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Finite Element Analysis of a Front Double-Sided Swing Arm for Electric Motorcycle

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Abstract: *This project focuses on the structural analysis of the front double-sided swing arm of an electric motorcycle, created recently to address the demands of the era of vehicle electrification. The major goal is to create a swing arm that can handle the stresses encountered during motorcycle operations while remaining as light as possible. Different force loading scenarios are addressed, with a focus on braking forces in emergency braking situations where heavier loads are imparted to the vehicle's front wheels. Through a series of finite element analysis simulations, specific Computer-Aided Engineering (CAE) software is utilized to evaluate the structural integrity of various swing arm designs. A topology optimization approach is also used to aid the redesign process and minimize the final design's weight. According to simulation findings under the worst-case loading conditions, the proposed structure is effective and promising for actual prototyping. A direct comparison of the results of the initial and final swing arm designs demonstrated a weight reduction of 7.14%.*

Keywords: Swing Arm; Double-Sided; Finite Elements Analysis (FEA); Two-Wheel Motorcycle; Topology Optimization.

I. Introduction

Motorcycle technology has progressed steadily throughout the years, keeping pace with or even exceeding automobile technology advances. As a result, electric motorcycles are becoming more common, with a significant market share (over 30% in 2019) [8]. The front suspension system, which connects the chassis to the front wheel, is an important structural component of all motorcycles. There are a variety of front suspension designs available, including girder forks, leading links, and hub center steering [12]. Scooters and motorbikes have telescopic forks almost universally. Motorcyclists and safety standards commissions alike are demanding more precise dynamical behavior under severe loads as modern motorcycles become more powerful. When it comes to evolving demands such as lateral flex, leverage, nosedive and the telescopic fork has a number of evident structural limitations due to its lengthy tubular construction [11]. Alternative front suspension systems have been explored and installed on production bikes because the suspension system chosen has a significant impact on the motorcycle's performance and handling. Due to these factors swing arm came into the picture.

A swing arm, originally known as a swing fork or pivoted fork, is a single or double-sided mechanical device that attaches the wheel of a motorcycle to its body, allowing it to pivot vertically. This component has been in place for front and rear suspension mounting and connecting between the frame and the rear wheel for a long time. Single-sided swing arms lie along only one side of the wheel and support it on one side, allowing it to be installed like a car wheel [4]. Double-sided swing arms hold the wheel by both sides of its axle. The most common swing arm is the double-sided swing arm, which is popular due to its simplicity and symmetrical shape. Single-sided swing arms are typically found on track/racing bikes. On older motorcycles, the swing arm consists of a basic pair of parallel or slightly diverging arms (usually round tubing) joined at the frame (front) end by a tube housing the pivot shaft, which is supported by bushings or bearings. Only the axle closes the opposite open end of the arms.

Considering rear double-sided swing arms, a relative approach is followed by several researchers in which structural analysis is based on braking and cornering, torsional loads or severe loading such as performing a wheelie. There are significant differences between the loads delivered to a front and rear swing arm, including (a) the effect of torque during acceleration, which is not considered on a front swing arm, (b) motorcycle weight distribution loads, and (c) higher braking forces applied to the front wheels. The non-design space around the hard points, such as the swing arm pivot, axle mounting, and shock absorber mounting, was set as non-design space, and design space was provided in accordance with design limitations. For the application of forces to represent the flow of external loads through a wheel spoke, the axle in the motorcycle model was converted to a T shape structure.

Several researches have been carried out, research in swing arm K. Satyanarayana, et al. [1] carried out the analysis observed that AL7075 was the best material of construction for swing arm from both static and fatigue load conditions. Taking the results of the analysis into perspective, it will be finally concluded that Al7075 is that the optimum suitable material with low deflection, stress, weight and high life and factor of safety to use as a material for the swing arm. Swathikrishnan S, et al. [2] described three models named SA1, SA2 and SA3. SA1 was the existing model of the swing arm where SA2 was the modified version of the SA1. Nicola Petrone [3] carried out the analysis on moped frame and main components were strain gauged and statically calibrated to collect field load histories in solo and dual riding, including extreme driving events. The moped mission and the mix between Urban, Extra Urban, Pave, Off-road and Mountain driving and load-based Fatigue Life Prediction were carried out adopting an experimental approach. Constant amplitude fatigue tests were performed on the welded frames to obtain the fatigue curves at the steering tube node under horizontal loads and at the rear seat support node under vertical pulsated seat loads. Joao Diogo DA Cal Ramos [4] were considered two specific scenarios for the rear swing arm design, high motor assembly (HE) and low motor assembly (LE). HE and LE solutions were explored through two different models. On both models, it had been verified that a truss type design is that the most effective way to reduce total mass while keeping satisfactory mechanical properties. Polychronis Spanoudakis [5] analysed through a series of finite element analysis simulations, a dedicated Computer-Aided Engineering (CAE) software is used to evaluate the structural integrity of various swing arm designs. A dedicated CAE software was used for this purpose, providing adequate results [5].Loading circumstances were separated by comparing a front and a rear swing arm. Two different loading situations were used in the simulations. The first scenario looked at weight distribution forces, while the second scenario, which was deemed the worst-case scenario, looked at the influence of braking forces [5-6]. Wojciech Pawlak carried out the analysis following that, the discrete model was primarily composed of S4R elements (19 820 elements) and S3R elements (19 elements), indicating the discrete model's reasonably high quality. Separate mesh sections were isolated in places where shock absorber and axle bearings were installed. G1, G1.9, Longitudinal stiffness, Torsional stiffness, Turning conditions, Buckling, and Fatigue were all identified during the FEM analysis. None of the types of analysis listed above was surpassed [6].

The main objective of this work is to carry out finite element analysis in order to check induced stresses and deformation at critical locations and subsequently topology optimization is carried out using commercial software. In this regard, the paper is organized as follows. Section-2 describes the construction and working of the swing arm. The finite element analysis and topology optimization of the swing arm is presented in section-3. Section-4 illustrates comprehensive results. The conclusion of this section is presented in the last section.

II. Swing Arm

A swing arm, originally known as a swing fork or pivoted fork, is a single or double-sided mechanical device that attaches the wheel of a motorcycle to its body, allowing it to pivot vertically. This component has been in place for front and rear suspension mounting and connecting between the frame and the rear wheel for a long time. Single-sided swing arms lie along only one side of the wheel and support it on one side, allowing it to be installed like a car wheel. Double-sided swing arms hold the wheel by both sides of its axle. The most common swing arm is the double-sided swing arm, which is popular due to its simplicity and symmetrical shape.

On the swing arm, the usual stress distribution is visible, with maximum stress occurring at one of the restricted points that joins it to the chassis. When it comes to stopping, the maximum braking forces are experienced during deceleration when only the front brakes are used. When considering the forces applied in various loading scenarios, the data obtained for the worst-case scenario, which is under emergency braking conditions, are the most important. It has been decided to redesign the swing arm in order to reduce weight and production costs. Hence the problem is taken to analyze using the topology optimization method.

III. Finite Element Analysis of Swing Arm

3.1 Structural Analysis of Swingarm

The use of computers to assist in the creation, modification, analysis, or optimization of a design is known as computer-aided design (CAD). CAD software is used to improve the designer's efficiency, the quality of the design, communication through documentation, and the creation of a database for manufacturing. The output of CAD is frequently in the form of computer files for printing, machining, or other man-made processes.

CAD is used To Produce thorough engineering designs of the physical component of the manufactured swing arm using 3-D and 2-D drawings, To develop a conceptual design, product layout, and strength and dynamic analysis of assembly and manufacturing processes, To create environmental impact assessments in which computer-aided designs are combined with images to create a visual representation of the situation.

CAD systems exist today for all of the major computer platforms, including Windows, Linux, Unix and Mac OS X. The user interface generally centers around a computer mouse, but a pen and digitizing graphic tablet can also be used. View manipulation can be accomplished with a space mouse (or space ball). Some systems allow stereoscopic glasses for viewing 3-D models. In the olden days, engineers, designers and draughtsman were struggling to produce and submit engineering drawings in their scheduled times. It was mainly due to the tremendous efforts they had taken to produce both new drawings or edited/updated drawings. Every line, shape, measurement, scaling of the drawings - all made their headache to the design/drafting field. All these difficulties and pressures are over-ridden by Computer-Aided Design Drafting (CAD Drafting) technology.

The advantages of CAD include: the ability to producing very accurate designs; drawings can be created in 2D or 3D and rotated; other computer programs can be linked to the design software. With manual drafting, you must determine the scale of a view before you start drawing. This scale compares the size of the actual object to the size of the model drawn on paper. With CAD, you first decide what units of measurement you will use, and then draw your model at a 1:1 scale, which should be one of the main benefits of CAD. When you draft manually, you first select a sheet, which usually includes a pre-printed border and title block. Then you determine the location for views' plans, elevations, sections, and details. Finally, you start to draw. With CAD, you first draw your design, or model, in a working environment called model space. You can then create a layout for that model in an environment called paper space.

A layout represents a drawing sheet. It typically contains a border, title block, dimensions, general notes, and one or more views of the model displayed in layout viewports. Layout viewports are areas, similar to picture frames or windows, through which you can see your model. You scale the views in viewports by zooming in or out. Manual drafting requires meticulous accuracy in drawing line types, line-weights, text, dimensions, and more. Standards must be established in the beginning and applied consistently. With CAD, you can ensure conformity to industry or company standards by creating styles that you can apply consistently. You can create styles for text, dimensions, and line types.

With manual drafting, you use drawing tools that include pencils, scales, compasses, parallel rules, templates, and erasers. Repetitive drawing and editing tasks must be done manually. In CAD, you can choose from a variety of drawing tools that create lines, circles, spline curves, and more. You can easily move, copy, offset, rotate, and mirror objects. You can also copy objects between open drawings. With manual drafting, you must draw objects carefully to ensure correct size and alignment. Objects drawn to scale must be manually verified and dimensioned. With CAD, you can use several methods to obtain exact dimensions. The simplest method is to locate points by snapping to an interval on a rectangular grid. Another method is to specify exact coordinates. Coordinates specify a drawing location by indicating a point along an X and Y axis or a distance and angle from another point. With object snaps, you can snap to locations on existing objects, such as an endpoint of an arc, the midpoint of a line, or the center point of a circle. With polar tracking, you can snap to previously set angles and specify distances along with those angles. Revisions are a part of any drawing project. Whether you work on paper or with CAD, you will need to modify your drawing in some way. On paper, you must erase and redraw to make revisions to your drawing manually. CAD eliminates tedious manual editing by providing a variety of editing tools. If you need to copy all or part of an object, you don’t have to redraw it. If you need to remove an object, you can erase it with a few clicks of the mouse. And if you make an error, you can quickly undo your actions. Once you draw an object, you never need to redraw it.

To work efficiently using the CAD the organization must focus on the following areas where it needs to be on the upper side. Every new release of the CAD software, the operator has to update their skills. Improper use of blocks and layers make updating and modification of the drawings a cumbersome task for another person.

The finite element method (FEM) is a numerical solution approach for engineering and mathematical physics issues. Structure analysis, heat transfer, fluid flow, mass movement, and electromagnetic potential are all common problem areas of interest. The analytical solution of these problems usually necessitates the solution of partial differential equations boundary value problems. The method of finite elements The problem is expressed as a system of algebraic equations. At a discrete number of points over the domain, the approach produces approximate values for the unknowns. It breaks a huge problem into smaller, simpler sections called finite elements in order to solve it.

In the first step, the element equations are simple equations that locally approximate the original complex equations to be examined, which are frequently partial differential equations (PDE). In mathematical terms, the procedure entails constructing an integral of the inner product of the residual and weight functions and setting the integral to zero simple terms, it's a method for reducing approximation error by fitting trial functions into the PDE. The weight functions are polynomial approximation functions that project the residual, and the residual is the error induced by the trial functions. The procedure removes all spatial derivatives from the PDE, allowing it to be approximated locally with a set of algebraic equations for steady-state problems and a set of ordinary differential equations for transient problems.

The element equations are these sets of equations. If the underlying PDE is linear, they are linear, and vice versa. Numerical linear algebra methods are used to solve algebraic equation sets that arise in steady-state issues, while conventional differential equation sets that form in transient situations are solved by numerical integration using classic techniques such as Euler's method or the Runge-Kutta method.

The easiest way to understand FEM is to look at how it's used in practice, which is called finite element analysis (FEA). FEA is a computer tool used in engineering to undertake engineering analysis. It entails the use of mesh generation techniques to break down a large problem into smaller components, as well as the usage of FEM-coded software tools. The complex problem in FEA is typically a physical system with underlying physics such as the Euler-Bernoulli beam equation, the heat equation, or the Navier-Stokes equations expressed as PDE or integral equations, and the divided small elements of the complex problem represent different areas in the physical system. In present research for analysis commercial CAE software is used. Basically, it presents the FEM method to solve any problem. Following are steps in detail 1-Geometry Formation, 2-Discretization (Meshing), 3-Boundary conditions, 4-Solve (Solution), 5-Interpretation of results.

3.2 Engineering Material - Structural Steel

A. Properties of the Structural Steel

Table 1: Engineering material - structural steel

Sr. No.	Property	Value	Unit
1.	Density	7850	Kg /m^3
2.	Coefficient of Thermal Expansion	1.2E-05	C^{-1}
3.	Young's Modulus	2E+11	Pa
4.	Poisson's Ratio	0.3	
5.	Bulk Modulus	1.666E+11	Pa
6.	Shear Modulus	7.6923E+11	Pa

3.3 Finite Element Analysis of Existing Swing Arm

Following are steps in detail 1-Geometry Formation, 2-Discretization (Meshing), 3-Boundary conditions, 4-Solve (Solution), 5-Interpretation of results.

Properties of Outline Row 3: Structural Steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7850	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
5	Coefficient of Thermal Expansion	1.2E-05	C^-1
6	Isotropic Elasticity		
7	Derive from	Young's Modulus and Poisson's...	
8	Young's Modulus	2E+11	Pa
9	Poisson's Ratio	0.3	
10	Bulk Modulus	1.6667E+11	Pa
11	Shear Modulus	7.6923E+10	Pa

Figure 1: Details of engineering materials

Details of material namely copper, steel, grey cast iron, composite material, fluid domain material is defined in engineering data. In the current work, Structural Steel is used for FEA as the existing model is made of Structural Steel. Import geometry created in any CAD software in the geometry section.

If any correction is to be made it can be created in the geometry section in the Design modeler or space claim. In the model section after import of component Material is assigned to the component as per existing material. Connection is checked in the contact region i.e. bonded, frictionless, frictional, no separation etc. for multibody components. Meshing or discretization is performed i.e. to break components into small pieces (elements) as per size i.e. preferably tetra mesh and hexahedral mesh for 3D geometry and for 2 D quad or tri are generally preferred. Boundary conditions are applied as per analysis namely in fixed support, pressure, force, displacement, velocity as per the condition. Now the problem is well defined and solves option is selected to obtain the solution in the form of equivalent stress, strain, energy, reaction force etc. Weight of existing swing arm is 3.447 kg.

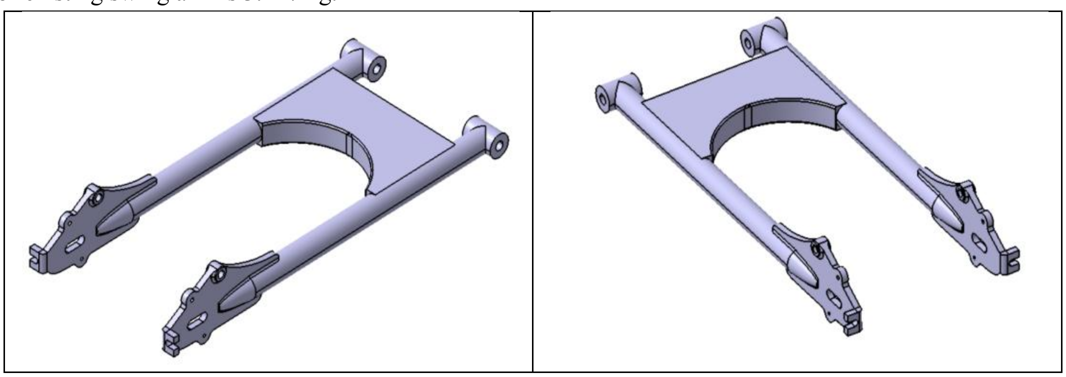


Figure 2: Existing model of double sided swing arm

3.3.1 Geometry

3D modelling of the existing swing arm has been done with the help of commercial modellling software.

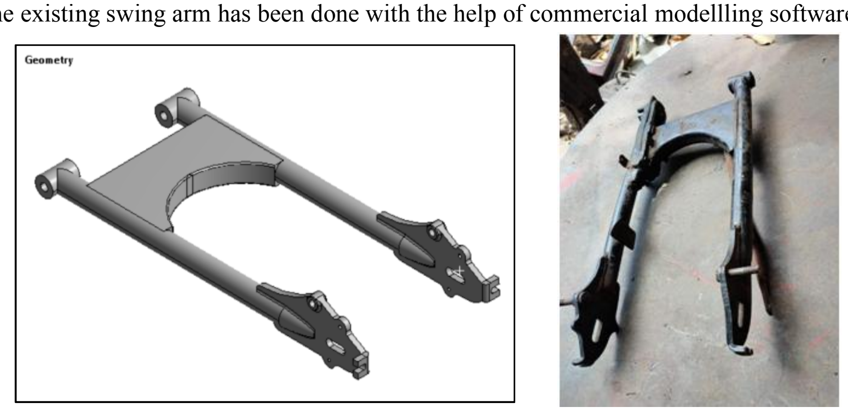


Figure 3: Geometry of swing arm

3.3.2 Mesh Model of Existing Swing Arm

Tetrahedral Meshing or discretization is performed with an element size of 10.0 mm. The partial differential equations have been solved for 12734 elements with 24575 nodes.

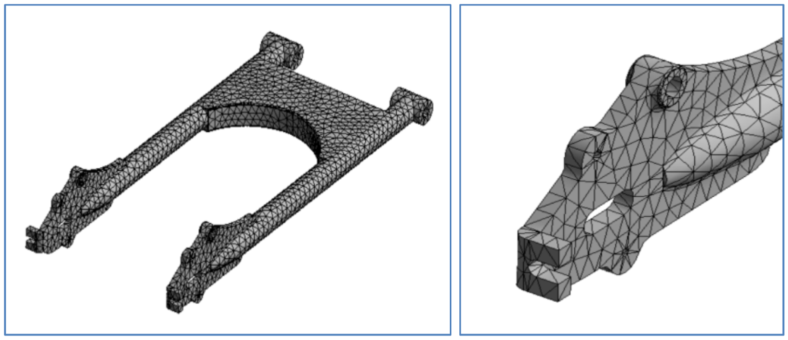


Figure 4: Swing arm meshing

3.3.3 Boundary Conditions

Boundary conditions are applied as per the real-life scenario. Where swing arm is fixed at point A which is connected to the structure and load is applied at point B which is connected to the axel. In this part, the force applied is F = 1000 N, which corresponds to weight distribution on the front wheel.

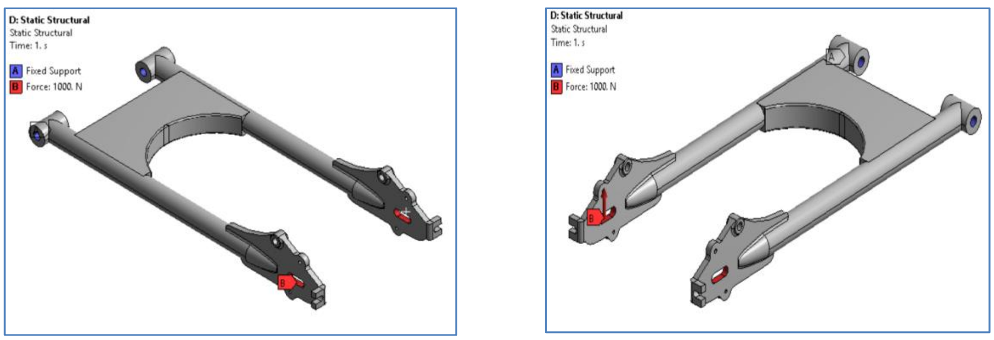


Figure 5: Boundary condition

3.3.4 Results

Considering the case of braking, the highest braking forces occur at a deceleration when using only the front brakes. According to this, the forces applied in the simulation are F = 1000 N. The results of stresses and displacements obtained are presented in Fig. Total deformation observed is 3.5997 mm and maximum equivalent von-misses stress is 232.17 MPa. Safety factor observed is 1.292.

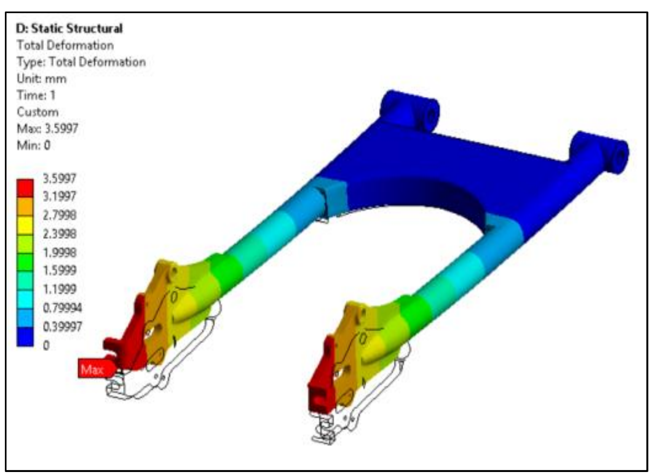


Figure 6: Total deformation

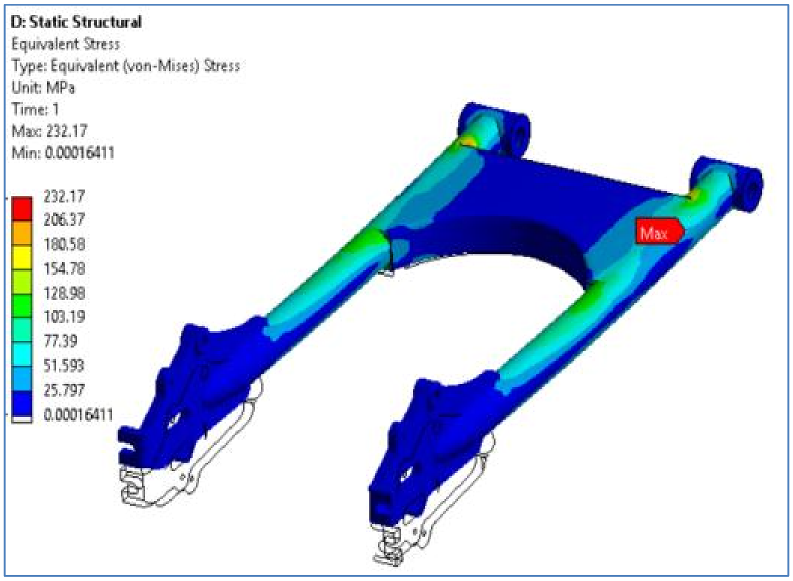


Figure 7: Total deformation

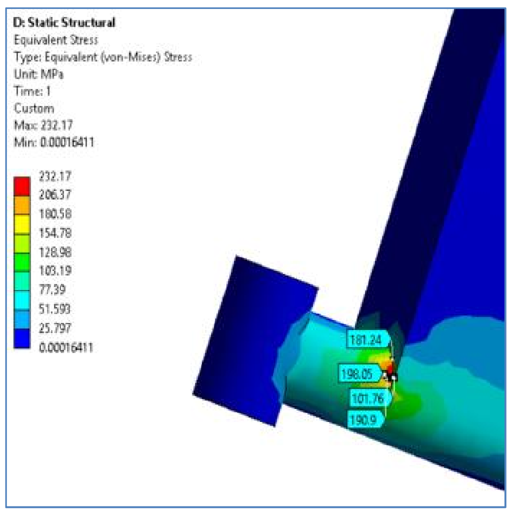


Figure 8: Equivalent stress

Comparing to the previous model the current model is having more strength, but again the weight factor of the model is needed to be considered due to its effect on vehicle handling. Hence the topology optimization process is used for the further weight reduction goal.

IV. TOPOLOGY OPTIMIZATION

Topology optimization is a mathematical approach that optimizes material layout within a given design space, for a given set of loads and boundary conditions such that the resulting layout meets a prescribed set of performance targets.

4.1 Theory of Topology Optimization

There are three kinds of a structure optimization, Size Optimization, Shape Optimization, Topology Optimization. The three stages of the product design process, namely detailed design, basic design, and conceptual design, are represented by three optimization algorithms. Size optimization keeps the structural shape and topology structure invariant, to optimize the various parameters of the structure, such as thickness, section size of the beam, materials' properties; shape optimization maintains the topology structure, to vary the boundary of structure and shape, seek the foremost suitable structure boundary situation and shape; Topology optimization is the process of determining the best path for material distribution in a continuous domain that meets the structure's displacement and stress criteria, resulting in optimal performance. As a result, when compared to size and form optimization, topology optimization has a higher degree of freedom and larger design space, and its most important feature is under the unknown structural structure. It is the most promising part of structural optimization to find the appropriate structure based on known boundary conditions and a given load, both for the conceptual design of new items and enhanced design for current products.

There are some established approaches for continuous structure topology optimization, such as the uniform method, evolutionary structural optimization method, variable density method, and so on. Each unit cell has three forms, namely non-material voids (size = 1), isotropic-material entity medium (size = 0), and orthotropic-material opening-hole medium (0 < size < 1). Uniform method introduced cell structure of microstructure (unit cell) in the elements of the structure; each unit cell has three forms, namely non-material voids (size = 1), isotropic-material entity medium (size = 0), and orthotropic-material opening-hole medium (0 < sizes < 1).

In an ideal structure, the distribution of each form will be able to represent the topology and shape of the structure; the evolutionary structural optimization approach thinks that stress in all areas of the structure should be at the same level. That suggests the low-stress local material isn't being used to its full potential, and you can destroy it artificially. As a result, gradually remove material in a low-stress state and then erase the update rate, resulting in a more uniform optimized structure. In this study, the variable density method is employed to carry out optimization.

The basic idea is to introduce a hypothetical material which density is variable and range from 0 to 1.

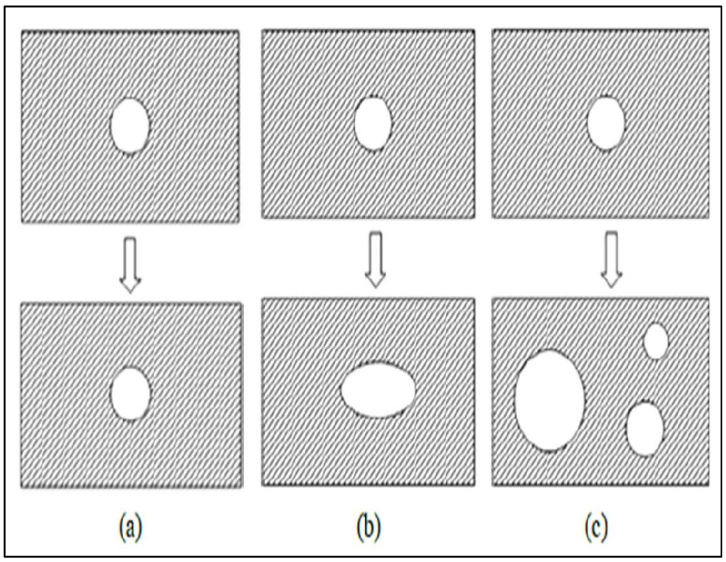


Figure 9: Three kinds of structure optimization. (a) Size optimization, (b) Shape optimization, (c) topology optimization.

After converting the continuous structure to a finite element model and making per unit density the design variables, the topology optimization problem was converted into the optimal material distribution problem, with the intermediate density of the material suppressed (material between void and entities), the addition of an interpolation penalty factor to characterize the link between Young's modulus and material density, as demonstrated in the formula $E = x^p E_0$.

where p is the interpolation penalty factor (p > 1), E0 is the densified material unit's Young's modulus, and E is Young's modulus after interpolation. In order to produce the best outcomes that are close to the entity, the initial model with intermediate density will be deleted or replaced by densified material. As a result, the relative density of units is a variable in topology optimization, and the structural topology optimization problem is translated into the optimal material distribution.

4.2 Process of Topology Optimization

Based on the CAE platform topology optimization holder, we first create a three-dimensional geometric model of the engine bracket based on the engine mounting position, then pre-treat in CAE software, define design area, objective function, and constraints under the optimization panel, and finally perform topology optimization.

4.3 Analysis

To establish the geometry model by modeling software, then input the geometry to the commercial CAE software to carry out pre-treatment operations like geometry clean up, meshing, loads, constraints, etc. Initially, we need to collect the information regarding different loads acting on the bracket and the packaging data for fixing design space. The base bracket results from testing and finite element analysis (FEA) point of view for evaluating the final optimized design. The topology optimization consists of the three sequence of steps: Define the design space, Define optimization parameters, Material removal process and detail design.

4.4 Topology Optimization of Existing Swing arm

4.4.1 Boundary Conditions

Boundary conditions have been applied to the model of the swing arm. Where the area defines the design region shaded with blue colour and exclusion region shaded with the red area. The objective of the optimization process is to minimize the compliance and response constraint is 50% mass.

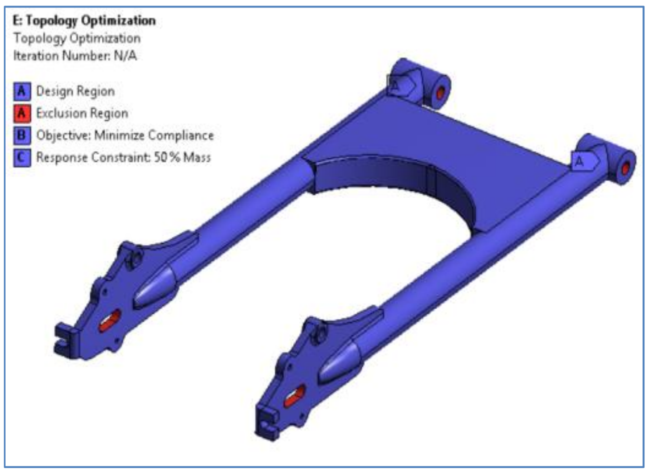
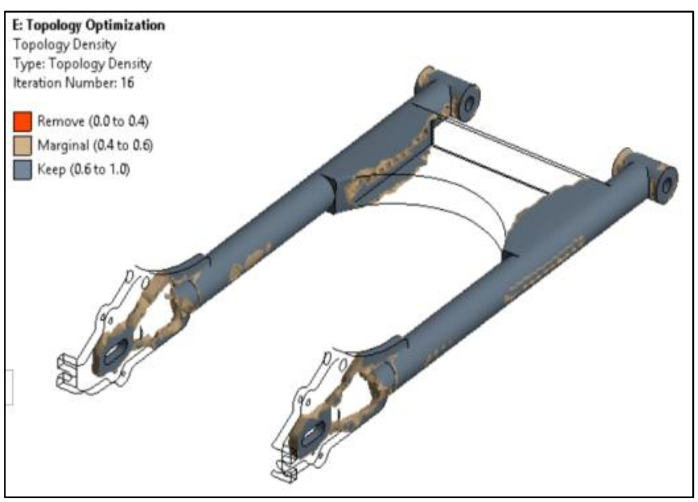


Figure 10: Boundary conditions of topology optimization

4.4.2 Topology Density



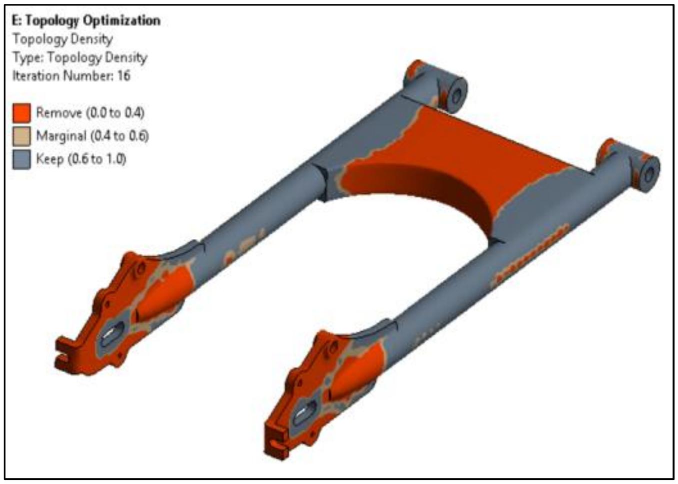


Figure 11: Topology density

The red region indicates the material removal area. The geometry modification needs to do considering the material removal area. Hence the model is modified by removing material in the red region.

4.4.3 Geometry of Optimized Swing arm

The additional material is removed from the swing arm and new model is suggested. 3D modelling of the existing swing arm has been done with the help of modeling software.

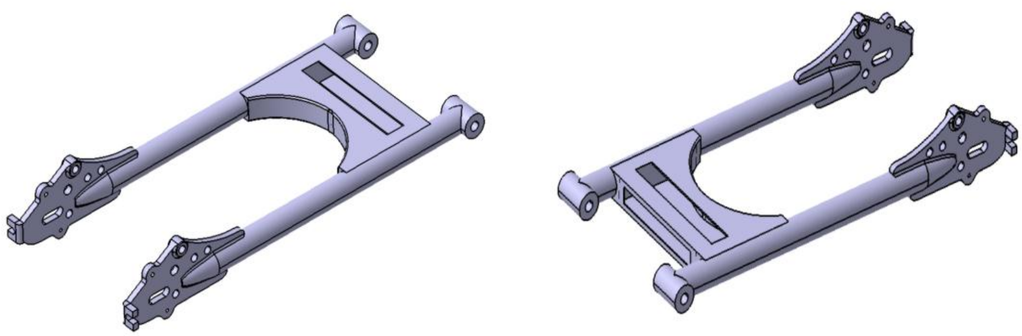


Figure 12: Optimized swing arm

4.5 Finite Element Analysis of Optimized Swing Arm

4.5.1 Mesh model of optimized swing arm

Tetrahedral Meshing or discretization is performed with an element size of 10.0 mm. The partial differential equations have been solved for 12409 elements with 24218 nodes.

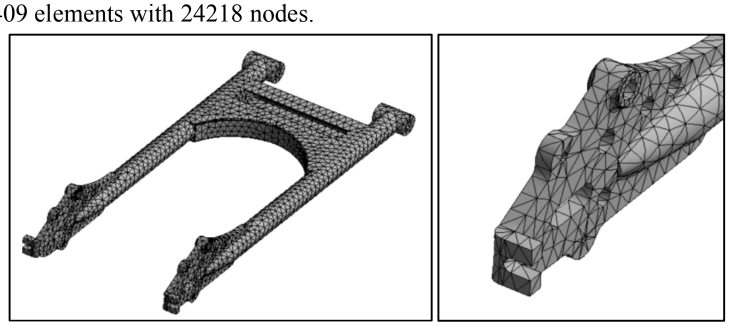


Figure 13: Meshing of wing arm

V. RESULTS

Considering the case of braking, the highest braking forces occur at a deceleration when using only the front brakes. According to this, the forces applied in the simulation are F = 1000 N. The results of stresses and displacements obtained are presented in Fig. Total deformation observed is 3.705 mm and maximum equivalent von-mises stress is 219.31 MPa. . Safety Factor achieved is 1.367. The equivalent strain obtained is 885 microns.

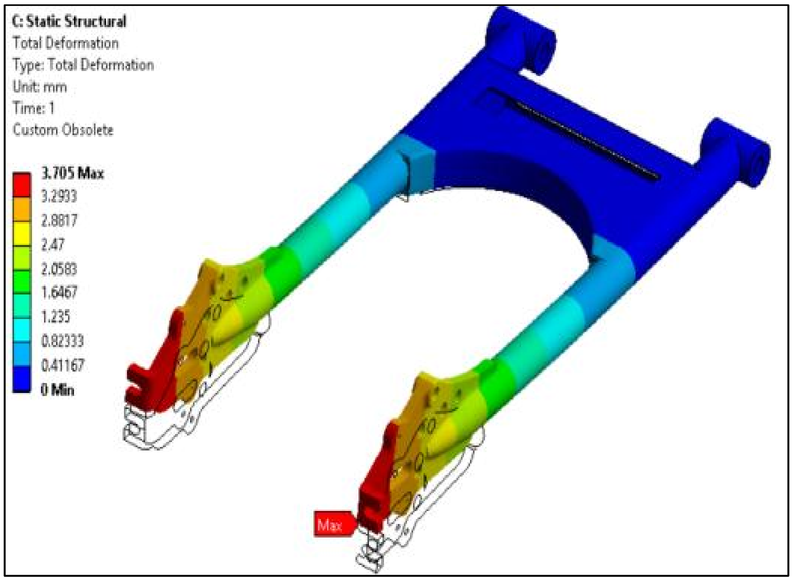
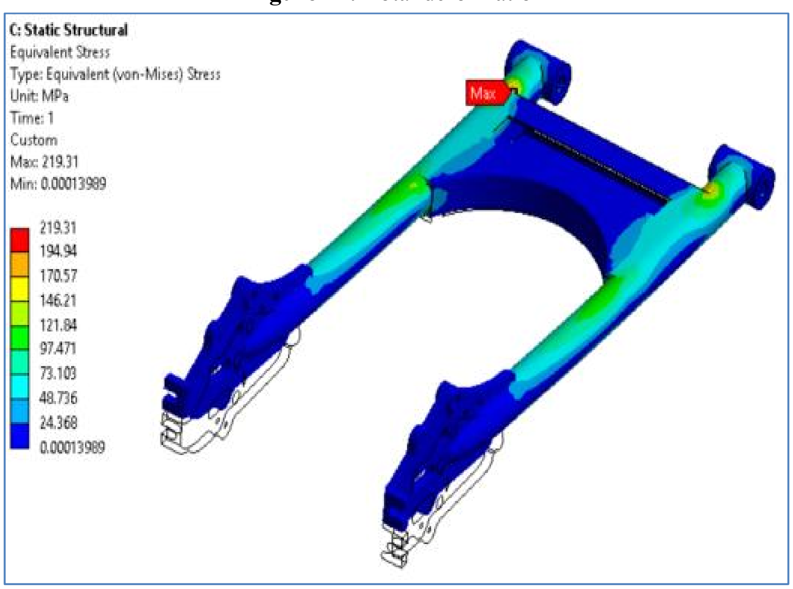


Figure 14: Total deformation



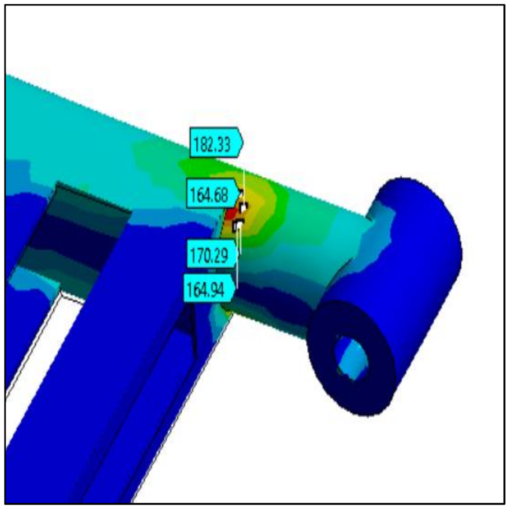
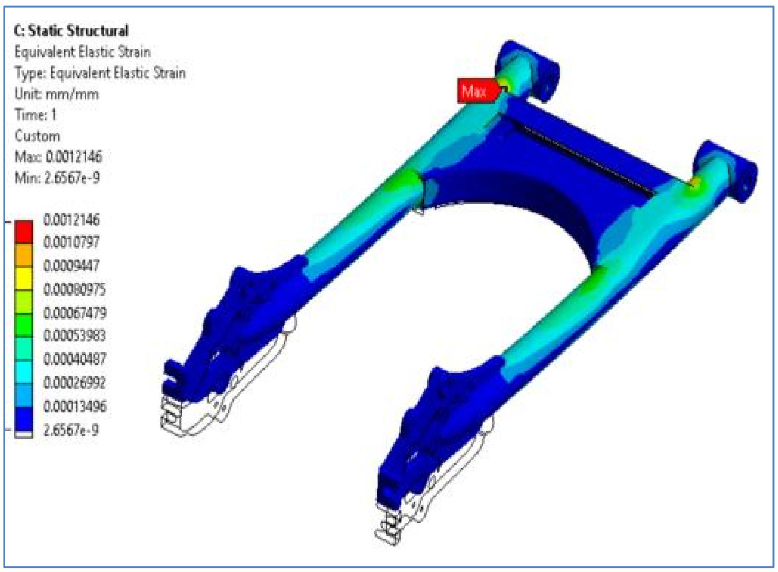


Figure 15: Equivalent stress



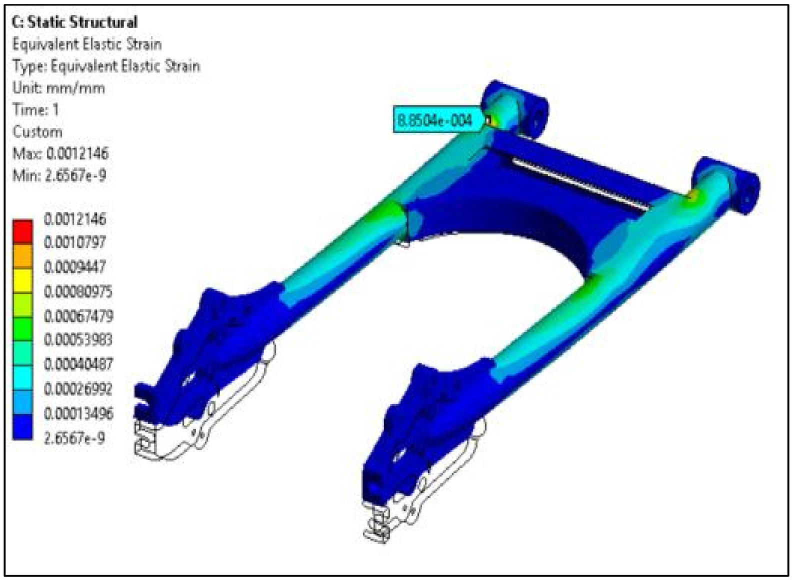


Figure 16: Equivalent elastic strain

VI. Results and Discussion

The present work focused on the finite element analysis of a front double-sided swing arm of the electric motorcycle. To our knowledge, there is no literature regarding front single-sided swing arm analysis, as most of the research is focused on rear swing arms. Loading circumstances change when comparing a front and rear swing arm. One difference is the effect of loads from the motor through the chain on a rear swing arm and on the other hand higher braking forces applied on the front wheel of a motorcycle. The main target is to reduce the weight using the topology optimization process. Through a series of finite element analysis simulations, specific Computer-Aided Engineering (CAE) software is utilized to evaluate the structural integrity of various swing arm designs.. Results of equivalent stresses and displacements were calculated and presented. and presented. Static structural analysis of the Swing arm is performed to determine deformation and equivalent stress. It is observed that around maximum deformation is 3.5 mm and equivalent stress is 232.17 MPa. Safety factor observed is 1.292.An optimized model is obtained from the topology optimization technique. The red region highlights the material-removing area. And redesign the swing arm for optimization.Static structural analysis of optimized Swing arm is performed to determine deformation and equivalent stress. It is observed that around maximum deformation is 3.7 mm and equivalent stress is 219.31 MPa. Safety Factor achieved is 1.367.

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