Review on Design and Analysis of Leaf Spring

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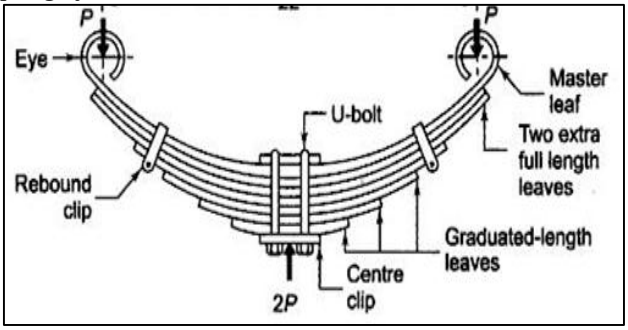
Abstract— A multi-leaf spring is one of the most important components of automobile suspension system. Leaves are basically a series of flat plates, usually of semi-elliptical shape. Generally, a multi-leaf spring used in automobile suspension, consists of two types of leaves i.e. graduated-length leaves and full-length leaves. The present work is an attempt to estimate the magnitude of bending stresses in the above mentioned leaves for a semi-elliptic multi-leaf spring made of steel. A lot of research work has been carried out in the context of leaf spring considering its material and a significant progress has been observed in the field of weight reduction, improvement of load carrying capacity when we replace the material of the spring by any advanced material like composites as E-glass/epoxy, carbon/epoxy etc. Finally referring to the results obtained in these research studies, the present work proposes a new idea regarding the construction of multi-leaf spring based on practical applications. Dimensions of the multi-leaf spring are taken from practical understanding and calculate dimension manually from standard chart of automobile spring. The multi-leaf spring was modelled in CATIA V5R18 and the same were analysed under similar conditions using ANSYS (Workbench 12.0) software considering structural-steel as the spring material.

Keywords: Leaf Spring, Computer Aided Engineering (CAE), CAD (Computer Aided Designing)

I. INTRODUCTION

A spring is an elastic machine element which undergoes deflection for the application of any load and intends to regain its original shape depending upon the magnitude of the applied load. The major applications of spring may include its use as a shock and vibration absorber and storing potential energy by its deflection during the application of load. A multi-leaf spring or laminated spring is a very important component in automobile suspension system. It is one of the oldest suspension components too and still today it is extensively used in all the heavy and light duty commercial vehicles, railway wagons and usually in the rear suspension of passenger vehicles. It differs from the conventional helical spring in a way that it can be guided along a definite path and it deflects under the application of load while acting as a structural member. This concept is employed during the analysis of bending stresses in different leaves by consideration of cantilever beam. The present work makes an attempt to validate the above concept by performing static structural analysis using ANSYS software for the evaluation of maximum bending stress and subsequently bending stresses in different leaves, which in all, construct the entire spring. Finally, the reader may get an exposure regarding the bending stress variation for multi-leaf spring, which obviously differs from that of any cantilever beam section.

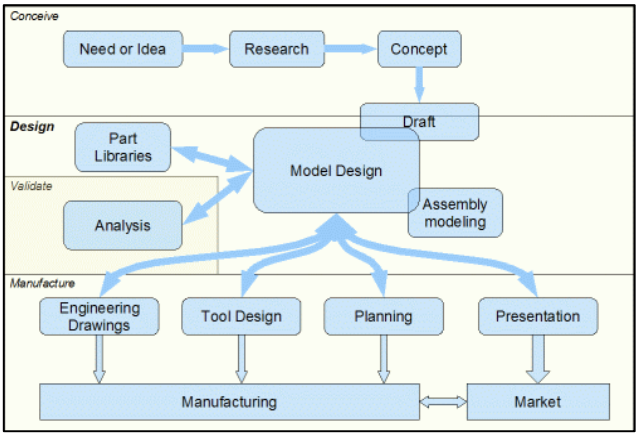
In its construction the leaf spring consists of a series of flat plates or leaves, usually of semi-elliptic shape, which are held together with the help of U-bolts and centre clip. Generally two types of leaves may be observed in a multi-leaf spring i.e. some graduated -length leaves and a few extra full-length leaves. The length of the leaves gradually decreases from top to bottom as shown in fig. The longest leaf in the top is known as master leaf which is bent at both the ends to form spring eyes.



II. COMPUTER AIDED ENGINEERING (CAE)

A. CAD (Computer Aided Designing)

Computer-aided design (CAD) is the use of computer systems to aid in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations. Each stage requires specific knowledge and skills and often requires the use of specific software.



1) Need or Idea

Usually, the design process starts with a defined need. The need can be defined by market research, by the requirements of a larger body of work (for example airplane part). Sometimes, but more rarely than you may think, the design process is begun with a new idea or invention. At any rate, a needs analysis should precede any decision to undertake a project. This includes defining the need in a highly detailed way, in writing. This is similar to the requirements specification process in software engineering.

2) Research

Professionals tend to research available solutions before beginning their work. There is no need to "reinvent the wheel". You should study existing solutions and concepts, evaluating their weaknesses and strengths. Your research should also cover available parts that you can use as a part of your design. It is obvious, that Internet and search engines like Google are very helpful for this task. There are also many libraries of standardized parts which you can import into your project.

3) Concept

Based on your research, start with a high level concept. You should specify the main principles and major parts. For example, you can consider Diesel or Sterling engines for stationary electric generators.

4) Draft

You can choose to create a draft by pen and paper. Some prefer to use simple vector graphics programs, others even simple CAD (for example Smart Sketch), yet others prefer to start directly in their main CAD system.

5) Model Design

2D and 3D modelling in CAD. The designer creates a model with details, and this is the key part of the design process, and often the most time consuming. This will be described in greater detail in further lessons. asaceva

6) Part Libraries

Standard parts, or parts created by other team members, can be used in your model (you don't have to reinvent the wheel). Files representing a part can be downloaded from the Internet or local networks. They are also distributed on CD ROMs or together with CAD as an extension (library). By putting these predefined parts into your project, you ensure that they are correct and save a lot of time and effort. When working on a large project, this becomes a requirement to ensure the parts operate together, swap out equivalent parts, and coordinate distributed teams' work. This was, a standard part can be inserted into the project by one team member.

7) Assembly Modelling

Parts are assembled into a machine or mechanism. Parts are put together using mating conditions such as alignment of the axis of two holes. More about how to do this in further lessons. Cad is used in industries.

8) Engineering Drawings

From your 3D models, you generate a set of engineering drawings for manufacturing. These drawings are then distributed to the departments and individuals responsible for producing that work. Also, these drawings must be tolerance for proper manufacturing.

9) About CATIA V5

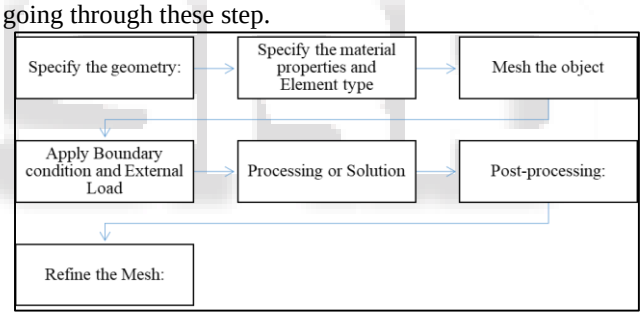
CATIA (an acronym of computer aided three-dimensional interactive application) is a multi-platform software suite for computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE), PLM and 3D, developed by the French company Dassault Systems. CATIA started as an in-house development in 1977 by French aircraft manufacturer Avions Marcel Dassault, at that time customer of the CADAM software to develop Dassault's Mirage fighter jet. It was later adopted by the aerospace, automotive, shipbuilding, and other industries.

III. Finite Element Analysis (FEA)

FEA is a numerical method. It is very commonly used in finding the solution of many problems in engineering. The problem includes deigning of the shaft, truss bridge, buildings heating and ventilation, fluid flow, electric and magnetic field and so on. The main advantage of using finite element analysis is that many designs can be tried out for their validity, safety and integrity using the computer, even before the first prototype is built. Finite element analysis uses the idea of dividing the large body in to small parts called elements, connected at predefine points called as nodes. Element behavior is approximated in terms of the nodal variables called degrees of freedom. Elements are assembled with due consideration of loading and boundary condition. This results in a finite number of equations. A solution of these equations represents the approximate behavior of the problem. The design and analysis have done with the 3D modeling software and FEA technique standard FEM tool. The analysis is carried out by using the ANSYS software. This gives the comparison between analytic and numerical value. Part is drawn in CAD software. The CAD software which is involved in this is CATIA and this part is a call to ANSYS in (.igs) format.

IV. Procedure for FE Analysis

There are a number of steps in the solution procedure using finite element method. All finite element packages require going through these step.



1) Specify the geometry: In this import the geometry from CAD software to FEA software.
2) Specify the material properties and Element type:
3) In this step, the selection of element type is done and the material properties are given. The Young's modulus and Poisson's ratio are the input for material properties.
4) Mesh the object: Here the object is broken in to small elements. This involves defining the type of element into which structure will be broken as well as specifying how the structure will be divided in to the element. This subdivision in to elements can either be input by the user or with same finite element programs can be chosen automatically.
5) Apply Boundary condition and External Load: This is followed by specifying the boundary condition and the external loads are specified.
6) Processing or Solution: The modified algebraic equations are solved to find the nodal values of the primary variable.
7) Post-processing: It involves improving the result of processing in to the model. These results are graphically displaced to enable user case of high deflection and stress.

8) Refine the Mesh: For the case of a judge of the accuracy of the result, there is need to increase or decrease no of elements of an object.

V. LITERATURE REVIEW

1) JOHN E and DAVID S.RICHARD, General Motors Co, .MUTZNER ltd Covington (2005) "Development And Testing Of Composite Truck Trailer Spring"Volume 2 Issue2 pp 103-107 Composite leaf spring constructed of glass fiber reinforced polymeric material has been recognized as a variable replacement for steel leaf springs since their introduction on the 1981 general motors corvette. This acceptance of composite leaf springs has given rise to applications in high volume production passenger cars and utility of composite leaf spring is clearly demonstrated in these applications. This paper will discuss the design, laboratory testing, field testing, and development over the past three years that has led to the commercialization of the lit flex trailer springs. This will include the design process for high and low deflection composite leaf spring and stress analysis for common springs used in various axle spacing worldwide. An explanation of laboratory test will be given and the rationalization for these test compared to steel spring test standards. An attempt will be made to correlate laboratory test tracks, servo hydraulic simulator and field tests of lit flex trailer International Journal of Scientific Research Engineering & Technology (IJSRET) Volume 2 Issue2 pp 103-107 This testing will demonstrate the soft failure mode if the composite leaf spring and the advantage this brings to fleet owners. The other advantage of weight reduction and increased durability will be discussed.[6]
2) KIKUA TANABE, TAKASHI SEINO of Central Engineering Laboratories, Nissan Motors co., ltd. Yokosuka, Japan(1999)"Characteristics of Carbon/Glass Fiber Reinforced Plastic Leaf Spring"volume 7 ,Pp.241–249. Designed and fabricated and evaluated a tapered leaf spring made of carbon fiber reinforced plastics. To construct the leaf spring, a carbon/glass fiber hybrid lamination is selected. This selection was made in concentration of chipping resistance, impact resistance and fatigue resistance. They constructed a prototype of leaf spring which weighed approximately 2kg included the front and rear steel eyes. In comparison with the steel spring, this represents a weight reduction of 76%. Prototype is put through a series of evaluations both on the bench and on the vehicle. The element used is SOLID 45(3-D four node tetrahedral structural solid with rotations). Solid 45 is well suited to model irregular meshes (such as produced from various CAD/CAM systems). The element is defined by four nodes having six degrees of freedom at each node; translations in the nodal x, y, z directions and rotations about the nodal x, y and z directions.
3) EerolSancaktar.Shenyang Jinzhou University, China(1999) "Design and manufacture of a functional composite leaf spring for solar powered light vehicle" Research Vol. 66, February 2007 pp 128-134

The main objective of this work was to provide and understanding of the manufacture, use and capabilities of composite leaf spring. The material selected for the fabrication of the initial design leaves consisted of a full thickness of unidirectional E-glass fibers with two layers of bi-directional fabric on the outer layers embedded in a vinyl ester resin matrix. The bi-directional fabric used to prevent leaf deformation and subsequent failure in bending about its longitudinal axis it was selected due to overall weight reduction of the vehicle primarily considered. This work attempted due to some failure aspect which occurs in the previous leaf spring. The reason behind the failure was: Cracks perpendicular to leaf longitudinal axis. Stress whitening on the outer layer. The reasons discussed in this paper were sort out by giving the alternative designs by modification of the initial leaf spring. The design offered many advantages over the initial design. By tapering the leaves in the thickness direction as well as in the width direction towards the ends, an even distribution of stresses was achieved providing efficient material usage. The low stress region at the tips of the hole, as well as the holes themselves, present in the initial design is now eliminated. Also, the fibers have a more uniform orientation resulting in a spring, which was easier to model analytically and manufacture. In the alternative design the material selected as E-glass due to their high extensibility, toughness and low cost. In order to facilitate the wetting of the fibers, epoxy resin with 2 h pot life was selected. When the comparison was done, it was found that the redesign of the solar car's front suspension leaf springs was successful as it met all design targets and requirements.[9]

4) Y. N. V. Santhosh Kumar, M. VimalTeja "design and analysis of composite leaf spring"International Journal of Mechanical & Industrial Engineering, Volume 1 Issue 1-2011

They also discussed the advantages of composite material like higher specific stiffness and strength, higher strength to weight ratio. This work deals with the replacement of conventional steel leaf spring with a Mono Composite leaf spring using E-Glass/Epoxy. For this they selected design parameters and analysis of it. Main objective of this work is minimizing weight of the composite leaf spring as compared to the steel leaf spring. For this they selected the composite material was E-Glass/Epoxy. The leaf spring was modeled in Pro/E and the analysis was done using ANSYS Metaphysics. From results they observed that the composite leaf spring weighed only 39.4% of the steel leaf spring for the analyzed stresses. So from result they proved that weight reduction obtained by using composite leaf spring as compared to steel was 60.48 %, and it was also proved that all the stresses in the leaf spring were well within the allowable limits and with good factor of safety. It was found that the longitudinal orientations of fibers in the laminate offered good strength to the leaf spring.[2]

5) PankajSaini, AshishGoel, Dushyant Kumar "design and analysis of composite leaf spring for light vehicles".ISSN: 0975-5462 Vol. 3 No. 9 Sept. 2011 (IJEST)

Main objective of this work is to compare the stresses and weight saving of composite leaf spring with that of steel leaf spring. Here the three materials selected which are glass fiber

reinforced polymer (E-glass/epoxy),carbon epoxy and graphite epoxy is used against conventional steel. The design parameters were selected and analyzed with the steel leaf spring From results, they observed the replacement of steel with optimally designed composite leaf spring can provide 92% weight reduction and also the composite leaf spring has lower stresses compared to steel spring. From the static analysis results it is found that there is a maximum displacement of in the steel leaf spring. From the result, among the three composite leaf springs, only graphite/epoxy composite leaf spring has higher stresses than the steel leaf spring. From results its proved that composite mono leaf spring reduces the weight by 81.22% for E-Glass/Epoxy, 91.95% for Graphite/Epoxy, and 90.51 % for Carbon/Epoxy over steel leaf spring. Hence it is concluded that E-glass/epoxy composite leaf spring can be suggested for replacing the steel leaf spring from stress and stiffness point of view.[5]

6) Mahmood M. shokrieh and Davood Rezaei "Analysis and optimization of a composite leaf spring " Composite Structures, 60 (2003) 317–325

The aim of this review paper was steel leaf spring was replaced with an optimized composite one. Main objective of this paper was to obtain a spring with minimum weight that is capable of carrying given static external forces without failure. Here the work is carried out of a four-leaf steel spring which used in the rear suspension system of light vehicles & heavy duty vehicles. The four-leaf steel spring is analyzed by using ANSYS V5.4 software. The finite element results showing stresses and deflections verified the existing analytical and experimental solutions. Using the results of the steel leaf spring, a composite one made from fiberglass with epoxy resin is designed and optimized using ANSYS. Main consideration is given to the optimization of the spring geometry. In this study stress and displacements were used as design constraint. The experimental results are verified with the analytical data and the finite element solutions for the same dimensions. Result shows that stresses in the composite leaf spring are much lower than that of the steel leaf spring. Compared to the steel leaf spring the optimized composite leaf spring without eye units weights nearly 80% less than the steel spring. The natural frequency of composite leaf spring is higher than that of the steel leaf spring and is far enough from the road frequency to avoid the resonance.

7) E. Mahdi a, O.M.S. Alkoles a, A.M.S. Hamouda b, B.B. Sahari b, R. Yonus c, G. Goudah " Light composite elliptic springs for vehicle suspension " Composite Structures, 75 (2006) 24–28.

They worked on based study marries between an elliptical configuration and the woven roving composites. In this paper, the influence of ellipticity ratio on performance of woven roving wrapped composite elliptical springs has been investigated both experimentally and numerically. A series of experiments was conducted for composite elliptical springs with ellipticity ratios (a/b) ranging from one to two. Here they were also presented history of their failure mechanism. Both spring rate and maximum failure increase with increasing wall thickness. In general, this present investigation demonstrated that composites elliptical spring can be used for light and heavy trucks and meet the requirements, together with substantial weight saving. The results showed that the ellipticity ratio significantly influenced the spring rate and failure loads. Composite elliptic spring with ellipticity ratios of a/b 2.0 displayed the highest spring rate.

8) Manas Patnaik, Narendra Yadav, Ritesh Dewangan "Study of a Parabolic Leaf Spring by Finite Element Method & Design of Experiments"International Journal of Modern Engineering Research Vol.2, Issue 4, July-Aug 2012 pp-1920-1922.

Main objective of this study was the behavior of parabolic leaf spring, design of experiment has been implemented. For DOE, they selected input parameters such as Eye Distance & Depth of camber. This work is carried out on a mono parabolic leaf spring of a mini loader truck, which has a loading capacity of 1 Tonnes. The modelling of the leaf spring has been done in CATIA V5 R20. Max Von Mises stress and Max Displacement are the output parameters of this analysis. In DOE Eye Distance & Depth of camber have been varied and their affect on output parameters have been plotted. The variation of bending stress and displacement values are computed. From design of experiments they observed 1530 Vol. 3 Issue 3, March - 2014 International Journal of Engineering Research & Technology (IJERT) IJERT ISSN: 2278-0181 IJERTV3IS031286 www.ijert.org following a) If the camber is increased there is a decrease in the average amount of displacement. b) If the eye distance is increased there is an increase in the average amount of displacement. c) If the camber is increased there is an increase in the average amount of von misses stress. d) If the eye distance is increased there is an increase in the average amount on von misses stress. Hence from results it is conclude that the optimum setting of dimensions pertaining to parabolic leaf spring can be achieved by studying the various plots obtained from Design of Experiments.

9) Malaga. Anil Kumar, T.N.Charyulu, Ch.Ramesh " Design Optimization Of Leaf Spring " International Journal of Engineering Research and Applications Vol. 2, Issue 6, November- December 2012, pp.759-765.

The automobile industry has shown increased interest in the replacement of steel spring with composite leaf spring. Main purpose of this paper is to replace the multi-leaf steel spring by mono composite leaf spring for the same load carrying capacity and stiffness. Composite materials have more elastic strain energy storage capacity and high strength-to-weight ratio as compared to those of steel. It is possible to reduce the weight of the leaf spring without any reduction on load carrying capacity and stiffness. The design constraints were limiting stresses and displacement. Here the dimensions of a leaf spring of a light weight vehicle are chosen and modeled using ANSYS 9.0. As the leaf spring is symmetrical about the axis, only half part of the spring is modeled by considering it as a cantilever beam. Three different composite materials have been used for analysis of mono-composite leaf spring. They are Eglass/epoxy, Graphite/epoxy and carbon/epoxy. Static and model analysis has been performed. From results it is concluded that E-glass/epoxy has lower stresses among using three materials. So they suggested E-glass/epoxy composite material for replacement of steel leaf spring.

10) Prahalad Sawant Badkar, Prahalad Sawant Badkar "Design Improvements of Leaf Spring of BEML Tatra 815 VVNC 8 X 8 Truck" International Journal of

Emerging Technology and Advanced Engineering, Volume 3, Issue 1, January 2013.

Main objective of this work is increase the PL carrying capacity of BEML Tatra by 5000 kg. by incorporating the necessary changes in suspension system(Leaf Spring) of the vehicle. The distribution of gross vehicle weight (GVW) on the front and rear tandem axles are Front axle weight is 2 x 6500 kg, Rear axle weight is 2 x 7500 kg , Gross vehicle weight is 28,000kg . Here they do some changes in design so they distributed weight of of Fifth wheel load (FWL) on the front and rear tandem axle is Front axle weight is 2 x 6750 kg, Rear axle weight is 2 x 9750 kg ,Gross vehicle weight is 33,000 kg . The new design of rear leaf spring, stress vehicles for rated load and maximum load are well within the yield stress of material. The new design rear leaf spring also gives the higher fatigue life this is most important in design of any leaf spring, this helps in measure the life of spring. Results showed that finite element analysis (FEA) on rear leaf spring verifies that, design were adequate. The material 60Cr4V2 is better for design of new leaf spring, which fulfills the requirement.

11) H.A.AI-Qureshi "automobile leaf spring from composite materials" Journal of materials processing technology, 118(2001).

The aim of this paper is design, analysis & fabrication of composite spring. For this compact car is taken as prototype. A single leaf, variable thickness spring of glass fiber reinforced plastic with similar mechanical and geometrical properties to the multi leaf steel spring was designed, fabricated and tested. Here they performed experiment in laboratory & was followed by road test. Field testing to determine ride characteristics were also carried out on a number of GFRP spring which were mounted in place of conventional steel spring on jeep. This test were limited to ride quality and sound observation on different road condition. From result it is observed that GFRP spring were more flexible then steel leaf spring. From test ride they observed that harshness & noise also reduced then steel leaf spring. Compared to the steel spring, the optimized composite spring has stresses that are much lower, the natural frequency is higher and the spring weight without eye units is nearly 80% lower.

12) Ashish V. Amrute, Edward Nikhil karlus, R.K.Rathore "design and assessment of multi leaf spring'' International journal of research in aeronautical and mechanical engineering, ISSN: 2321-3051. November (2013). 1532 Vol. 3 Issue 3, March - 2014 International Journal of Engineering Research & Technology (IJERT) IJ

Main objective of this work is to compare the load carrying capacity, stresses and weight savings of composite leaf spring with that of steel leaf spring. Here the multi leaf spring consist three full length leaves in which one is with eyed ends used by a light commercial vehicle. For analysis of leaf spring Tata ace ex vehicle taken as prototype. This work deals with replacement of conventional steel leaf spring of a light commercial vehicle with composite leaf spring using E-glass/Epoxy. Dimensions of the composite leaf spring are to be taken as same dimensions of the conventional leaf spring. The Theoretical and CAE results are compared for validation. From results it is proved that the bending stresses are decreased by 25.05% in composite leaf spring means less stress induced with same load carrying conditions. The conventional multi leaf spring weights about 10.27kg whereas the E-glass/Epoxy multi leaf spring weighs only 3.26 kg. Thus the weight reduction of 67.88% is achieved by using composite material rather than using steel material.

VI. CONCLUSION

From the literature review it is seen that the objective was to obtain a spring with minimum weight that is capable of carrying given static external forces by constraints limiting stresses and displacements. For that the steel leaf spring is replaced by composite leaf spring. Composite leaf spring is better than using steel leaf spring. The performance of steel leaf spring was compared with the composite leaf spring using analytical and experimental results. FEA are used for prediction about the total life cycle and fatigue life of composite and steel leaf spring. Results show that the composite leaf spring is lighter than conventional steel leaf spring with similar design specifications but not always is cost effective over their steel counterparts. The natural frequency of composite leaf spring is higher than that of the steel leaf spring and is far enough from the road frequency to avoid the resonance. The stresses in the composite leaf spring are much lower than that of the steel spring. Composite materials have more elastic strain energy storage capacity and high strength to weight ratio as compared with those of steel therefore, it is concluded that composite leaf spring is an effective replacement for the existing steel leaf spring in automobile.

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[2] 1Suraj B. Pawar (2015). Design & Analysis Of Multi Steel Leaf Spring, International Engineering Research Journal (IERJ) Special Issue 2 Page 4468-4474

[3] G HARINATH GOWD (2012) STATIC ANALYSIS OF LEAF SPRING, International Journal Of Engineering Science And Technology (IJEST)

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