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Development of Mathematical Model for Optimization of Chassis Design of on-Road Heavy Vehicle

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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 with stand the loads in static and dynamic conditions. In most of the On-Road vehicles the cross section of the chassis structure is uniform in spite of the variable loads. In order to overcome failure in the chassis structure and ensure the safety, the variable section chassis structure to be designed based on the variable loads along the length of the vehicle. This research work has developed a mathematical model for optimizing the cross section of chassis.**

Keywords- Optimization, Chassis Design, Mathematical model

INTRODUCTION

In modern world ON-Road vehicles have changed drastically based on the design and other functional aspects. Market demands the faster and higher transportation in a short span. In order to meet this market demand, vehicle manufacturers are designing heavy load carrying vehicles. These heavy load carrying vehicles gives an advantage of faster, heavy transportation in a short span. On the other side the safety of the heavy load carrying vehicle has to be ensured. Based on the historical data Chassis/body is responsible for only 7% of the failure types. However, failures of chassis are catastrophic with serious consequences. In some cases, a consequence of these in-service failures results in the recall of all affected vehicles with heavy costs and bad publicity.

Every vehicle has a body, which has to carry both the loads and its own weight. Vehicle body consists of two parts; chassis and bodywork or superstructure. The conventional chassis frame, which is made of pressed steel members, can be considered structurally as grillages. The chassis frame includes cross-members located at critical stress points along the side members. To provide a rigid, box-like structure, the cross-members secure the two main rails in a parallel position. The cross-members are usually attached to the side members by connection plates. The joint is riveted or bolted in trucks and is welded in trailers. Chassis is the backbone of any vehicle. If any failure occurs in chassis it will leads to the collapse of a whole vehicle system. Also chassis is not a component that can be replaced easily. If any failure occurs at chassis, either have to replace the chassis totally or require the cost and effort similar to the new vehicle assembly.

Chassis design should be cost effective, lesser weight, maximum payload, ensures vehicle safety by withstanding the worst loading conditions. A primary criterion in chassis design is to meet safety requirements first and later to reduce weight in order to satisfy fuel economy requirements. 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.

LITERATURE SURVEY

Alireza Arab Solghar, Zeinab Arsalanloo (2013) studied and analyzed the chassis of Hyundai Cruz Minibus. ABAQUS Software was used for modeling and simulation. Self weight of the chassis is considered for static analysis and Acceleration, Braking and Road Roughness were considered for dynamic analysis. It's observed that the stresses on chassis caused by braking were more compared with acceleration.

Kenji KARITA, Yoichiro KOHIYAMA, Toshihiko KOBIKI, Kiyoshi OOSHIMA, Mamoru HASHIMOTO (2003) had developed a chassis made by Aluminium. The material selected for the frame is 6061-T6. They used the Variable section extrusion method for making the chassis. It's developed with the help of computer Aided Engineering. Aluminium material gives an advantage of weight reduction. From this study authors found that the Aluminium chassis meets the target of weight reduction, strength and rigidity. Also they concluded that the remaining technical issues will be addressed to enable commercial adoption of the aluminum frame.

Teo Han Fui, Roslan Abd. Rahman (2007) have studied the 4.5 Ton truck chassis against road roughness and excitations. Vibration induced by Road Roughness and excitation by the vibrating components mounted on chassis were studied. Chassis responses were examined by stress distribution and displacements. Mode shape results determine the suitable mounting locations of components like engine and suspension systems. Analysis results reveal that the road excitation was a main disturbance to the chassis.

M. Ravichandra, S. Srinivasalu, Syed altaf Hussain (2012) studied the alternate material for chassis. They studied and analyzed Carbon/Epoxy, E-glass/Epoxy and S-glass/Epoxy as chassis material in various cross sections like C, I and Box Section. TATA 2515 EX chassis was taken for study. Pro-E and Ansys software were used for this work. Study reveals that the Carbon/Epoxy I section chassis has superior strength, stiffness and lesser weight compared to other materials and cross section.

Kutay Yilmazcoban, Yasar Kahraman (2011) have studied and optimized the thickness of a middle tonnage truck chassis by using Finite Element technique. The main objective of this work was to reduce the material usage through that gaining reduction in material cost. They had analyzed three types of thickness material to chassis and compared the results by stress and displacement. Study reveals that the 4mm thickness is safe enough to carry 15ton load.

Ojo Kurdi, Roslan Abdul Rahman (2010) studied the road roughness effects on stress distribution of heavy vehicle chassis. They had analyzed Static and Dynamic conditions using Finite Element Analysis software to reduce the cost and get optimum design. The load was assumed as a uniform pressure obtained from the maximum loaded weight divided by the total contact area between cargo and upper surface of chassis. In order to get a better result, locally finer meshing was applied in the region which was suspected to have highest stress. From study it's understood that the dominant loading on the truck chassis comes from cargo and its contents as static loading. The road roughness has not given a significant effect to the stress of component.

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Zhongzhe D, Ping Z. (2006) has performed Fatigue life analysis and improvement of the auto body in a sports utility vehicle (SUV). The stress distribution under unit displacement excitation was obtained by the finite element (FE) method. A bilateral track model was adopted to obtain load spectra in accordance with the vehicle reliability test. The total life of the auto body was evaluated by the nominal stress method with the assumption of a uni-axial stress state, and thus the critical regions were determined. The life of components with critical regions was further investigated on the basis of multi axial fatigue theory. The results showed that components near suspension were damaged due to impact loads from the road. Topological optimization of the spot weld location in the critical region was carried out by the homogenization method to improve its fatigue life.

DEVELOPMENT OF MATHEMATICAL MODEL

Chassis design for heavy vehicle applications starts 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 has to resist the bending moment acting on it. As per the basic equations of pure bending,

M/I = F/Y =E/R -------- (1)

Where,

M= Bending moment, N-mm,

I= Mass moment of inertia, mm4,

F= Bending stress, N/mm2,

Y= Distance of the most distance point at the section from the neutral axis, mm,

E= Modulus of elasticity, N/mm2,

R= Radius of curvature, mm

From equation (1),

M/I = F/Y

M = F*(I/Y) -------- (2)

But Z = I/Y = section modulus.

Therefore

Bending moment = bending stress* section modulus

From the above equations the bending moment is directly proportional to the section modulus. If we need to increase the pay load we have to keep the section modulus proportionately to withstand the bending moment created by the pay load.

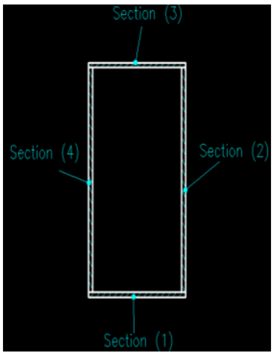
In most of the On-Road vehicles the cross section of the chassis structure is uniform in spite of the variable loads. The variable section chassis concept is based on the basic principle of more section modulus at more load acting places and less section modulus at less load acting places.

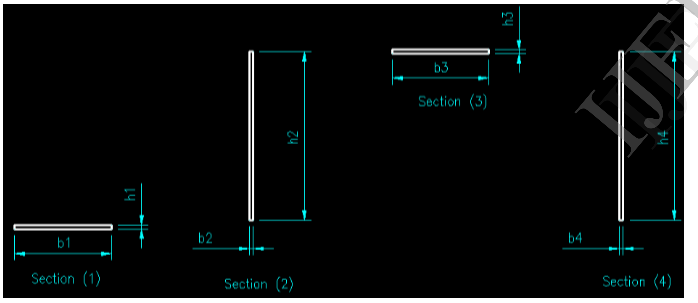
Section modulus $Z = I/Ymax$ -------- (3)

Where $I = I_1+I_2+I_3+I_4$

$Ymax = \sum(a*y)/\sum a$ -------- (4)

$\sum a = a_1+a_2+a_3+a_4$





Where a_1= area of the section 1, a_2 = area of the section 2 , a_3 = area of the section 3, a_4 = area of the section 4

$\sum a = b_1 h_1+ b_2 h_2+ b_3 h_3+ b_4 h_4$

Where $h_1 = b_2 = h_3 = b_4,\ b_1 = b_3$ & $h_2 = h_4$

$\sum a = b_1 h_1+ h_1 h_2+ b_1 h_1+ h_1 h_2$

$\sum a = 2(b_1 h_1+ h_1 h_2)$ -------- (5)

$\sum ay = a_1 y_1+ a_2 y_2+ a_3 y_3+ a_4 y_4$

$= [(b_1 h_1)* (h_1 /2)] + [(h_1 h_2)* (h_1 +h_2/2)] + [(b_1 h_1)* (\{(3/2) h_1\} +h_2)] + [(h_1 h_2)* (h_1 +h_2/2)]$

$= [(b_1 h_1)* \{(h_1 /2) + (3h_1 /2)+ h_2\}]+[(h_1 h_2)* \{(h_1 +h_2/2+ h_1 +h_2/2)\}]$

$= (2h_1+h_2)* (b_1 h_1 + h_1 h_2)$ -------- (6)

Sub Eqn (5) & (6) in Eqn (4)

$Ymax = (2h_1+h_2)* (b_1 h_1 + h_1 h_2) / 2(b_1 h_1+ h_1 h_2)$

$Ymax = (2h_1+h_2) / 2$ -------- (7)

$I = bh^3/12 + aY^2$

$Y = Ymax \sim y$

$I = I_1+I_2+I_3+I_4$

$I = (b_1h_1^3/12 + a_1Y_1^2) + (b_2h_2^3/12 + a_2Y_2^2) + (b_3h_3^3/12 + a_3Y_3^2) + (b_4h_4^3/12 + a_4Y_4^2)$

$I = (b_1h_1^3/12 + b_1 h_1Y_1^2) + (b_2h_2^3/12 + b_2 h_2Y_2^2) + (b_3h_3^3/12 + b_3 h_3Y_3^2) + (b_4h_4^3/12 + b_4 h_4Y_4^2)$

$= (b_1h_1^3/12 + b_1 h_1Y_1^2 +b_1h_1^3/12 + b_1 h_1Y_3^2) + (b_2h_2^3/12 + b_2 h_2Y_2^2 + b_2h_2^3/12 + b_2 h_2Y_4^2)$

$= 2(b_1h_1^3/12) + b_1 h_1 (Y_1^2 + Y_3^2) + 2 (b_2h_2^3/12) + b_2 h_2 (Y_2^2 + Y_4^2)$

$I = (b_1h_1^3/6) + b_1 h_1 [(Ymax \sim y_1)^2 + (Ymax \sim y_3)^2] + (b_2h_2^3/6) + b_2 h_2 [(Ymax \sim y_2)^2 + (Ymax \sim y_4)^2]$ -------- (8)

$y_1= h_1/2$

$(Ymax \sim y_1) = ((2h_1+h_2) / 2) \sim h_1/2$

$(Ymax \sim y_1) = ((h_1+h_2) / 2)$ -------- (9)

$y_2= (h_1+ (h_2 / 2))$

$(Ymax \sim y_2) = ((2h_1+h_2) / 2) \sim (h_1+ (h_2 / 2))$

$(Ymax \sim y_2) = 0$ -------- (10)

$y_3= (h_1+ h_2+ (h_3/2))$

$(Ymax \sim y_3) = ((2h_1+h_2) / 2) \sim (h_1+ h_2+ (h_3/2))$

$(Ymax \sim y_3) = ((h_1+h_2) / 2)$ -------- (11)

$Y_4= (h_1+ (h_2 / 2))$

$(Ymax \sim y_4) = ((2h_1+h_2) / 2) \sim (h_1+ (h_2 / 2))$

$(Ymax \sim y_4) = 0$ -------- (12)

Sub Eqn (9), (10), (11) & (12) in Eqn (8)

$I = (b_1h_1^3/6) + b_1 h_1 [((h_1+h_2) / 2)^2 + ((h_1+h_2) / 2)^2] + (b_2h_2^3/6) + b_2 h_2 [(0)^2 + (0)^2]$

$I = (b_1h_1^3/6) + b_1 h_1 [((h_1+h_2) / 2)^2 + ((h_1+h_2) / 2)^2] + (b_2h_2^3/6)$

$= 1/6(b_1h_1^3+ b_2h_2^3) + b_1 h_1 [((h_1+h_2)^2 / 4) + ((h_1+h_2)^2 / 4)]$

$= 1/6(b_1h_1^3+ b_2h_2^3) + b_1 h_1 [2((h_1+h_2)^2 / 4)]$

$= 1/6(b_1h_1^3+ b_2h_2^3) + b_1 h_1 [2((h_1+h_2)^2 / 4)]$

$I = 1/6(b_1h_1^3+ b_2h_2^3) +1/2(b1\ h_1) (h_1+h_2)^2$ -- (13)

Sub Eqn (7) & (13) in Eqn (3)

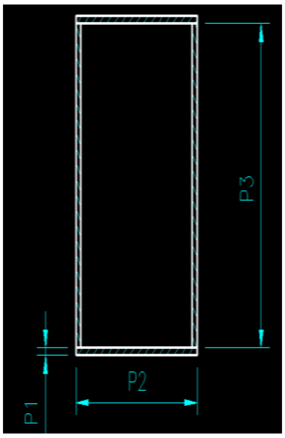
$Z = [1/6(b_1h_1^3+ b_2h_2^3) +1/2(b1\ h_1) (h_1+h_2)^2]/ [(2h_1+h_2) / 2]$ -------- (14)

When we use this mathematical model to optimize the cross section of On-Road Heavy vehicle we have to define the parameters as a variables.

In a rectangular cross section chassis

h1 = P1, b1 = P2 & h3 = P3.

Where P1, P2 & P3 are the Parameters



Then,

$$\text{Section Modulus } Z = [1/6(P_2P_1^3 + P_1P_3^3) + 1/2(P_2\,P_1)(P_1+P_3)^2] / [(2P_1+P_3)/2] \quad \text{-----} \quad (15)$$

CONCLUSION

In most of the On-Road vehicles the cross section of the chassis structure is uniform in spite of the variable loads. Hence in order to fill the gap, Variable section chassis concept has been developed. The variable section chassis concept is based on the basic principle of more section modulus at more load acting places and less section modulus at less load acting places. The present study has developed a mathematical model for optimizing the cross section of the chassis structure based on section modulus.

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