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3-Dimensional FE Analysis and Optimization of Bike Structure

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Abstract: The major challenge in design of bike structure is to produce a lightweight and potentially stiff bike frame structure, which takes the structural response of the original bike frame into account. This is done by performing a topology optimization with the objective to improve the structural stiffness and to reduce the weight of the bike space frame structure. Four different load cases are applied to the bike frame, one rider weight case, one bump hit case and two fork moment cases which are, weighted equally when optimizing. When comparing the result of the analyses, the maximal displacement, the Von Mises stresses, stiffness and the weight of the bike frame are considered. The final optimized bike frame has overall homogenous stress distribution with a reduction of the maximal displacement thus it increases stiffness.

Keywords: Finite Element Analysis, 3-Dimensional, Optimization, Stress analysis

I INTRODUCTION

Topology optimization is the most general form of structural optimization. It allows material to be added or removed from any point within the design domain. With this structural connectivity and material distribution are optimized simultaneously. This freedom in the design space often enables discovery of new, high performance structures. Paris et.al. [1] explored the feasibility of introducing global constraint, to limit the maximum stress (and/or displacement) within all the structure by means of single inequality, in topology optimization of structures. Navarrina et.al. [2] analyzed and compared two approaches. Size and shape structural optimization problems normally stated in terms of a minimum weight approach and topology structural optimization problems usually stated in terms of a maximum stiffness (minimum compliance) approach. Kilian et.al [3] used topology optimization, topography optimization and combination of both the techniques to optimize a contact start-stop suspension with respect to torsion, bending and sway mode frequencies. Dong-Chan Lee et.al [4] has presented the optimization methodology in the design stage of the large optical mirror to obtain the optimal layout through the topology optimization and then design the details through the size or shape optimization for structural rigidity. Van Hooreweder Brecht, Faid Saphir et.al [5] have suggested the development of a lightweight tubular space frame of a solar powered vehicle using 2D topology optimization. Zhen Luo, Jingzhou Yang, Liping Chen et.al [6] have presented a new procedure for aerodynamic missile designs using topological optimization approach of continuum structures. In this paper an attempt has been made to optimize the bike space frame structure using Optistruct. The commercial code Optistruct [7] developed by Altair Engineering ltd. has been used for structural optimization. OptiStruct facilitates an analysis-driven design process that results in more efficient designs in shorter design cycle times. As the design process advances, OptiStruct's powerful shape and size optimization capabilities can be applied to further improve design performance. Thus Optistruct has the capability of performing optimization as well as analysis. The paper is organized into four chapters after introduction and literature review in chapter 1, the paper briefly describes baseline analysis and topology optimization in chapter 2. Chapter 3 presents the results obtained from F.E model of the frame and the frequency response study. At the end conclusions from the study are presented.

II METHODOLOGY

A method for optimizing process of bike frame, which takes the structural response of the frame into account, while reducing its weight and increasing the stiffness is generated. The methodology adopted in this work is presented in the flowchart in Figure 1. It is applied to the only few parts of the bike frame i.e., near tank rods and seat rods. Only one part of the frame is being optimized. The optimized form of the other parts may be derived analogously. The method is based on Finite element software HyperWorks, using the linear solver Optistruct. Four different load cases are applied to the bike frame. They are rider weight load case, bump hit load case and other two being fork moment load cases. These are weighted equally during optimization. Along with these load cases a frequency response load case is defined for the 3g acceleration at the engine centre of gravity within the given frequency range. The maximum displacements from all the four static load cases and maximum FRF displacement from the frequency response analysis is found from base line analysis and later on applied during topology optimization. In the set up of the topology optimization problem, the four load cases are weighted equally. The bump hit load case and rider weight load case occurs to be much larger extent than the fork moment load cases, however, as a safety precaution they are still given the same relevance.

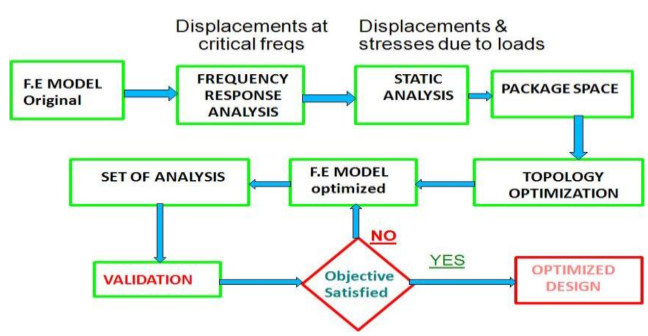

Fig. 1: Proposed methodology

Base Line Analysis

The loads acting on the frame and their corresponding effects on the frame need to be known in order to be able to perform a topology optimization. The finite element model of bike frame is run for the static load cases while restraining the model at tank rod and near the engine mounting rod as shown in the Figure 2, with four load steps defined, each one for one load case. Maximum displacement obtained in each load case and corresponding node numbers are tabulated for the further use in the optimization problem setup. Frequency response analysis is performed on the bike frame F.E model for 3G acceleration at the engine centre of gravity within the frequency range of 80 Hz to 140Hz, while the model being constrained at the engine centre of gravity. Maximum FRF displacement is evaluated from the graphs plotted between frequency and amplitude at the response points on the seat rods and tank rods.

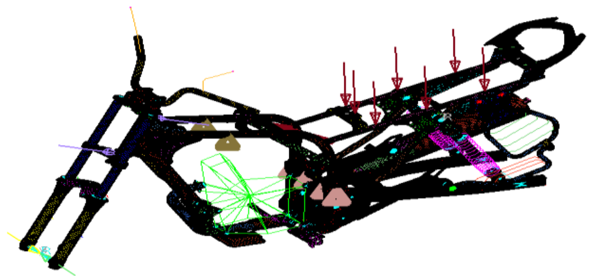

Fig. 2: F.E model used in Static analyses.

Topology Optimization

The method is based on determining the optimal distribution of the material within the structure, to attain an as stiff structure as possible. To achieve this, a topology optimization problem is set up, where the main task is to determine which points in space that should be material points and which should be void points. A general structural optimization problem aims to determine the optimal value of the design variables such that they maximize or minimize the objective function while satisfying the constraints.

In this case a topology optimization problem is set up with the objective to give the structure a maximum stiffness, also expressed as minimum compliance given a certain available amount of material mass. The finite element discretized formulation of the topology optimization problems reads:

Objective: min: $c(\rho)$ (1)

Constraints: $\mathbf{K}(\rho)\mathbf{u} = \mathbf{F}$

$\int \rho \, d\Omega \leq V$

$0 \leq \rho_I \leq 1$ (2)

Where ρ is Density of the element, **K** is Element Stiffness and **F** is Force acting on the structure. **u** is Displacement and **V** is Volume. Ω represents the design space domain consisting of 'i' number of elements. The formulation can be seen in [6]. The finite element model of the bike frame structure is modeled by the use of 3D solid elements. In the set up of a topology optimization problem, the total package volume needs to be divided into a design and a non-design space, according to the restrictions of the problem, see Figure 3. Since the objective is to find the optimal material distribution in the design space, the loadsteps, responses, design constraints and objective function in Optistruct are defined. Optimize the design through topology optimization in Optistruct. Re-design the Finite element model in the hypermesh/any modeling tool, based on the density contour and manufacturing feasibility taken into consideration. Other than the seat rods and tank rods, rest all parts are set as non-design space. That is, the characteristic of this material is not to be changed during topology optimization. Design space is built around tank and seat rods where the design is intended to change with suitable 3D elements, see Figure 3. The design space is the brown area in the figure, which will be optimized and rest all are non-design space.

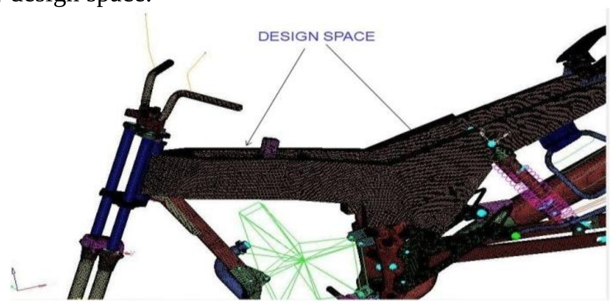

Fig.3: FE model used for topology optimization.

The objective function is set to find the minimum compliance of the package domain. The optimal distribution of material in the design domain is determined. The constraint is set to only use 20% of the volume in the design space, by defining a volume fraction of 0.20. In topology optimization, the structure is free to take any shape within the given design domain. One concern in topology optimization is that the design concept developed is often not manufacturable. To overcome this, few features such as, minimum and maximum member size, pattern grouping that allows a part of the domain to be designed in a certain pattern, for example that two halves of the domain should be symmetrical are introduced and during remodeling of the component manufacturing feasibility is considered from the experience of the designer. The non-design domain is not a part of the topology optimization problem, since it is wished for to remain unchanged.

III RESULTS & DISCUSSIONS

The results from the topology optimization can be viewed in Figure 4. These are the results satisfying the objective function and the constraints, to minimize the compliance and to use a volume fraction of 0.20. The results are been used as an indication of the new design of the frame for the given loads. The outer red frame in the figures is earlier set as non-design space and therefore they are remained fix through the topology optimization. The red areas in the design space indicate the need of placement material.

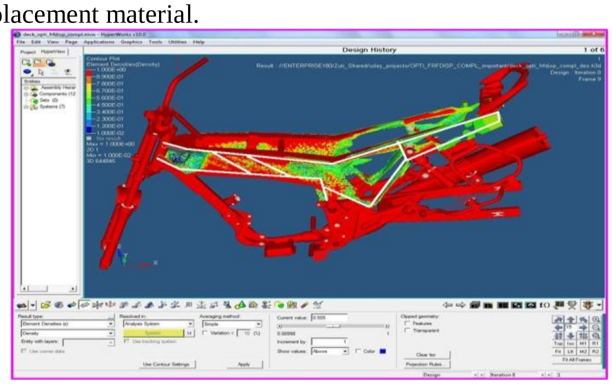

Fig.4: Interpretation of results from the topology optimization.

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A finite element model is created from the pattern seen in the result of the topology optimization. The non-design surfaces are maintained and the new structure is created. Fig 5 shows the F.E-model of the new optimized frame.

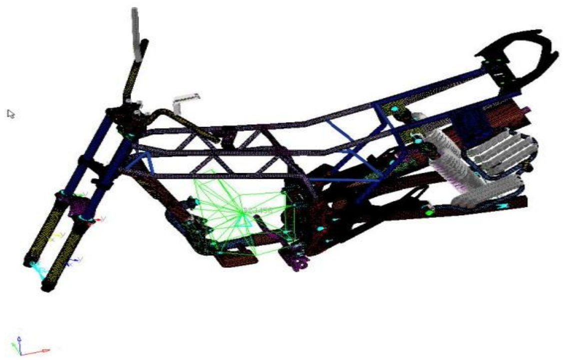

Fig.5: F.E-model of the new and optimized frame.

When evaluating the results, it is important to keep in mind that this is the result of an exact given load and that variation in the applied load might give a different result. A great advantage with topology optimization is the fact that optimal design is ensured irrespective of the number of load cases applied. These load cases can be of great complexity and hard for the human mind to grasp.

Displacement and Stress Analysis of Optimized Frame

To analyze the results of the optimized frame the displacements, Von Mises stresses and resonating frequency in the frame are to be evaluated. These results are compared with the displacements, Von Mises stresses and resonating frequencies in the original frame. Effects of bump-hit and rider weight load cases are major area of interest and therefore results from these load cases are critically evaluated.

Displacement analyses

Results of the analyses of the displacements of the optimized frame can be viewed from Figure 6.

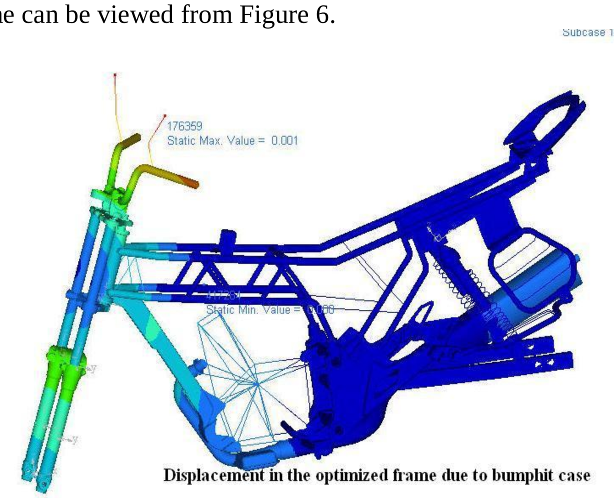

Fig.6: Displacement analysis of optimized frame due to bump hit load case

Von Mises Stress Analyses

The result of the analyses of the Von Mises stresses shows that the maximal stress in the optimized frame are 323.9MPa, 676.3Mpa, 288.9 Mpa for bump-hit load case, rider weight load case and two fork moment load cases respectively.

Fig.7: Von Mises stress analysis of optimized frame (bump-hit load case).

Frequency Response analyses

The result of the analyses of the frequency response shows that the maximum amplitude in the optimized frame is 1.4 mm at 106Hz frequency on the front part of the seat rod, 1.381mm at 106 Hz on mid part of the seat rod and 1.5 mm at 114 Hz on the rear part of the seat rod.

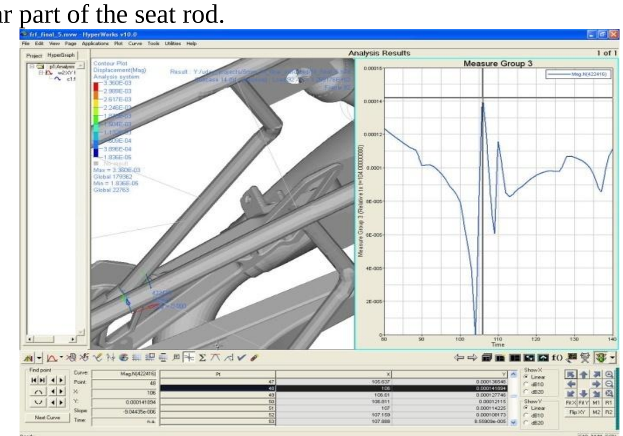

Fig.8: Graph showing Resonating frequency of optimized frame on front part of seat rod.

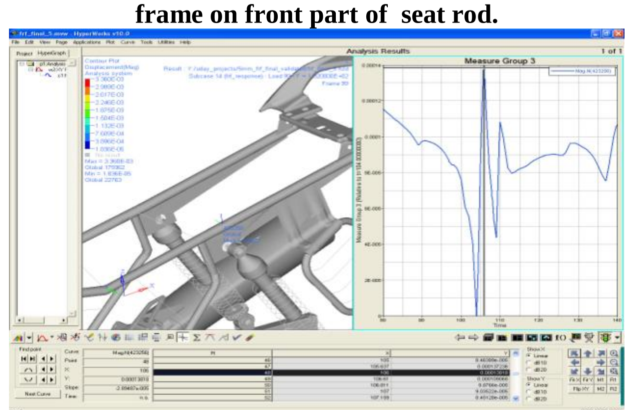

Fig.9: Graph showing Resonating frequency of optimized frame on mid part of seat rod.

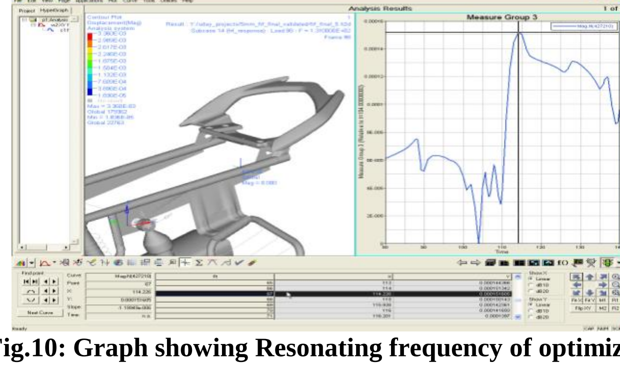

Fig.10: Graph showing Resonating frequency of optimized frame on rear part of seat rod.

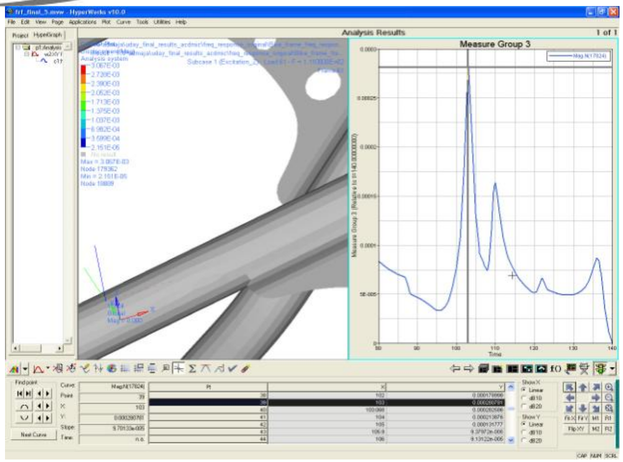

Fig.11: Graph showing Resonating frequency of original frame on seat rod.

Table1 shows the numerical values of the displacements, stresses and weight in the original and optimized frame. The weight of the optimized frame is 2.08% lighter than the original frame.

Table1: Comparison between Original frame And Topology Optimized frames.

Type of result	Description	Original frame	Optimized frame
Maximum displacement	Bump-hit load case	5.29mm	0.546mm
	Rider weight load case	4.88mm	1.434mm
	Fork moment case	7.885mm	7.298mm
Maximum Von Mises stress	Bump-hit load case	528MPa	323.9MPa
	Rider weight load case	1203MPa	676.3MPa
	Fork moment case	315.9MPa	288.9MPa
Resonating frequency and its amplitude	On front part of the seat rod	2.62mm at 103.06Hz	1.41mm at 106Hz
	On rear part of the seat rod	3.33mm at 103.06Hz	1.49mm at 110Hz.
Weight		81.466Kg	79.767Kg

IV CONCLUSIONS

This study shows that a bike space frame of reduced weight can be obtained through topology optimization subjected to Realistic loading conditions.

- In designing tubular space frame of bike, topology optimization in 2D surfaces can be used to develop 3D frame, which allows significant gain in modeling and processing time and insured conformity of the results within the production constraints.
- A full shape and size optimization is made in order to get the best results from the topology optimization. The topology optimization gives only a coarse layout of the optimal material distribution. When adding shape and size optimization to the procedure, the best result is obtained.

REFERENCES

i. *J.Paris, F. Navarrina, I.colominas, M.Casteleiro., Block aggregation of stress constraints in topology optimization of structures., Advances in Engineering Software 41 (2010) 433–441.*

ii. *F. Navarrina, I. Muinos, I. Colominas, M.Casteleiro., Topology optimization of structures: A minimum weight approach with stress constraints, Advances in Engineering Software 36 (2005) 599–606.*

iii. *S.Kilian, U.Zander, F.E Talke., Suspension modeling and optimization using finite element analysis, Tribology International 36 (2003) 317–324.*

iv. *Dong-Chong Lee, Jeong-ick Lee., Structural Optimization design for large mirror., Optics and Lasers in Engineering 42 (2004) 109–117.*

v. *Van Hooreweder Brecht, Faid Saphir., Development of a lightweight tubular space frame of a solar powered vehicle using 2D Topology Optimization, Group T Leuven Engineering College, Belgium, F2008-SC-048.*

vi. *Zhen Luo, Jingzhou Yang, Liping Chen., A new procedure for aerodynamic missile designs using topological optimization approach of continuum structures, Aerospace Science and Technology 10 (2006) 364–373.*

vii. *Altair optistruct optimization manual: analysis, concept and optimization: Hyperworks 10.0, Altair Engineering, 2010.*

viii. *M. P. Bendsoe, O. Sigmund, Topology Optimization: Theory, Methods and Applications, Springer-Verlag, Heidelberg New York, 2003.*