A REVIEW ON DIFFERENT PROCESS PARAMETERS OF LEAF SPRING AND MATERIAL USED FOR THEIR MANUFACTURING

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***Abstract*: Leaf springs are generally utilized in the suspension system of a vehicle and are subjected to a fluctuating cycles resulting to failure by fatigue. A great amount of exploration has been conducted to enhance leaf spring performance. The automobile industry has shown increased interest in the replacement of steel spring with composite leaf spring due to high strength to weight ratio. Increasing competition and innovation in automobile sector tends to modify the existing products by new and better material products. In this paper a complete review of leaf spring different process parameters on which the performance of leaf spring depends, it also review the different lightweight materials which may use for the manufacturing of leaf spring.**

***Keywords*: Leaf spring, composite material, process parameters, optimization technique**

1. Introduction A leaf spring is a simple form of spring commonly used for the suspension in wheeled vehicles. Originally called a laminated or carriage spring and sometimes referred to as a semi elliptical spring or cart spring, it is one of the oldest forms of springing, appearing on carriages in England after 1750 and from there migrating to France and Germany. A leaf spring takes the form of a slender arc-shaped length of spring steel of rectangular cross-section. In the most common configuration, the centre of the arc provides location for the axle, while loops formed at either end provide for attaching to the vehicle chassis. For very heavy vehicles, a leaf spring can be made from several leaves stacked on top of each other in several layers, often with progressively shorter leaves. Leaf springs can serve locating and to some extent damping as well as springing functions. While the interleaf friction provides a damping action, it is not well controlled and results in restriction in the motion of the suspension. For this reason, some manufacturers have used mono-leaf springs. A leaf spring can either be attached directly to the frame at both ends or attached directly at one end, usually the front, with the other end attached through a shackle, a short swinging arm. The shackle takes up the tendency of the leaf spring to elongate when compressed and thus makes for softer springiness.

2. Leaf spring history

There are a variety of leaf springs, usually employing the word "elliptical". "Elliptical" or "full elliptical" leaf springs referred to two circular arcs linked at their tips. This was joined to the frame at the top centre of the upper arc; the bottom centre was joined to the "live" suspension components, such as a solid front axle. Additional suspension components, such as trailing arms, would usually be needed for this design, but not for "semi-elliptical" leaf springs as used in the Hotchkiss drive. That employed the lower arc, hence its name. "Quarter-elliptic" springs often had the thickest part of the stack of leaves stuck into the rear end of the side pieces of a short ladder frame, with the free end attached to the differential, as in the Austin Seven of the 1920s. As an example of non-elliptic leaf springs, the Ford Model T had multiple leaf springs over its differential that was curved in the shape of a yoke.

3. Manufacturing process

Different manufacturing process was used to manufacture different types of leaf spring, according to the use and load applied on the spring. Different manufacturing process of leaf spring are Shearing of flat bar, Centre hole punching / Drilling, Heating process (hot & cold process).

4. Types of leaf spring

4.1 Multi-Leaf Spring - This type of leaf spring has more than one leaf in its assembly. It consists of a centre bolt that properly aligns the leaves and clips to resist its individual leaves from twisting and shifting.

4.2 Mono Leaf spring - Consists of one main leaf where the material's width and thickness are constant. Example - the leaf will be 2 ½" wide throughout its length, and 0.323" in thickness throughout its entire length. The spring rate is lighter than other styles of leaf springs and usually requires a device to control positive and negative torque loads as well as requiring coil springs to hold the chassis at ride height.

4.3 Parabolic Single leaf spring - Consists of one main leaf with a tapered thickness. This style is sufficient to control axle torque and dampening, while maintaining ride height. The advantage of this style is that the spring is lighter than the multi-leaf.

4.4 Fiberglass Leaf Spring - The fiberglass leaf spring is made of a mixture of plastic fibres and resin; it is lighter than all other springs. However, the cost is three times greater. In addition, fiberglass springs are sensitive to heat.

5. Existing Research work

Many people optimize the different process parameters of leaf spring and use the different material for the construction of leaf spring. In order to make lighter leaf spring, people have used different lighter materials or composite with compromising the strength and life of the spring. Some of the existing work is mention in the below section.

1. **Qian et.al (2017)** In this analysis the study of composite leaf springs has been popular in automotive light weighting. Particularly, the research on the fatigue reliability of composite leaf springs is crucial. This paper proposed the fatigue law inference of the parabolic composite leaf spring, which was validated by fatigue bench tests. On the bases of the ply scheme design method and the sandwich unit concept, the non-continuous layer section and the stacking order were presented. The stacking sequence was optimized using Genetic Algorithm. The failure fatigue inference of composite leaf spring was proposed according to the fatigue law and was verified by experiments. On the basis of the inference, GA was used to optimize the stacking sequence.

2. **Sonmez et.al (2016)** In this study the optimum structural design of composites is a research subject that has drawn the attention of many researchers for more than 40 years with a growing interest. In this study, a review of the literature on this subject is presented. The papers are classified according to the type of the composite structure optimized in those studies, the loading conditions, the objective function, the structural analysis method, the design variables, the constraints, the failure criteria, and the search algorithm used by the researchers. Keywords Composites, design optimization. Although composite materials offer great flexibility in product design with a large number of design variables, this feature also leads to an immense number of locally optimum designs.

3. **Noorman et.al (2014)** In the present review the paper the laminated composites is a material that is rapidly being adapted in the aircraft industry and new joining techniques are being researched for new structural designs. One such technique is adhesive bonding, which can result in decreased weight, fuel saving and improved strength of aircraft components. Robust strength and failure analysis methods are required to assess new designs beforehand. One of these methods is cohesive zone modelling. Cohesive zone modelling is a technique based on cohesive forces and energy within a material or interface region which keeps material together. Damage can be tracked progressively along a region with cohesive elements and damage propagation can be monitored in a structure. With a fixed maximum traction, an increase in the critical energy release rate can make the damage initiation till propagation more gradual instead of sudden within the traction models for a traction law.

4. **Reis et.al (2009)** This paper is about representing the results of current research on the fatigue life prediction of carbon/epoxy laminate composites involving twelve balanced woven bidirectional layers of carbon fibres and epoxy resin manufactured by a vacuum moulding method. The plates were produced with 3 mm thickness and 0.66 fibre weight fraction. The dog bone shape specimens were cut from these plates with the load line aligned with one of the fibre directions. The fatigue tests were performed using load control with a frequency of 10 Hz and at room temperature. The fatigue behaviour was studied for different stress ratios and for variable amplitude block loadings. The tensile ultimate strength obtained for woven balanced bidirectional laminated carbon/epoxy composites is significantly higher (about 69%) than the compressive ultimate strength.

5. **Almeida et.al (2009)** In this analysis a technique for the design optimization of composite laminated structures is presented. The optimization process is performed using a genetic algorithm (GA), associated with the finite element method (FEM) for the structural analysis. The GA is adapted with special operators and variables codification for the specific case of composite laminated structures optimization. Some numerical examples are presented to show the flexibility of this tool to solve different kinds of problems. Two cases of multi objective optimization of plates under transverse or in-plane load are studied. In these examples the minimization of two objectives, such as weight and deflection or weight and cost, are simultaneously performed and comparatively optimal set is obtained by shifting the optimization emphasis using a weighting factor.

6. **Naik et.al (2008)** In this paper, minimum weight design of composite laminates is presented using the failure mechanism based (FMB), maximum stress and Tsai–Wu failure criteria. The objective is to demonstrate the effectiveness of the newly proposed FMB failure criterion (FMBFC) in composite design. The FMBFC considers different failure mechanisms such as fibre breaks, matrix cracks, fibre compressive failure, and matrix crushing which are relevant for different loading conditions. A genetic algorithm is used for the optimization study. The main objective of design optimization in aerospace composite structures is to minimize the weight of the laminate for a given loading. Therefore, three different failure criteria are evaluated based on the optimum weight prediction made from these failure criteria for different loading condition and different ply orientation, which enter as the design variable. These three different failure criteria are the failure mechanism based (FMB), maximum stress and Tsai–Wu failure criteria.

7. **Salekeen et.al (2007)** In this study one of the significant mechanical property variations under long term fatigue is the change in material or component stiffness. So stiffness reduction can be used as a damage parameter to assess damage in composite laminates under fatigue loading. It has been observed that the stiffness decreases monotonically under cyclic loading. One of the main advantages of using stiffness as a damage parameter is, it can be measured non-destructively in service. In this investigation the S–N diagram of two thick section fiberglass/epoxy composites has been determined and their stiffness degradation during fatigue loading has been monitored. In order to verify the accuracy of the proposed residual stiffness

degradation models, it is necessary first to fit the data obtained from the experiments conducted specifically for this purpose. The proposed models have been verified using data obtained from the experiments.

8. **Kathiravan et.al (2007)** This work addresses the optimum design of a composite box-beam structure subject to strength constraints. Such box-beams are used as the main load carrying members of helicopter rotor blades. A computationally efficient analytical model for box-beam is used. Optimal ply orientation angles are sought which maximize the failure margins with respect to the applied loading. The Tsai–Wu–Hahn failure criterion is used to calculate the reserve factor for each wall and ply and the minimum reserve factor is maximized. Ply angles are used as design variables and various cases of initial starting design and loadings are investigated. Both gradient-based and particle swarm optimization (PSO) methods are used. It is found that by allowing different walls to have different orientation angles gives a better design than forcing all the walls to have the same orientations.

9. **Pakdil et.al (2007)** In this study, the effect of preload moments on failure response of glass-epoxy laminated composite bolted-joints with bolt/hole clearance was investigated. To evaluate the effects of bolted-joint geometry and stacking sequence of laminated plates on the bearing strength and failure mode, parametric analyses were performed, experimentally. Two different geometrical parameters, edge distance-to-hole diameter ratio (E/D) and plate width-to-hole diameter ratio (W/D), were examined. For this reason, the E/D ratio was selected from 1 to 5, whereas the W/D ratio was chosen from 2 to 5. The bearing strength and failure mode are evaluated for various geometrical and material parameters. During the experiments, one of the variables is changed while the others are held constant.

10. **Pawar et.al (2006)** In the present study, models of the key damage modes in composite materials such as matrix cracking, debonding/delamination and fibre breakage are included in a thin walled composite beam analysis for helicopter rotor blade applications. The effects of transverse shear, elastic couplings and restrained warping are also included while modeling the thin walled composite beams. Matrix cracking is modelled at the laminate level and debonding/delamination and fibre breakage at the lamina level and included in the formulation by adjusting the A, B and D matrices for composite laminates. The beam analysis is used to investigate the effect of damage on the various properties of thin walled composite beams such as out-of-plane stiffness, in-plane stiffness and torsion stiffness and deflections such as bending slopes and twist under an applied load. Progressive damage accumulations in thin walled composite beams for rotor blade applications are studied.

11. **Swann et.al (2005)** In this analysis the optimal placement of sensors is a critical issue in detecting damage in laminated composite structures. The aim is to use a minimum number of sensors, placed at the correct locations, so that the voltage signals received from the sensor set can be used to detect both the presence and the extent of damage. In this study, an optimization procedure is developed to detect arbitrarily located discrete delamination in composite plates using distributed piezoelectric sensors. The probability of damage distribution in the plate is determined using a statistical model. A genetic algorithm (GA) is used to detect the number and location of the sensors. The analysis uses a Monte Carlo method to generate the initial population. The simulation and signal processing is performed using a finite element procedure based on the refined layer-wise theory, A genetic algorithm is used to formulate the optimization problem and the Monte Carlo method is used to generate the initial population.

12. **Murugan et.al (2005)** In this review paper an optimization procedure to reduce the revolution oscillatory hub loads and increase the lag mode damping of a four-bladed soft-in-plane hingeless helicopter rotor is developed using a two-level approach. At the upper level, response surface approximations to the objective function and constraints are used to find the optimal blade mass and stiffness properties for vibration minimization and stability enhancement. An aeroelastic analysis based on finite elements in space and time is used. The numerical sampling needed to obtain the response surfaces is done using the central composite design of the theory of design of experiments. The approximate optimization problem expressed in terms of quadratic response surfaces is solved using a gradient-based method. The vibration reduction problem and stability enhancement problem are studied independently. The objective of the vibration reduction problem is to minimize the 4/revolution hub loads with constraints on blade root dynamic stresses.

13. **Gudla et.al (2005)** This paper is about the genetic algorithm (GA) have good global search characteristics and local optimizing algorithm (LOA) have good local search characteristics. In the present work, best characteristics of GA and LOA are combined to develop a hybrid genetic algorithm (HGA). A bank of GA_s is used to get a good starting solution for a conjugate gradient algorithm. The number of GA banks is selected using an automated procedure based on Fibonacci numbers. This automated hybrid genetic algorithm (AHGA) is used for solving general multimodal optimization problems while assuring global optimality to a significant degree. The designed algorithm is also tested against a variety of standard test functions. It also transfers the need of tuning the GA parameters to the selection of n and hence saving considerable computational effort and human time on the part of the user. Later, the selection of the value n is also automated via developing an AHGA.

14. **Deka et.al (2005)** The present paper deals with the method of optimum design of laminated composite structures using the finite element method (FEM) and the genetic algorithm (GA) for single-material as well as hybrid laminates. Eight-noded layered elements have been used for 3-D finite element analysis. Weight and cost optimization of Graphite-epoxy/Kevlar-epoxy hybrid composite plate subjected to Tsai–Hill criteria-based design constraint have been carried out. Fiber orientation and material in each lamina, as well as the number of lamina in the laminate have been used as design variables. In the first

section, strength optimization through minimization of the F.I. corresponding to the Tsai–Hill theory has been done for a single-material laminate.

15. **Soremekun et.al (2001)** In this analysis genetic algorithms with exclusive selection based on cloning a best single individual (SI) from one generation to the next are popular, but generalized elitist selection (GES) procedures have been proposed and tried in the past. The present paper explores several generalized elitist procedures for the design of composite laminates. It is shown that GES procedures are superior to an SI procedure for two types of problems. The first type involves many global optima, and the GES procedure can find several global optima more efficiently than the SI procedure. This may give a designer more design freedom. The first problem has multiple global optima while the second has a single optimum surrounded by a large number of near optima.

6. Conclusion

From the literature survey it is seen that the main objective of researchers was to get a spring with least weight that is prepared to do conveying given static outside powers by limitations restricting burdens and removals. For that the steel leaf spring is supplanted by composite leaf spring. As reducing weight and increasing strength of products are high research demands in the world, composite materials are getting to be up to the mark of satisfying these demands. The model with minimum deflection, minimum von misses stress and high strength to weight ratio will be the best combination which can be used for multi-leaf spring with economic in cost.

References

[1] Chen Qian, Wenku Shi, Zhiyong Chen, Shixiang Yang, Qianqian Song, Fatigue Reliability Design of Composite Leaf Springs Based on Ply Scheme Optimization, composite structures (2017).
[2] Fazil O Sonmez, Optimum Design of Composite Structures: A Literature Survey, Journal of Reinforced Plastics and Composites Author(s) 2016.
[3] D.C. Noorman, Cohesive zone modelling in adhesively bonded joints analysis on crack propagation in adhesives and adherends, the Delft University of Technology, September, 2014.
[4] P.N.B. Reis, J.A.M. Ferreira, J.D.M. Costa, M.O.W. Richardson, Fatigue life evaluation for carbon/epoxy laminate composites under constant and variable block loading, Composites Science and Technology 69 (2009) 154–160.
[5] F.S. Almeida, A.M. Awruch, Design optimization of composite laminated structures using genetic algorithms and finite element analysis Composite Structures 88 (2009) 443–454.
[6] G. Narayana Naik, S. Gopalakrishnan, Ranjan Ganguli, Design optimization of composites using genetic algorithms and failure mechanism based failure criterion, Composite Structures 83 (2008) 354–367.
[7] Sirajus Salekeen, Douglas L. Jones, Fatigue response of thick section fiberglass/epoxy composites, Composite Structures 79 (2007) 119–124.
[8] R. Kathiravan, R. Ganguli, Strength design of composite beam using gradient and particle swarm optimization, Composite Structures 81 (2007) 471–479.
[9] Murat Pakdil, Faruk Sen, Onur Sayman, Semih Benli, The Effect of Preload on Failure Response of Glass-Epoxy Laminated Composite Bolted-Joints with Clearance Journal of Reinforced Plastics and Composites 2007 26: 1239 originally published online 14 June 2007.
[10] Prashant M. Pawar, Ranjan Ganguli, Modeling progressive damage accumulation in thin walled composite beams for rotor blade applications, Composites Science and Technology 66 (2006) 2337–2349.
[11] Cynthia Swann, Aditi Chattopadhyay, Optimization of piezoelectric sensor location for delamination detection in composite laminates, Engineering Optimization Vol. 38, No. 5, July 2006, 511–528.
[12] Senthil Murugan, Ranjan Ganguli, Aeroelastic Stability Enhancement and Vibration Suppression in a Composite Helicopter Rotor, JOURNAL OF AIRCRAFT Vol. 42, No. 4, July–August 2005.
[13] Pradeep Kumar Gudla, Ranjan Ganguli, An automated hybrid genetic-conjugate gradient algorithm for multimodal optimization problems, Applied Mathematics and Computation 167 (2005) 1457–1474.
[14] Dhyan Jyoti Deka, G. Sandeep, D. Chakraborty, A. Dutta, Multiobjective Optimization of Laminated Composites using Finite Element Method and Genetic Algorithm, Journal of reinforced plastics and composites, Vol. 24, No. 3/2005.
[15] G. Soremekun, Z. Gurdal, R.T. Haftka, L.T. Watson, Composite laminate design optimization by genetic algorithm with generalized elitist selection, Computers and Structures 79 (2001) 131-143.