Topology Optimization of Motorcycle Swing Arm

Trupti Rankhambe[1] , Gajendra Kumar Nhaichaniya [2]
Department of Mechanical Engineering
[1, 2] Pimpari Chinchwad College Of Engineering, SPPU, Pune-47.

Abstract*-This article is based on weight reduction of a motorcycle swing arm by Topology optimization. The development of optimized model is based on design space which takes into account overall dimensions, topological optimization and validation using finite element analysis. The weight is known to be one of the most important factor that impact the performance and the cost and for this reason its reduction often becomes the main objective to achieve. The goal of the experiment is to reduce the mass of the component without compromising the other relevant factors. For analysis and study, a well reputed general class 150 cc motorcycle's swing arm was selected.*

Keywords-Swing-arm, topological modification and validation

I. INTRODUCTION

The Indian two wheeler segment contributes the largest volumes amongst all the segments in automobile industry. India was the sixth largest motor vehicle/car manufacturer in the world in 2013 (Wikipedia). India is the second largest motorcycle (6.54 m produced in 2007-08) and the fourth largest commercial vehicle manufacturer in the world. India is the third largest producer of two wheelers in the world it come just next to Japan and China. In last few years the Indian two-wheelers industry has got spectacular growth. This shows that motorcycles are major contributors to the overall vehicles. They share a large part of total daily fuel consumption of our country. An average human weighs about 65-75 kg. The combined weight of motorcycle and rider would be near about 200-220 kg. Hence we can say that about 70 % of fuel is consumed by the motorcycle itself.

II. NOMENCLATURE

L_s static load per side beam
M_t total mass on vehicle
M average mass of person
L vertical load on side beam
L horizontal load on side beam
F horizontal load on inner horizontal side
F horizontal load on outer horizontal side
Θ spring damper inclination

III. LITERATURE REVIEW

Fei Niu, Shengli Xu, Gengdong Cheng[1] from the National Natural Science Foundation of China . To find the stiffest design of structure, minimum structural compliance has been a very popular formulation in structural topology optimization. The structure being optimized in this formulation is subjected to given external forces and fixed structural support, i.e., the second type boundary condition in continuum mechanics. Low compliance is equivalent to small displacement and high stiffness, i.e. a minimum compliance design implies a stiffest design.

Hrishikesh Joshi, Ashish Powar, Sanket Khuley and D.P.Yesane[2] (2016) from Mechanical Engineering, Marathwada Mitra Mandal's Institute of Technology, FEA analysis is performed on both the original and modified components. Two basic designs exist, namely single-sided and double-sided swing arms. The aim is to maximize the vertical stiffness and ensure it is considerably higher than the rear suspension spring stiffness.

Marco Cavazzuti, Andrea Baldini, Enrico Bertocchi, Dario Costi, Enrico Torricelli, Patrizio Moruzzi (January 2011)[6],In particular, topology & size optimizations are coupled with fem analyses and adopted in cascade for reaching an optimum chassis configuration. The objective of the optimization process is the chassis weight reduction, yet in fulfillment of structural performance constraints as required by Ferrari standards.

Book of Anton Olason, Daniel Tidman[7], the focus of this work is to develop a practical method when using topology optimization in the design process. Topology is an area of mathematics that studies properties of geometric objects that depend on the shape, but not size, distances or angles; properties that are independent of any continuous deformation.

IV. SWING ARM

A motorcycle's suspension serves a dual role, providing the rider with control of steering and braking while also absorbing the road conditions to give a more comfortable ride. The suspension components consist of fork tubes on the front of the bike and a swing arm in the rear. The swing arm is the main component of the rear suspension and also provides a base for the rear axle to be mounted.There are two types of swing arms found on most bikes. Typically, most bikes have what is referred to as a monoshock regular swing arm. In this design, a coil over shock is joined to a linkage that is connected to the bike frame and the H-shaped swing arm itself. A newer version is the single-sided swing arm. This type is similar to the H-shaped swing arm in function and design, except that one side has been removed so a tire can be easily changed. Many types of suspension were tried, including Indians leaf spring suspended swing arm, and Matchless cantilevered coiled-spring swing arm. The swing arm has also been used for the front suspension of Scooter. In this case it aids in simplifying maintenance. The function of swing arm is joined to the motorcycle at a higher pivot point than where the rear axle is connected. This works to prevent squat in the tail of the bike when you accelerate and helps to provide adequate spacing for the shocks to function. When the rear brakes are applied, the swing arm is pulled level with the road. This lowers the pivot point where the swing arm joins the bike frame and lengthens the wheelbase at the same time, making the bike more stable and easier to control. A design space is the initial part from which material is removed until a final shape is reached during optimization. Creating design space by using the modeling tools in CATIAV5. Any part that is a design space will be reshaped during optimization, while any part that is not a design space will remain as it is. A design space can have any shape or topology as long as it is a single solid volume. A part that is used as a design space should not be very detailed. Using the simplest design spaces ensures the most freedom to generate a shape. By giving more fine details in the design space, it will take longer time to run the optimization. A shape generated by optimization is contained entirely within the volume of the original design space, since material is only removed and not added.Fig.1.shows design space for swing arm.

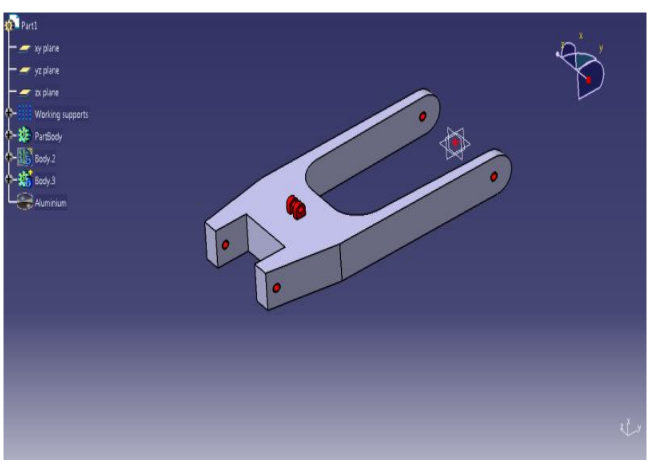

Fig.1 3D Modeling of initial swing arm

V. MATERIAL PROPERTIES

Sr. No.	Property	A206
1	Ultimate Tensile Strength	436 MPA
2	Yield Tensile Strength	350 MPA
3	Young's Modulus	70 GPA
4	Density	$2.8*10^3$ Kg/m^3
5	Poisson's Ratio	0.3
6	BHN	120

VI. BOUNDARY CONDITIONS AND WEIGHT

The swing arm, you will note, is joined to the bike frame via a pivot which is higher than the hub of the wheel. Wherever the swing arm attaches to the frame, it is behind the bike's Centre of Gravity.The rear suspension system connects the frame of the bike to the rear wheel by attaching one end of shocks to the swing arm. The horizontal force at the swing arm pivot goes to accelerate mass of machine but it also creates the moment or torque about COG tending to rotate the bike backword, cause squat in other words. On the other hand (Fv), the vertical force tends to lift the machine relieving suspension spring load but also create torque about COG tending to rotate bike forword is antisquat effect. In this case where the forces passes through COG squat and antisquat moments balanced each other out and remaining vertical force just tend to lift sprung part of machine without any pitch moment. During static running condition, the dampers exert forces due to the dead weight of bike and people on the swing arm, which acts on the rear side of the motorcycle. Also during maximum acceleration, the chain exerts torque on the sprocket. This load acts as pressure on the swing arm on rear lateral faces where the wheel hub is mounted. Considering these two conditions, one critical condition could be the simultaneous application of these two loads. This condition needs to be analyzed.

Loads Calculations:- The weight of the motorcycle is 134 kg. Considering average weight of person as 75 kg, total dead weight is 209 kg. In most two-wheelers, the distribution of weight on rear axle is 58% to 65%. For the model selected, the weight distribution is taken to be 60 % on rear axle. Also 30% of weight is reduced due to tires and wheels and other unsprung masses. Thus net load on swing arm can be calculated as,

$Ls = [ms + 2mp] \times 0.6(1) = 170.04$ kg.

This 170.04 kg which will be distributed equally on the two side beams in case when the motorcycle is running straight. The load will be acting at an angle of about 53^0 at which the damper is mounted. Thus, the loads are separated into vertical and horizontal components.

-Vertical load *Lvs* = *Ls Sin θs* = 170.04*(sin53) = 1335.01N

-Horizontal load *Lvh*= *Ls Cos θs* = 170.04*(cos 53) = 1003.88N. In analysis by applying resultant of these forces further results are obtained.

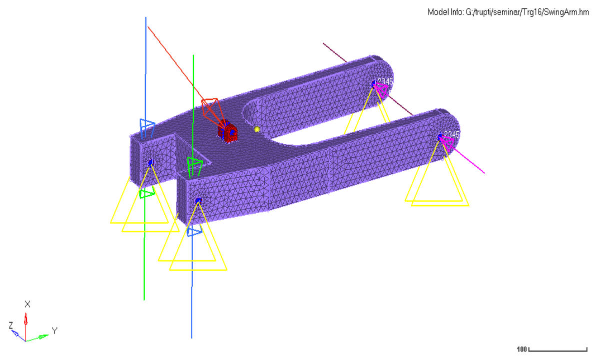

Fig.2 Boundary conditions on swing arm

VII. CORNERING CONDITION

Cornering is one of the important criteria in design on motorcycle components. During cornering, different components are subjected to variation in loads in magnitude as well as direction. In case of swing arm, high lateral forces act in unbalanced state. The magnitude of variation depends upon the angle of inclination and the vehicle speed.

Boundary Conditions: **-** It is assumed that 20% more load are transferred to the inner side during cornering. Thus, the inner side beam will have 70% of the total weight and remaining 30% on the outer side beam. If we consider a maximum cornering angle of 40^0, and divide the forces into vertical and horizontal components, there will be torsional and lateral imbalance on the middle part.

70% of weight,

Fmax = 0.7×209×9.81 = 1435.203 N and remaining 30% = Fmin = 615.087 N.

The maximum values i.e. the inner side swing arm and the middle part is analyzed. The inner side Swing arm will experience more force than outer one. The imbalance will be acting on the middle part.

VIII. ANALYSIS AND TOPOLOGY OPTIMIZATION

To get precise result design domain is divided into 25501 first order tetra elements. In design space (initial swing arm design) by applying above boundary conditions following displacement and stresses generated as shown in fig. below:-

Maximum Displacement = $6.745*10^{-2}$mm

Maximum Stress = 2.759 MPA

Minimum Stress = $3.803*10^{-3}$MPA

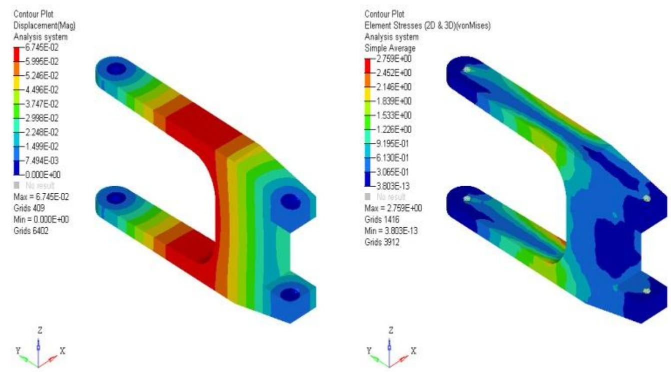

Fig.3 Analysis of initial swing arm

IX. STIFFNESS MAXIMIZATION OF VEHICLE STRUCTURE

The structural body of a vehicle is required to provide stiffness in bending and torsional direction beyond some lower limits prescribed by design team based on previous experience or competitive vehicle. Maximization of stiffness equal to minimization of mean compliance of structure under load. Stress level in any part of structure can be determined by conducting finite element analysis. A reliable indicator of inefficient use of material is low value of stress in some part of structure. Ideally stress in every part of structure should be close to the same, safe level. This concept leads to rejection criterion based on local stress level, where low stress material assumed to be under utilize, therefore removed subsequently. The removal of material can be conveniently undertaken by deleting element from finite element model. The stress level at each element is determined by comparing, for e.g. von mises stress of element σ_e^{vm} with maximum von mises stress of whole structure σ_{max}^{vm}. After each finite element analysis, element which satisfy following condition are deleted from model.

$(\sigma_e^{vm} / \sigma_{max}^{vm}) < RR_i$ ……...where RR_i = Current rejection ratioSuch a cycle of finite element analysis and element removal is repeated using the same value of RR_i until a steady state is reached, which means that there are no elements being deleted using current rejection ratio. At this stage evolutionary rate, ER is added to rejection ratio, i.e. $RR_{i+}1$ = RRi+ER.

With the increased rejection ratio the iteration takes place again until a new steady state is reached.

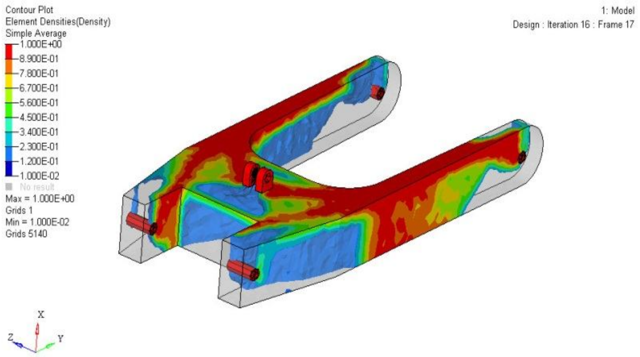

Fig.4 Isometric view of Optimized swing Arm

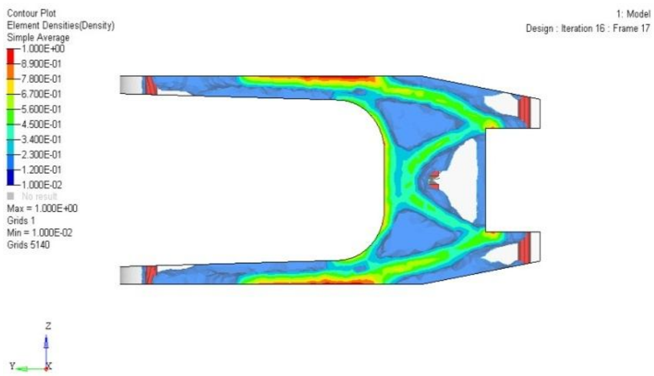

Fig.5 Bottom View of optimized Swing Arm

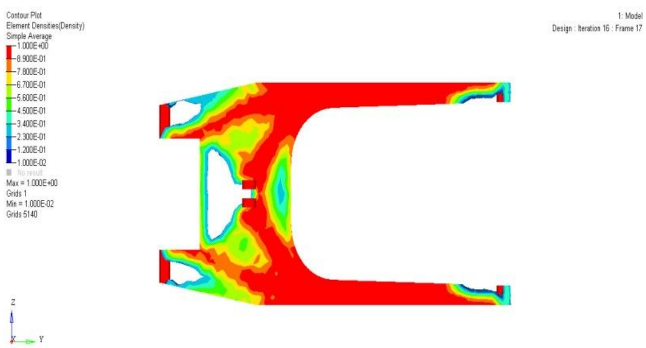

Fig.6 Top View of optimized Swing Arm

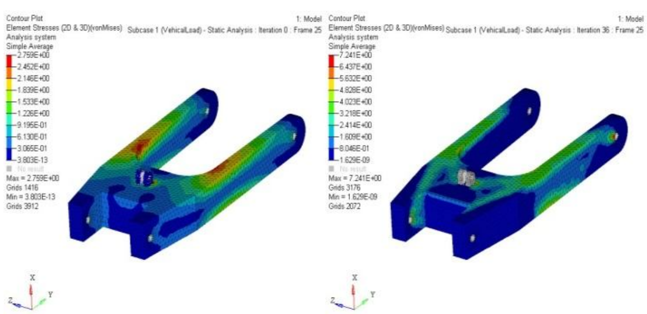

Fig.7 Developed stress before and after Optimization

Topology Optimization suggest Optimized design of swing Arm as shown in fig. below, which is very difficult to manufacturing or may have high cost to manufacturing. So for efficient manufacturing process with low cost, component have to redesign according to manufacturability with sense of optimization.

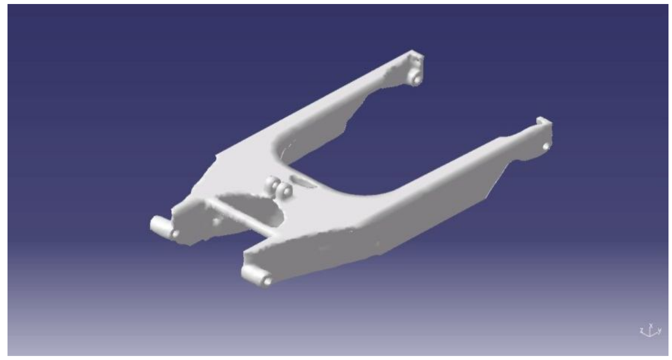

Fig.8 Imported optimized model of Swing Arm in CATIA

By importing model in different CAD software it can be redesign as above conditions. Here CATIA software is used to redesign such component as shown in below fig.

Fig.9 Different views of final model of optimized Swing Arm

X. CONCLUSION

The Topology Optimization method starts from the full design space and removes inefficient material from structure according to stress level of elements. The resulting design provides a clear definition of Topology ('without grey area'). Element removal can be done by simply assigning material property number of rejected elements to zero and ignoring those elements when the global stiffness matrix is assembled in subsequent finite element analysis. Weight of design space is about 11.2 Kg, it reduces by Topology

Optimization up to 5.8 Kg. which is notable. Reduction in weight achieved 50%.

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