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Review of Optimization Aspects for Weight Reduction

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Abstract - *In today's global competitive environment there is a need for optimize the excess parameters to develop the components in short lead time. Hence for doing this it's important to study the process of optimization. Also important to understand the methods of optimization that are helpful in optimizing the component with reducing weight and cost. FEA analysis, Simulation methods, Reverse Engineering / 3D scanning etc. are the methods that are basically used in the weight optimization process. Each method plays its own role in optimization. This paper is used to give a review on weight optimization process. Mainly the paper is focuses on two important optimization process one is topology optimization and other one is composite optimization. Among with the optimization process the paper also helpful to give bottlenecks that are directly effect on the optimization process and some of methods that are basically used in the weight optimization process.*

Key words: **Optimization, FEA analysis, Simulation, 3D scanning.**

1. INTRODUCTION

Engineering is a profession whereby principles of nature are applied to build useful objects. A mechanical engineer designs a new engine, or a car suspension or a robot. A civil engineer designs a bridge or a building. A chemical engineer designs a distillation tower or a chemical process. An electrical engineer designs a computer or an integrated circuit. The process of determining the best design is called optimization. Thus during the design of smallest heat exchanger that accomplishes the desired heat transfer or design the lowest-cost bridge for the site or to maximize the load a robot can lift, so optimization is a process that can be seen in almost every aspect of life, Engineering requires optimization so that they can design faster planes and cars, that use less fuel, lighter, stronger and more comfortable. Engineers have been optimizing designs since the beginning, but recent advances in computing have made numerical optimization techniques a more effective way than the original trial-and-error and experience-based optimization. The computational costs increase highly nonlinearly as the number of design variables increases.

In design, construction and maintenance of any engineering system, engineers must take many technological and managerial decisions at several stages. The goal of all such decisions is either to minimize the effort required or to maximize the desired benefit. Since the effort required or the benefit desired in any practical situation can be expressed as a function of certain decision variables, optimization can be defined as the process of finding the conditions that give the maximum or minimum value of a function. So in optimization of a design, the design objective could be simply to minimize the cost of the production or to maximize the efficiency of production. An optimization algorithm is a procedure which is executed iteratively by comparing various solutions till an optimum or a satisfactory solution is found. With the advent of computers, optimization has become a part of computer-aided design activities.

There is no single method available for solving all optimization problems efficiently. Hence several optimization methods have been developed for solving different types of optimization problems. The optimum seeking methods are also known as mathematical programming techniques. Many problems in today's world rely on the trial-and-cut method which in return takes a considerable time to obtain the optimal solution. Nevertheless, solving engineering problems involve many conflicting objectives. Optimization is a method of obtaining the best result under the given circumstances. It plays a vital role in machine design because the mechanical components are to be designed in an optimal manner. While designing machine elements, optimization helps in several ways to reduce material cost, to ensure better service of components, to increase production rate, and many such other parameters. Engineering problems with optimization objectives are often difficult and time consuming, and the application of nature or biology-inspired algorithms in combination with the conventional optimization methods has been very successful in the last several decades.

A review paper is used to gives such an idea about the weight optimization as well as the process of optimization.

2. LITERATURE REVIEW

2.1) Literature review on Topology optimization

Junichi Fukushima, Junichi Fukushima, Noboru Kikuchi (1992) [26] conducted a study on shape and topology optimization of car body. This optimization was done under multi-loading condition. The optimization technique based on homogenization method was elaborated in this study. Also some car body design problems was solved to justify the validity and the strength for engineering application.

Murali M.R. Krishna (2002) [23] conducted a study on shape optimization of jounce bumper bracket. Due to unsatisfactory weight there was decision taken for shape optimization. Design loads applied on test sample and observed that the bracket fails much before the design. By using the finite element technique model definition and design criterion was done. Collected FEA model was used for topography optimization. The weight of the bracket has been increased by 29.1%.

Hui Wang, Zheng-Dong Ma, Noboru Kikuchi, Christophe Pierre, Basavaraju Raju (2003) [22] was studied numerical and experimental verification methods of optimum design obtained from topology optimization. It was done with numerical analysis and physical test. Also this work was combined effort with numerical, theoretical and experimental methods. The goal of research paper was to develop a systematic verification tool, which used to investigate the optimality of design in a cost-effective way.

P. Cervellera, M. Zhou, U. Schramm (2005) [21] optimize driven design of shell structure which has the main part in aerospace industries. Optimization has been done with respect to stiffness, stability and combination of both. It also introduce about the method SIMP where optimization tools based on it. Also study of optimization driven design of an aircraft door beam was done under the single beam model where beam deflection was calculated.

Murali M.R. Krishna (2005) [20] was studied topology and topography optimization of a drive shaft. Drive shaft optimization was used to improve noise, vibration and harshness (NVH) performance. In that, first finite element based topology optimization and later topography optimization carried out. Number of design solution were obtained and it was seen that the designer choose a circular cross-section of drive shaft with suitable bulge at the center. It means from topology optimization it seen that bulge at center gives more stiffening effect.

Yang Dai, Das. M. Ramnath (2007) [18] studied on new technology that improving noise radiation in transaxles by using topography optimization. An artificial parameter β proposed as an objective function. With transmission noise study ford transaxle system modeled in numerical form and studies carried out at ford transaxle driveline engineering (TDE). Velocity analysis with method acoustic transfer vector (ATV) was used. Then using β method it was seen that radiated sound level was reduced by 7.4dB to the original.

Muniyasamy Kalanchiam, Uma Anand D (2009) [14] was studied topology optimization technique in aircraft design. In that one case study named pylon design was introduced to illustrate the advantages of involving topology optimization in design cycle. A block of material used as design space and loading requirements was imposed in the model in appropriate boundary conditions. Finite element based software used for optimization process that reduces time, cost and weight of the design, also it was applicable for all the structural components in the aircraft.

Rajan R. Chakravarty (2009) [13] conducted a study of topography optimization used for automotive body structure. It also includes shape optimization, which can be used to change sheet metal shapes. The paper also highlight the advantages of topography optimization, easy optimization setup, large number of design variables, identification of sheet metal shape morphing locations and mass efficient solution. One case study with full body structure on the application of topography was illustrated. Results was obtained that optimization model was easy to setup, large number of design variables can be handled and shape changes on the sheet metal was identified easily.

Chundong Jiang, Haipeng Jia, Lijun Qin, Taihang Du, Ping Zhang, Chunbo Jiang (2009) [12] conducted a study on to control rotating compliant mechanism through topology optimization. To design rotating complaint mechanism topology optimization was applied based on Finite element analysis. With triangles elements, triangle micro-gripper illustrates that this algorithm was effective to multi-connected design region. The paper studied conceptual model design algorithm through topology optimization and further application it can be applied to design of more complicated compliant and rigid mechanism.

Bharath.V.G, Ranjith.S & Dr.Shantharaja.M (2013) [10] conducted a study on topology and size optimization of composite ply cargo door method. Three phase optimization process for composite laminates was illustrated in paper. First phase was introduce material distribution, phase two interpreted ply based structural model and phase three contain ply stacking optimization was performed to refine the design according to detailed manufacturing constraints. The maximum displacement at the center was 11.91mm which was less than allowable

displacement 12mm, also final thickness was 9.09mm compared to 12mm initial thickness and final mass of the composite cargo door was 89.98kg.

Mengshi Deng, Jian Lan (2016) [5] conducted a study on topology optimization on rope-wheel glass lifter. In order to design a lighter and reasonable glass lifter, the optimization methods was studied in this paper. Firstly single target mathematical models was built and secondly multi-objective topology optimization models of guide rail was built. It was consider with volume friction and dynamic characteristics from that it was obtained that, the structure of the optimized guide rail was more reasonable and structural load path was clear, also more triangular structure generated and with dynamic characteristic makes the optimized guide rail have better rigidity and vibration characteristics.

Y.S. Kong, S. Abdullah, M.Z. Omar, S.M. Haris (2016) [6] conducted a study on topology and topographical optimization of automotive spring lower seat. In that reduction of suspension mass in suspension system has been done. Topology optimization was performed to identify the density of required elements, whereas topography optimization was used to strengthen the structure. With the combination of topography and topology optimization the weight of coil spring lower seat has been successfully reduced, based on topology optimization the mass of model was improved by a reduction 36.5% instead of that weight of the coil spring remains same.

Xiaojie Tiana, Qingyang Wanga, Guijie Liua,Yunxiang Liua, Yingchun Xiea, Wei Dengc (2019) [1] was studied topology optimization design for offshore platform jacket structure. Jacket structure was normally bulky, hence structural optimization was introduced in early design stages. In that design space was chosen as design variables and goal was to maximize structural stiffness. The set was constraints were applied and results was compared with original platform for static, dynamic performance. By the proposed optimization model the mass of the jacket structure reduced by 13.7% compared to the global mass and 46.31% reduction in the maximum equivalent stress was obtained.

Wolfgang Achtziger, Michal Ko cvara [27] was studied structural topology optimization with eigenvalues. The study considers problems of different topology optimization of discrete or discretized structures with eigenvalues as constraints. With multiple load case formulation, paper discusses interrelation of problems and shows how solution of one problem used to solve another problem. Numerical examples for truss was provided, also theoretical results that was archived illustrated in paper. Also study conclude with an extension on multiple non-structural mass conditions.

2.2) Literature review on Composite optimization

Sung K. Ha, Dong-Gun Lee and Dong-Jin Kim (1998) [24] optimize a hybrid composite rotor in flywheel battery. The study was done to maximize the total energy stored structural analysis has been performed considering ring by ring variation of material properties. An analytical solution for each ring has been obtained and expressed in terms of stiffness matrix. By solving the stiffness matrix and calculating the stress in each ring and finally calculate the strength ratio for each ring. An optimum design was thus performed maximizing TSE with size of magnet and the thickness of each composite ring as design variables.

J.H.Luo, H.C.Gea (1998) [25] was studied energy based method to determine the optimal orientation of orthotropic material under static loading. The variations of strain and stress due to the orientation of material was approximated by an energy factor. Strain based and stress based method was recovered by extreme values of energy factor. By giving one numerical example, it shows that energy based method was effective and accurate for optimization. It provided a solid foundation for both the composite material design and orthotropic material based topology optimization.

Salah a. Elmoselhy, Badr s. Azzam, Sayed m. Metwalli, Hasan h. Dadoura (2006) [19] was optimize hybrid laminated fibrous composite E-spring for vehicle suspension system. Optimization conducted both of the geometrical configuration and laminate structure of E-spring. Hybrid global optimization of both external configuration and internal laminate structure of hybrid laminated fibrous composite E-spring was performed. An innovative midware technology was introduced and implemented for a modified NURBS based scheme. A new composite structure design ratio “directional load ratio” was introduced and implemented to facilitate and enhance arriving at the optimum set of fiber orientation angle value. Also Tsai-wu theory along with the interlaminar shear stress criterion and buckling instability scheme was comprised.

Ke Zhang (2008) [17] was studied optimization design of the rectangular 3D braided composite which was based on PSO algorithm. In this paper, a hollow rectangular section 3D braided composite was considered and the stiffness analysis was done by two step method. Than the mathematical model for optimization of the stiffness of 3d braided composite was proposed. Numerical examples proves that by using optimal design better stiffness

characteristic could be obtained. It was effective for design and engineering application.

Ming Zhou (2009) [16] conducted a study on comprehensive process that was used to optimize the design of composite structure. Study mainly focuses on the material properties of composite structure and three phase process used in optimization. To understand the three phase process application example of aircraft underbelly was given. From the results, it was obtained that comprehensive process that was used more flexible and easily implemented.

Ming Zhou, Raphael Fleury, Martin Kemp (2009) [15] optimize fiber reinforced composite material used in aircraft. Research study mainly focuses on three optimization phases that leading from concept design to final play-book details. Demonstration was done through the design of the wing of a wide body aircraft. Due to this it helps to allow the optimization process to fit into an established complex environment of commercial aircraft engine.

Dong Ensheng, Yu Xiangbin, Chao He (2013) [11] was studied optimization of multielectrode capacitive sensor. Some damages in aircraft composite material caused due to increase in service time, hence in order to improve the sensitivity in aircraft, optimization for the structure parameters was carried out. With given mathematical model, optimization index of the uniplanar capacitive sensor with eight electrodes was investigated. Analysis and comparison of sensitivity was done by using experimental setup. Results was obtained that for better performance of sensor, the optimization of structure parameter of the electrode was important. Also the technique discussed was visible one for damage detection of aircraft composite material.

Yvan Blanchard (2014) [9] was studied composite design optimization for automated fiber. In that new innovative approach has been developed to include engineering material and process specification to optimize the final layup program in terms of structural properties and productivity rate. Also research paper include one case study on aerospace by using the automated fiber placement process.

Diogo Andre Baltazar Goncalves Domingues (2015) [8] optimize gearbox casing used in LMP1 race car. In that topography and composite optimization system were carried out using FEA software. The main objective was design a composite version of the gearbox housing, which was lighter than the initial model and satisfied the strength criterion. The final composite design was approximately 44% lighter and 1.31% stiffer than the initial model.

Danilov V.E., Danilov V.E., Bessert O.B. (2016) [7] conducted study on optimization of the composite binder. In that, optimization of the composition of the composition of the basalt-polymineral sand mixture in order to increase the binder activity. The optimum composition of the composite binder was achieved by 95% basalt and 5% of sand. This ratio was achieved by the different testing methods that were discussed in the study.

Rohan Brella, Mayank Sehgal, Naveen Kumar (2018) [4] conducted a study on optimization of composite horizontal axis wind turbine blade. In that, an aerodynamic mathematical model was developed to obtain optimal chord length and twist angle distribution. Initially blade airfoils was analyzed on 2D platform and by using these results 3D model was constructed. The study was mainly focused on the importance of structural design for optimization of HAWT blade.

Binoj J S (2018) [3] conducted a study on characterization and optimization of mechanical properties of natural fiber reinforced composite named Moringa Oleifera Fruit Husk (MOFH) fiber for polymer composite applications. In the study MOFH fiber was tested comprehensively for ensuring its potentiality as a reinforcement in polymer matrix and to optimize the mechanical properties. From the experimental results on the fabricated MOFH fiber composite reveals that 15 Wt. % of fiber has sufficient strength and the flexural test on the composite suggests that 20 Wt. % MOFH fiber composite provide better strength in heavy duty applications.

Ashish Sathaye, Indranil Bhattacharyya (2019) [2] conducted a study on light weighting of automobile hood using multistep optimization. In that one of the front runner light weight material carbon fiber reinforced polymer was introduced. For the right structure from available design space topology optimization was utilized and then free size optimization was implemented. The results was used to decide the ply layups in different hood frame regions. Hood developed using this approach shows mass saving of 44%, when compared to equivalent steel hood.

Dattatraya Parle, Ravi Udali, Anirudha Ambulgekar CHV Veerabhadram [28] conducted a study on integrated optimization approach for laminated composite panels by using FEA and EXCEL-VBA. Research paper gives an integrated optimization approach for laminated composite panel and it was implemented by using MSC.Nastran and Excel-VBA tool. First F.E model was created and then optimization tool used to check laminate thickness. By using MSC.Nastran results were obtained that saving of

weight was approximately 2%. Some optimization problems were solved using the proposed approach.

CONCLUSION

In this paper modern optimization techniques that includes topology, topography and composite optimization are discussed. Modern optimization technique is used to solve Non Linear and non-differentiable optimization problems which are not possible to solve by traditional optimization methods. Weight optimization is an important parameter for time and cost reduction, for this the modern optimization techniques are a perfect tool. Also there are some research papers which are based on optimization of gearbox casing, drive shaft, car body structure, aircraft design where the modern optimization techniques has been used. Most of research papers gives percentage weight reduction, due to this it is much clear that how these optimization techniques are effective. Hence the final conclusion is that for cost and weight reduction topology and composite optimization techniques are effective one.

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