivatives calculated analytically or numerically.
- The scatter plot drawn with the data formed by genetic algorithm, as the value of diameter of crankpin, length of crankpin and web width decreases the diameter of crankshaft.
- The surface plots give the relationship of diameter of crankshaft to the three parameter and it concludes that the diameter of crankshaft is proportional to 1) diameter of crankpin, 2) length of crankpin, 3) web width.
- Genetic algorithm gives the different solution each time so that more generations need to be created for better and correct solution.

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