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Genetic Algorithm Based Optimization of Box-Cross Section Modulus for Heavy Vehicle Chassis

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ABSTRACT:

Chassis is the most important structural member in the on-road vehicles. All the loads generated by other components of the vehicle are transferred to chassis only. So the chassis structure has to be strong enough to withstand the loads. In order to overcome failure in the chassis structure, the variable cross-section chassis structure has to be designed based on the variable loads along the length of the vehicle. In this work genetic algorithm has been used to optimize the chassis cross section height, width and thickness by using their mathematical relationship with section modulus. The objective function is to optimize the section modulus based on bending moment equation. The optimization process is automated using C++language. The optimum values of the chassis cross section parameters were found to be efficient in the design of chassis.

KEYWORDS:

Heavy vehicle; Chassis; Section modulus; Optimization; Genetic algorithm

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ACRONYMS AND NOMENCLATURE:

Z	*Section modulus (mm^3)*
M	*Bending moment (N-mm)*
I	*Mass moment of inertia (mm^4)*
Y	*Distance of the most extreme point at the section from the neutral axis (mm)*
F	*Bending stress (N/mm^2)*

1. Introduction

In modern world on-road vehicles have changed drastically based on their design and other functional aspects. Market demands the faster and higher transportation in a short span. In order to meet this demand, vehicle manufacturers are designing heavy load carrying vehicles. However, the safety of heavy load carrying vehicle has to be ensured. Based on the historical data chassis related failures has been reported only 7% [1]. But the failures in chassis lead to serious injury to the driver and major accidents. Chassis design should be cost effective, optimum weight and carry maximum payload which ensures vehicle safety by withstanding the worst loading conditions. A primary criterion in chassis design is to meet the safety requirements first and then to reduce weight in order to satisfy the fuel economy requirements [2]. It is important to fully understand the primary loads that the vehicle structure must be capable to withstand. These loads must be efficiently transferred through the structure so that the chassis will not be prone to mechanical failure.

Fui et al [3] have studied the 4.5 ton truck chassis vibration due to excitation, road roughness and vibration of components fixed on chassis. Chassis responses were examined by stress distribution and displacements. Suitable locations for engine and suspension systems were determined by the results of mode shape. Analysis results revealed that the major disturbance of the chassis was the road excitation. Patel et al [4-5] have studied ladder chassis frame of Eicher E2 by static structural analysis by assuming chassis as a simply supported beam with overhang. Pro-E and Ansys software were used for this work. The stress value and max. displacement obtained using simulation software was 10% and 5.92% respectively more than those from analytical solution.

Yilmazçoban et al [6] have studied and optimized the thickness of a middle tonnage truck chassis by using finite element technique. The main objective of their work was to reduce the material usage and thereby reduction in material cost. They analyzed three types of thickness material for the chassis and compared the results of stress and displacement. Study revealed that the 4mm thickness is safe enough to carry 15 ton load. Chandra et al [7] have studied S-Glass/Epoxy, Carbon/Epoxy and E-glass/Epoxy materials for chassis in various cross sections like C, I and box sections. TATA 2515 EX chassis was taken for study and Pro-E and Ansys software were used. The chassis using Carbon/Epoxy I-type section shown better mechanical properties compared to other materials and sections.

Genetic algorithm is the search technique that applies the natural evolution based procedure to optimize the problem. Series of bit strings representing the design variables are generated and manipulated using genetic algorithm and then are applied to an objective function to get the optimum values. An example of genetic algorithm application to a transportation problem can be found in [9]. The main objectives of this research work are to develop an initial conceptual design of on-road heavy vehicle chassis by variable cross section method and to optimize the cross section modulus of chassis at different locations using genetic algorithm. In this paper, the application of genetic algorithm to optimize the chassis cross section height, width and thickness by using their mathematical relationship with section modulus as an extension of authors earlier work [10].

2. Section modulus

In most of the on-road vehicles, the cross section of the chassis structure is uniform, as shown in Fig. 1, in spite of the loads variation. To design the optimum chassis cross section, the load distribution on the vehicle has to be studied. The variable cross section chassis as shown in Fig. 2 is based on the principle of high section modulus at highly loaded sections and vice-versa. Chassis design for heavy vehicle applications are based on the loads primarily acting on it. In heavy transportation vehicles the vertical load due to pay load is a primary. In order to overcome this vertical load the chassis frame has to resist the bending moment in accordance with the following relationship,

$$M/I = F/Y = E/R \tag{1}$$

Where M is the bending moment (N-mm), I is the mass moment of inertia (mm^4), F is the bending stress (N/mm^2), Y is the distance from the neutral axis (mm), E is the modulus of elasticity (N/mm^2) and R is the radius of curvature (mm), Simplifying Eqn. (1) in terms of section modulus (Z) becomes,

$$M = F*(I/Y) = F*Z \tag{2}$$

If the pay load has to be increased then the section modulus has to be kept proportionately to withstand the bending moment created by the pay load.

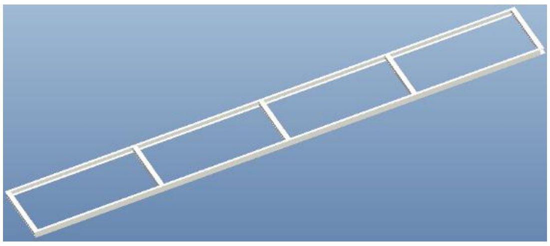

Fig. 1: Uniform cross section chassis

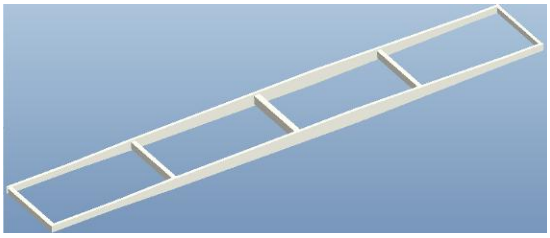

Fig. 2: Variable cross section chassis

The cross section parameters P1 to P3 represents thickness, width and height respectively as shown in Fig. 3. The section modulus in terms of P1 to P3 is given by,

$$Z = \frac{(P_2 P_1^3 + P_1 P_3^3)/6 + P_2 P_1 (P_1 + P_3)^2/2}{(2P_1 + P_3)/2} \tag{3}$$

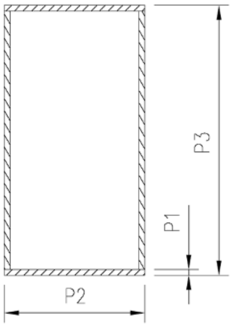

Fig. 3: Cross section parameters of chassis frame

3. Genetic algorithm process & results

In this research work section modulus of the chassis structure has been optimized using genetic algorithm. Computer program in C++ language has been developed to automate the genetic algorithm based optimization process. The parameter ranges and accuracy were assigned as an input to the computer program. The optimum results are given in an output file. The parameters ranges are taken as the nearest values of the standard cross sections which are commercially used in chassis design as given in Table 1. Table 2 lists the initial population of 30 binary strings which are randomly generated to represent the section modulus parameters using 11 digits. First 2 bits, second 4 bits and third 5 bits represent the cross section parameters P1, P2 and P3 respectively.

Table 1: Parameter ranges with accuracy

Parameter	Range (mm)		Accuracy (mm)
	Min	Max	
P1	6	12	2
P2	50	125	5
P3	75	230	5

Table 2: Parameters and section modulus at initial population

S. No.	P1	P2	P3	Section modulus	Binary string
1	8	60	125	3.76E+12	00110101011
2	6	100	130	8.10E+11	10101001111
3	8	50	80	1.37E+15	00111001010
4	6	55	80	3.36E+15	11001000010
5	6	50	75	1.02E+15	10010100001
6	8	60	75	1.03E+15	00010011110
7	8	50	75	1.52E+09	10110111101
8	8	50	80	1.03E+15	11011100010
9	6	55	125	7.55E+14	01001010101
10	8	55	75	1.52E+09	11111010010
11	6	100	130	4.47E+15	00101010010
12	6	50	145	3.37E+15	10000110011
13	8	105	225	1.37E+15	10111010100
14	6	55	130	1.50E+09	00101100110

S. No.	P1	P2	P3	Section modulus	Binary string
15	6	55	175	7.84 E+11	00010011001
16	8	60	125	4.98 E+11	11011110110
17	8	50	175	1.37E+15	00111001011
18	6	60	155	1.00E+15	11111111000
19	8	50	80	1.03E+15	00000110010
20	8	100	125	1.42 E+11	01011010111
21	8	55	130	3.63E+15	01010110011
22	8	60	180	1.37E+15	11101000101
23	6	55	125	4.35E+15	01100010110
24	8	105	180	1.56 E+09	10010110011
25	10	50	230	2.00 E+09	01000100010
26	12	55	125	3.27E+15	00111101010
27	12	60	155	3.52E+15	00010100100
28	8	105	125	7.33 E+07	11001011001
29	6	105	75	1.00E+15	00010001011
30	8	105	125	1.56 E+07	00000010000

In reproduction stage the strings are decoded into parameter values which are then substituted in the objective function. Based on the fitness function, these strings are reproduced. Bits are decoded into equivalent decimal values (dv) and then substituted in the following equations to get the corresponding parameter values:

$$DV = (dv * Acc) + \text{min. value} \quad (4)$$

$$Acc = (\text{max. value} - \text{min. value}) / ((2^n)-1) \quad (5)$$

Where n is the number of bits representing each parameter, DV is the decoded value, dv is decimal value and Acc is the accuracy. After decoding 30 sets of parameter values and their corresponding Z values are stored separately. Then two integer numbers X_1 & X_2 between 1 and 30 are randomly generated. The corresponding Z values of X_1 & X_2 are compared and stored as the superior & inferior values respectively. Variable X_3 is randomly generated with an accuracy of 0.01 between 0 and 1. Based on matting condition of $X_3 \leq 0.75$ the superior value is copied. If this condition did not meet then the inferior value is copied. The reproduction outcome is listed in Table 3.

Table 3: Reproduction results

X_1	X_2	Section modulus of X_1	Section modulus of X_2	X_3	Copied section modulus	Reproduced binary strings
8	16	1.03E+15	4.98E+12	0.71	1.03E+15	01010010101
10	26	1.52E+09	3.27E+15	0.12	3.27E+15	10100110010
10	29	1.52E+09	1.00E+15	0.37	1.00E+15	00001111000
25	27	2.00E+09	3.52E+15	0.63	3.52E+15	11111010010
14	1	1.50E+09	3.76E+12	0.41	3.76E+12	11111001010
27	7	3.52E+15	1.52E+09	0.12	3.52E+15	11111010010
12	8	3.37E+15	1.03E+15	0.69	3.37E+15	10000010111
18	28	1.00E+15	7.33E+07	0.36	1.00E+15	00011111000
26	1	3.27E+15	3.76E+12	0.08	3.27E+15	10100110010
3	5	1.37E+15	1.02E+15	0.61	1.37E+15	10100111101
13	9	1.37E+15	7.55E+14	0.32	1.37E+15	01001111110
29	25	1.00E+15	2.00E+09	0.05	1.00E+15	00001111000
29	27	1.00E+15	3.52E+15	0.5	3.52E+15	11111010010
26	11	3.27E+15	4.47E+15	0.96	3.27E+15	10100110010
10	17	1.52E+09	1.37E+15	0.55	1.37E+15	01000011100
4	6	3.36E+15	1.03E+15	0.25	3.36E+15	10010110101
20	8	1.42E+12	1.03E+15	0.51	1.03E+15	01010010101
26	12	3.27E+15	3.37E+15	0.51	3.37E+15	10000010111
8	19	1.03E+15	1.03E+15	0.58	3.37E+15	10000010111
11	13	4.47E+15	1.37E+15	0.87	1.37E+15	01001111110
2	8	8.10E+11	1.03E+15	0.83	8.10E+11	00101001011
23	13	4.35E+15	1.37E+15	0.65	4.35E+15	10000111010
9	15	7.55E+14	7.84E+11	0.15	7.55E+14	00110110010
11	28	4.47E+15	7.33E+07	0.31	4.47E+15	10001011111
18	16	1.00E+15	4.98E+12	0.9	4.98E+12	11011101110
22	8	1.37E+15	1.03E+15	0.38	1.37E+15	01011111101
24	22	1.56E+09	1.37E+15	0.82	1.56E+09	01001100101
24	12	1.56E+09	3.37E+15	0.9	1.56E+09	01001100101
3	17	1.37E+15	1.37E+15	0.89	1.37E+15	01000011100
24	21	1.56E+09	3.63E+15	0.2	3.63E+15	11010010111
14	19	1.50E+09	1.03E+15	0.46	1.03E+15	01100010101

In cross over stage the 30 binary strings are first formed into 15 pairs. Then it is decided that which pairs has to go under the cross over process and after which bit the pair has to cross over the bits. A random number X_4 between 0 and 1 is generated with the accuracy of 0.1 If $X_4 \leq 0.75$ then the corresponding pair has to go under the cross over process or else the pair has to be copied for the next operation. If $X_4 \leq 0.75$ then another integer number X_5 between 1 to 10 is randomly generated. Then the bits after X_5^{th} digit of the strings are exchanged. The generation of random number X_4 is repeated for 15 times. Table 4 lists the outcome of cross over stage.

Table 4: Cross over results

S. No	X_4	X_5	Result of cross over
1	0.8	Not Applicable	01010010101 10100110010
2	0.9	Not Applicable	0001111000 11111010010
3	0.3	6	11111***010010*** 11111***001010***
4	0.7	Not Applicable	10000010111 00011111000
5	0.5	3	10***110011101*** 01***000110010***
6	0.8	Not Applicable	01001111110 00001111000
7	0.7	Not Applicable	11111010010 10100110010
8	0.4	9	01010110***101*** 10000011***100***
9	0.9	Not Applicable	01010010101 10000010111
10	0.2	8	1000111***1110*** 0100001***0111***
11	0.5	4	001***00111010*** 100***01001011***
12	0.6	7	001010***11111*** 100101***10010***
13	0.9	Not Applicable	11011101110 01011111101
14	0.7	Not Applicable	01001100101 01001100101
15	0.8	Not Applicable	01000011100 11010010111

Mutation means changing the bit value from 1 to 0 and vice-versa. The number of bits to be mutated has been decided based on the mutation probability using,

$$N = (Mp * 30 * 11) \qquad (6)$$

Where N is the number of bits to be mutated and *Mp* is the mutation probability. An integer number X_6 between 1 and 330 is randomly generated. Mutate the X_6^{th} digit position bit valve from 1 to 0 or 0 to 1. Random number X_6 generation is repeated for N times. For example, before mutation:

010100101011010011001000001111000111110100 10

If X_6 = 5 then after mutation:

0101***1***1010110100110010000011110001111101 0010

At the end of mutation process these binary strings are decoded into corresponding section modulus parameters. The output of this mutation process is taken as an input to the initial population of the next iteration. The iteration process is repeated for 'R' number of times. The section modulus values of every mutation process have been stored and optimum value has been selected and copied for output. In the output file the optimum section modulus and its corresponding cross section parameter values are printed. The spool of results after mutation is shown in Fig. 4. The optimum values of parameters are highlighted in Table 5. Keeping the parameters P1 & P2 as same as the ones from the first optimum result, the parameter P3 is optimised in various locations along the length of the chassis based on vehicle loading.

Table 5: Parameters and section modulus after mutation

S. No	DV of P1	DV of P2	DV of P3	Section modulus
1	8	55	80	1.03E+15
2	6	50	125	3.27E+15
3	6	105	75	1.00E+15
4	8	60	125	3.52E+15
5	8	100	130	3.52E+15
6	8	50	80	3.7 E+13
7	6	55	80	3.37E+15
8	6	50	75	7.53 E+14
9	***6***	***90***	***175***	***4.46E+15***
10	8	50	75	1.00E+15
11	8	50	80	1.37E+15
12	6	55	125	1.00E+15
13	8	55	75	3.52E+15
14	6	100	130	3.27E+15
15	8	50	145	1.03E+15
16	12	105	125	4.36E+15
17	8	55	130	1.03E+15
18	10	55	175	3.37E+15
19	6	60	125	3.47E+15
20	8	50	175	1.03E+15
21	6	60	155	1.00E+15
22	12	50	80	3.51 E+13
23	8	100	125	1.03E+15
24	10	55	130	3.27E+15
25	8	60	180	4.98 E+13
26	12	60	125	1.37E+15
27	8	100	130	1.56 E+13
28	10	105	80	1.56 E+13
29	8	50	75	1.37E+15
30	8	55	155	3.63E+15

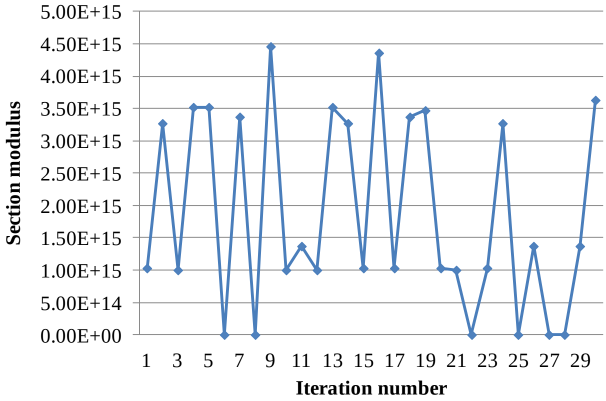

Fig. 4: Results after mutation

4. Conclusion

In this work height, width and thickness of cross section of heavy vehicle chassis were optimized using genetic algorithm. The objective function was to optimize the section modulus based on bending moment equation. The computer program in C# language has been developed to automate the optimization process of genetic algorithm. Predicted optimum values were found to be conformance with the chassis design intent.

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