Design and analysis of light weight swing arm using generative design concept

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Abstract. A Swing arm is a mechanical device that connects the rear wheel of the motorcycle to its body, allowing it to pivot vertically. It holds the rear axle firmly while pivoting to absorb bumps and suspension loads induced by acceleration and braking. Swing arm can be single or double-sided and has appeared in a variety of geometries. The original version consists of a pair of parallel pipes holding the rear axle at one end and pivoting at the other. A shock absorber is mounted just before the rear axle and attached to the frame, below the seat rail. The primary concern is to design a lightweight swing arm that can replace conventional motorcycle swing arm design, which consists of tubular sheet metal structure throughout the swing arm neglecting the stress-induced at various positions along the length of the swing arm, i.e. (from pivots to axle blocks). The vehicle selected for this project is Yamaha FZ-S V2. The material chosen for the swing arm are Al 6061, Al 6061 T6, and Al 7075. This project uses an iterative design method called Generative design to design a lightweight swing arm without compromising the mechanical properties and performance of its counterpart. Analysis of the part will be carried forward using static Analysis comprising various load cases and extreme load conditions. The whole design and analysis process is carried forward using Autodesk Fusion 360. This swing arm design involved economic utilization of material as it reflects the in the analysis through induced stresses.

Keywords: Swing arm, Generative Design, Lightweight, Analysis, and Fusion 360.

1 Introduction

Motorcycles are a popular means of transportation. In the coming hundreds of years, electric vehicles will mostly replace internal combustion engines. Despite the fact that electric vehicles have been in use for a while, their development is slow. Every day, a large number of bikes, both electric and IC Motor vehicles, are produced. To build their safety and prevent mishaps, the plan must be sturdy. In this way, all components of the vehicle should be specifically designed. A swing arm, often known as a swing fork or turned fork, is the most important component of most modern Two-wheeler transportation & ATVs' back suspension. The swing arm will support the cruiser's unusual layout. The swing arm is linked to the rear

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suspension of a motorcycle. The swing arm will take on forces such as cornering power, half-weight of the bicycle, rider weight, vibrations, and other loads at knocks. [7] Most modern motorcycles' back suspension may include a powerful swing arm. It's accustomed to hold the back un-sprung mass immovably in place while turning upward on the casing to allow the suspension to absorb hits from the street.

Hundreds of thousands of pounds pass through the swing arm as you drive and slow down, and it eventually becomes an essential component of the motorcycle. Weight loss is important in a swing arm since it works as un-sprung mass for the most part, and decreased weight directly correlates with enhanced vehicle performance and ride quality.

2 Literature Review

Syed H. Abdullah et.al has published a paper aiming to design a swing arm component for MotoGP standard motorcycle using the Shape Optimisation technique (under multi axial loading scenario). Since weight is a salient factor, Aluminium 7075 T6 is selected as the component material because of its structural rigidity and strength-to-weight ratio. Aluminum 7075 T6 alloy is being used in this research to ease machinability, high durability, and high strength to weight ratio. Aluminum has another great property: during an impact, it distributes the load throughout the component, reducing the deformation, unlike steel. Successful shape optimization of the generic swing arm design was performed by the multi axial structural analysis method. As a result, about 4.2 kg of weight was reduced in the original design while maintaining safety. From the model outcomes, it is flawless that using the shape optimization technique, the weight of the swing arm can be further reduced, resulting in reduced curb weight of the Motorcycle. Since mass is one of the essential criteria in the MotoGP event, as lighter mass vehicles tend to travel faster, hence shape optimization can be helpful to reduce mass up to 15%. For a similar design, strength can be improved using Ti-Al alloy material instead of Al 7075 T6 alloy. [1]

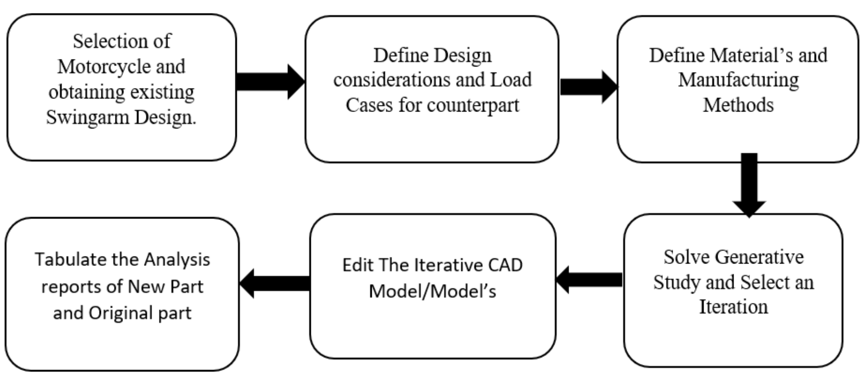
Ashish Powar, Hrishikesh Joshi et.al carried work to optimize a motorcycle swing arm. The CAD modeling of the swingarm was done by using CATIA v5 software. The original swing arm material (AISI 1010) is replaced with Al 7075. Aluminum is used in its place of steel because it can tolerate heavy loads in the form of forces compared to the steel swing arm, with the advantage is a lower density of aluminum than the steel component. The geometry of the swing arm is improved from hollow rectangular to I section. The adjustment process is based on material topological modification and validation using FEA (finite element analysis). They performed FEA analysis on both the original and modified components under various conditions, and the conditions are Weight and acceleration, Weight and braking, cornering condition. Mass of component is reduced without compromising other relevant factors. The weight was 1.8 kg for the modified swing arm, whereas the original swing arm weighed 3.2 kg. The stresses brought are found to be within parameters. The overall weight reduction achieved was 44%. [3]

Atishay Jain describes an Al alloy swing arm as a better material layout and helps achieve weight minimization. The paper explains how to apply concept-based design methodology to an aluminum alloy swing arm design using topology optimization techniques to meet the styling and structural targets and obtain an end-user product. The CAD model is created by keeping the fundamental geometry as non-design space and generating a design space restricted to the design, as mentioned earlier considerations, in which the material layout will be optimized. To evaluate validation designs produced from improved material layouts, he picked a standard design utilized in a comparable bike segment as a baseline design. [8]

K. Satyanarayana studied the static and fatigue stress circumstances behaviour of the swing arm and static simulation results are observed. The study results are drawn from the examination of two distinct materials: AISI 1020 and AL7075. SOLIDWORKS 2017 was used for modelling, and ANSYS 17.0 was used for Analysis. Both AISI 1020 and AL7075 create approximately comparable stresses, namely 44.132 MPa and 45.046 MPa. The safety factor for AISI 1020 is 2.829. However, the AL7075 swing arm has a safety factor of 3.329, which is higher than the AISI 1020 swing arm. In comparison to AISI 1020, which has a deformation of 0.33345 mm, AL7075 has a deformation of 0.0096692 mm in the swing arm. The swing arm is also lighter with Al7075, weighing 3.506 kg versus 9.7981 kg with AISI 1020. Taking the study findings into consideration, it can be stated that Al7075 is the most suitable material when compared with AISI 1020 for the swing arm, with low deflection, stress, weight, and high life and safety factor. [7]

Swathikrishnan S published a paper, His work shows the Analysis of the existing swing arm CAD model's. After a series of iterative geometric modifications and subsequent Analysis, two designs (SA2 and SA3) were kept under consideration. Materials used in SA2 and SA3 are AISI 4340 steel and Aluminium alloy 6061 T6 respectively. In this study the load applications considered where chain pull, extreme loading and stiffness. The results shows that the extreme load application is acting on the swing arm when the bike undergoes a front wheelie and this load condition has the maximum chain pull load also acts simultaneously on the swing arm[4].

3 Methodology



3.1 Design and Analysis of Original Swing Arm

The Motorcycle considered for the design of the new swing arm is Yamaha FZ-S V2. The Vehicle Specification is tabulated below:

Table 1. Vehicle Specification

Max power	14Hp @7500 rpm
Max torque	14Nm @6000 rpm
Transmission	5 speed
Wheel base	1334 mm
Capacity	153cc
Kerb weight	133 kg

The CAD model of swingarm was obtained from open source, and the material of the swing arm is AISI 1010[Cold drawn Carbon Steel]. The material properties are tabulated below:

Table 2. AISI 1010 material properties

Property	**Value**
Yield Strength	350 MPa
Tensile Strength	650MPa
Mass Density	7.870 g/cm^3
Poisons Ratio	0.30
Elastic Modulus	210 MPa

The load cases and boundary conditions are defined after understanding the functional aspects of the swing arm and determining potential loads which act on swing arm assembly. All simulation analysis is conducted in static analysis mode by considering the swing arm pivots to be fixed [rigid].

Load case 1 [Weight and Acceleration]: In this load case, we consider the swing arm is inclined to its original

orientation, and weight distribution to the rear wheel is assumed to be 62 % as we already know that the weight distribution on the rear wheel is considered to range between 58 – 65 %. [3]

The total deadweight is calculated by adding the kerb weight of the Motorcycle [133 Kg] and twice the ideal weight of the driver [2*70 Kg]. Total deadweight [273 Kg], So 62% of total deadweight is 169.26 Kg. This weight acts on a suspension mount with the suspension inclination [60 °].

When converted to force, it translates to 1658.75 N. Force due to acceleration of the vehicle is considered to be calculated using the formula

$$\mathbf{F_a = ma} \qquad \textbf{Eq.(1)}$$

Where, F_a = Force due to acceleration, N

m = Total Dead Weight of Motorcycle, Kg

a = Acceleration of Motorcycle, m/s^2

In this case, acceleration of the Motorcycle was determined by testing the bike to attain the speed from 0-60 Km/Hr and time taken to attain 60 Km/Hr was recorded, and results were recorded. Using the recorded data, the Acceleration of the Motorcycle was calculated to be 2.32 m/s2.

$$\textbf{Therefore,} \quad \mathbf{F_a = 273*2.32 = 633.36\ N}$$

This F_a [force, due to acceleration], acts longitudinally regarding swing arm orientation [3].

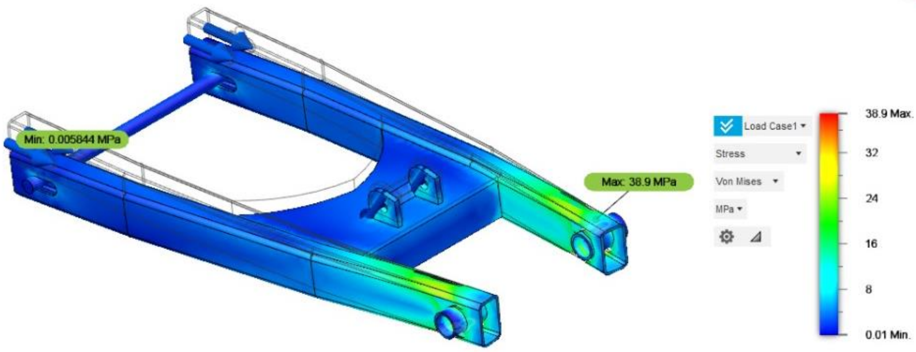


Fig. 1. Original part load case 1(weight and acceleration)

For this Load case condition, the corresponding stress created in the original side beam was 37.66 MPa. The stress is significantly well under the yield strength value of the material. The minimum factor of safety is 9.153. Moreover, the maximum displacement is 0.3404 mm.
Load Case 2 [Cornering]: Cornering is the load condition under which a motorcycle has to maintain its stability, contact with the road without slipping at a specified lean angle. As the lean angle reduces with respect to horizontal, the tire contact area reduces with road/ground.

Swing arm has to be rigid enough to endure these cornering loads. In the cornering load case, the force distributed on either side axle blocks of the swing arm is assumed to be 70% of total deadweight on the inner axle block and 30% of total dead weight on the outer axle block. The lean angle is assumed to be 40° to horizontal [3]

Right Cornering: In the proper cornering, 70% of total deadweight acts on the right axle block, and 30% of total deadweight acts on the left axle block at a lean angle of 40°.

Therefore F_{rr} **[Force on right Axle Block] = 273*0.7*9.8 = 2675.4 N** **Eq.(2)**

F_{rl} **[Force on left axle block] = 273*0.3*9.8 = 802.62 N** **Eq.(3)**

We are considering cornering right with a lean angle of 40 degrees. The maximum stress observed in this simulation is 120.6 MPa, and the factor of safety is 2.852.

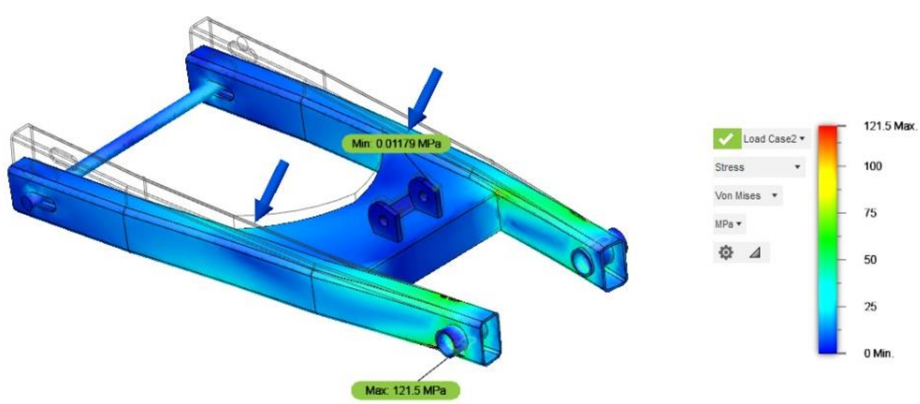


Fig. 2. Original part load case 2(right cornering)

Left Cornering: In Left Cornering, 70% of total deadweight acts on the left axle block, and 30% of total deadweight acts on the right axle block at a lean angle of 40°.

F_{lr} [Force on right axle block] = 273*0.3*9.8 = 802.62 N **Eq.(4)**

F_{ll} [Force on left axle block] = 273*0.7*9.8 = 2675.4 N **Eq.(5)**

We are considering cornering the left with a lean angle of 40 degrees. The Maximum stress observed in this simulation is 117.8 MPa, and the factor of safety is 2.926.

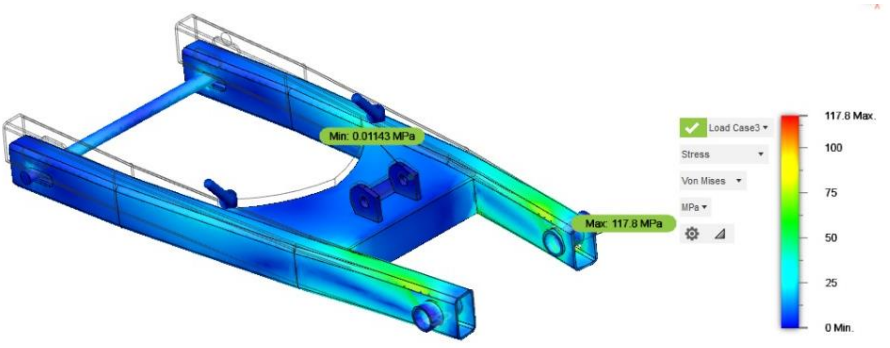


Fig. 3. Original part load case 2(left cornering)

Load Case 3[Extreme Load Case]: This extreme load case is also called wheelie condition. In this load case, the forces which act on the swing arm are the combination of total deadweight, force due to acceleration, and Chain pull force.

To calculate chain pull force, first, we need to calculate the maximum torque at the wheel and the pitch circle distance of the sprocket wheel.

F_p [chain pull force] = 2000*M/d **Eq.(6)**

Here M [Torque at rear wheel] is calculated to be 37.996 Nm

d [Pitch circle diameter of sprocket] is calculated to be 165.69 mm

Now,

F_p = 458.63 N

Now,

F_e [extreme load force] =

Total Dead Weight + Chain Pull force + force due to acceleration
Eq.(7)

Fe = 2675.4 N

This Extreme Force is transferred to the swing arm via the rear Axle rod to Axle blocks [4]. The simulation study showed maximum stress of 255 MPa and a maximum displacement of 3.387mm. The minimum FOS was found to be 1.352.

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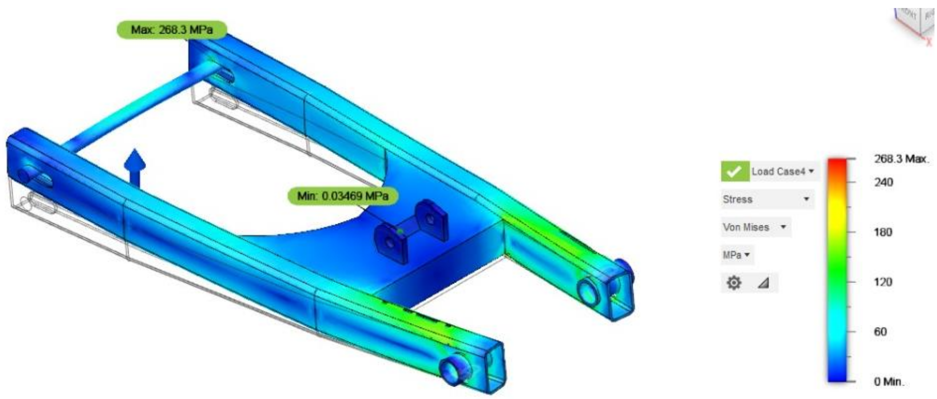

Fig. 4. Original part load case 3(extreme)

3.2 Design and Analysis of Counterpart

The new swing arm [counterpart] is designed using a Generative design workspace provided by Autodesk Fusion 360 that is powered by means of artificial intelligence (AI) and the computing influence of the cloud. Autodesk generative design technology allows us to simultaneously create numerous CAD-ready solutions built on real-world manufacturing constraints and product performance necessities. Thanks to low-cost, high-performance calculating power offered by the cloud and logical design algorithms driven by machine learning abilities, a new variety of generative design software have emerged that will offer a step-change in computer-aided engineering (CAE). The connection of software abilities, high-speed computers, considerations about manufacturing skills, and the capacity to engineer innovative materials will modernize engineering and product improvement in the future.

Generative design, however, drives much advance in comparison to topology optimization. Generative technology can take numerous specific objectives input by a designer or engineer, such as size, weight, strength, style, materials, cost, schedule, manufacturability, and service algorithms running in the cloud to generate many potential design results. The intelligent design software, which incorporates machine learning and advanced modeling, can quickly cycle through hundreds of millions of design alternatives and test configurations to generate options that would be impossible for designers and engineers to identify and model successfully.

The forthcoming vision of these systems and the incorporation of artificial intelligence holds unbelievable potential, but there is the hazard of overblown anticipations. It would be challenging to generate an algorithm that enables a generative design system to judge a designer's aesthetic thoughtfulness. That is a complex difficulty to try to analyze and have a computer support with. Right now, it is decent at weighing ten design variables beside each other and that is more than a human brain can embrace. However, it is still initial days for this technology.

Design of counterpart: The Initial Design of the new swing arm [counterpart] is carried out by sketching the preserve regions of the swing arm.

The preserve regions identified in the design of swing arm are:

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- Right Pivot
- Left Pivot
- Suspension Mount
- Right Axle Block
- Left Axle Block

The right and left pivots are hollow cylindrical bodies used to assemble swing arm with the engine block or frame of the Motorcycle, depending on the motorcycle companies. Suspension mount is the preserve region where mono-shock suspension is assembled to the swing arm. Right, and Left axle blocks are used to mount the swing arm to the rear wheel. These preserve regions must be present in the final CAD model of the new swing arm. [12]

Obstacle regions are sketched to identify the regions where potentially the Swing arm material should not form as that region has to be dedicated to other geometries of the Motorcycle. [8]

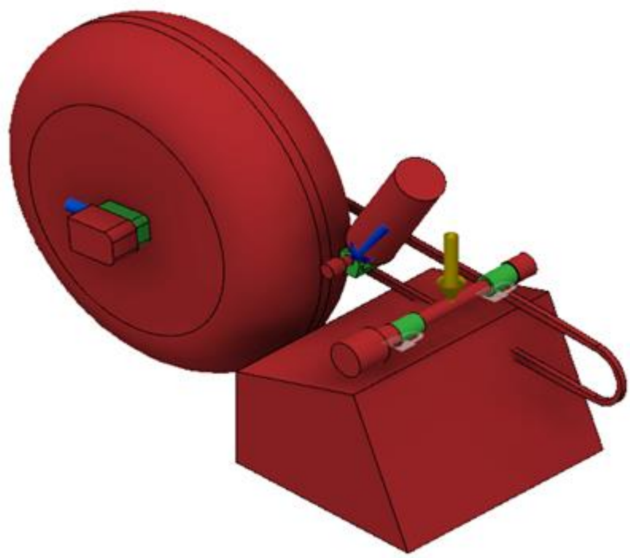

Fig. 5. Preserve Regions and Obstacle Regions

The Obstacle Regions identified in the design of the swingarm are:

- Rear Wheel
- Rear Tyre
- Rear Axle Stud
- Mono-Shock Suspension
- Rear Braking System
- Sprocket and Chain Assembly
- Tool Clearance

All these parts mentioned above are significant obstacle regions as they have their particular functional activities to be performed in the Rear wheel assembly region. Hence swing arm material formation should not occur in those regions; also, tool clearances for that part assembles need to be considered as the tools must pass through the available spaces on any part damage inspection or part replacement.

Chain Moving volume will also be considered as an obstacle region as the path followed by the moving chain may vary with speed and also with time as the chain gets loose, and its path should not be obstructed by any motorcycle part or assembly [12].

Loads and Constraints: The load cases and boundary conditions are defined after understanding the functional aspects of the swing arm and determining potential loads which act on swing arm assembly. All simulation analysis is conducted in static analysis mode by considering the swingarm pivots to be fixed [rigid].However the load conditions and value of load remain same as for original part model.

Material Selection: Aluminum is 10% to 40% lighter than steel, depending on the product, yet its malleability allows engineers to design and produce optimized forms for optimal performance. Aluminum-component automobiles are roughly 24% lighter than steel-component automobiles and save around 0.7 gallons per 100 miles, equating to a 15% reduction in fuel consumption. These vehicles also offer superior acceleration, braking, and handling due to the stiffness of aluminium components, giving the driver rapid and accurate control. Aluminium is selected for the swing arm due to the following reasons: Low Weight without compromising specific mechanical properties.

Al 7075 is an Al alloy that has zinc as the primary alloying element. It possesses good ductility, high strength, toughness, and fatigue resistance, among other mechanical characteristics. Due to micro-segregation, it is more vulnerable to embrittlement than many other aluminium alloys, although it has much higher corrosion resistance[1].

Al 6061 is a precipitation-hardened aluminium alloy with the main alloying constitutes magnesium and silicon. It offers exceptional corrosion resistance and weldability, but has a lower strength in the weld zone. It has high cold formability and mild fatigue strength. It is individual of the utmost broadly used aluminium alloys for general-purpose applications.

Al 6061 T6 is one of the most widely used in the world. The T6 refers to the hardness or temper that is obtained by precipitation hardening. This grade is heat-treatable and has an excellent strength-to-weight ratio. It is utilized in engineering and structural applications due to its high formability and weld ability[4].

Manufacturing Methods: Considering the main aim of the new swing arm design is to reduce weight [mass Reduction], the manufacturing methods were selected during the setup of generative study in order to obtain the solved iterations of swing arm[12].

The manufacturing methods selected are:

- Unrestricted
- Additive Manufacturing
- Milling

In the Unrestricted Manufacturing method, the manufacturing constraints do not limit the shape generation of Part/Body. Hence we can explore different shapes and dimensions of Generative solutions.

In the Additive Manufacturing method, we need to specify the orientation of the part, Maximum overhang angle and Minimum thickness desired. Satisfying these conditions, AI generates possible generative outcomes.

We need to specify milling configuration [three axes, four axes, and five axes], Tool direction, Minimum tool diameter, Tool Shoulder Length, Head Diameter. According to these specifications, Generative design provides possible outcomes.

After setting up the generative study and obtaining results, we filter the required outcome using parameters such as mass range, Min FOS, Max Displacement, Max Stress. Visually by Aesthetics, Symmetry, etc. After comparing the obtained results, final iterations are selected.

Design Refinement and Simulation: After selecting the final iteration, we import the CAD model of the final iteration and edit the CAD model wherever potential issues arise, unwanted material has to be removed near preserve regions, Unnecessary Holes have to be repaired and filled, Smoothen the surface wherever required, repair the overlap of mesh.

After the CAD model is considered acceptable, the CAD model is again simulated using the specific load cases, and potential errors of design are observed, and again design is refined by observing simulation results. This process continues until we obtain the required results. After the design is considered to be satisfactory in terms of simulation results, the final simulation results are Tabulated and compared with the original swing arm.

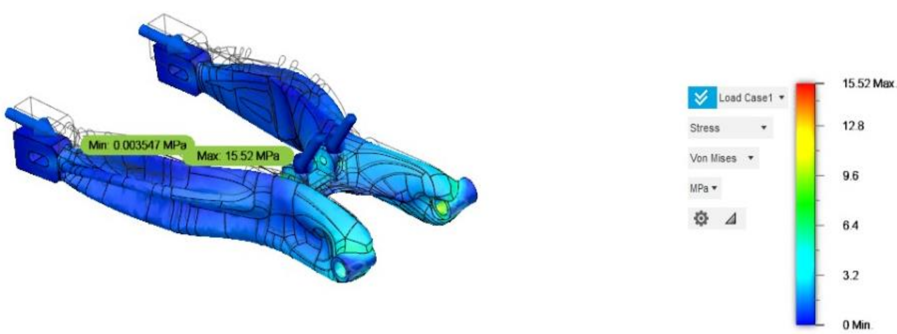

Fig 6. Counterpart load case 1(weight and acceleration)

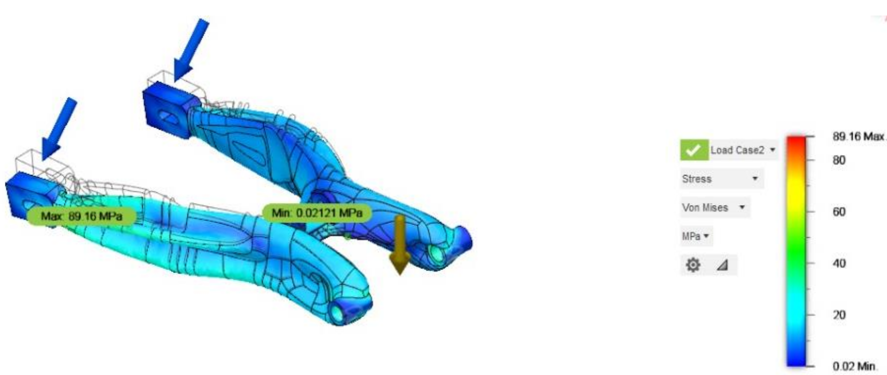

Fig. 7. Counterpart load case 2 (Right Cornering)

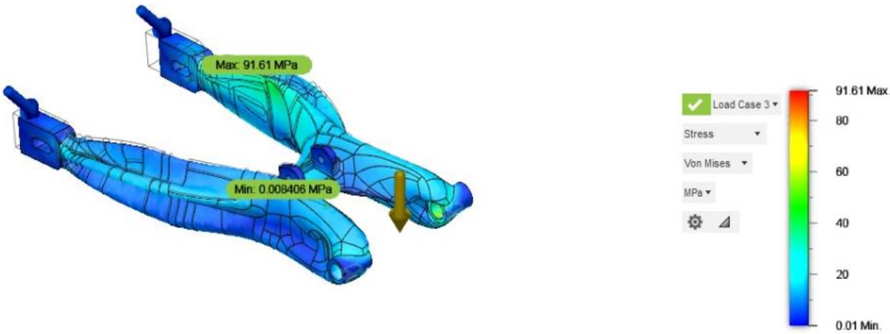

Fig. 8. Counterpart load case 2 (Left Cornering)

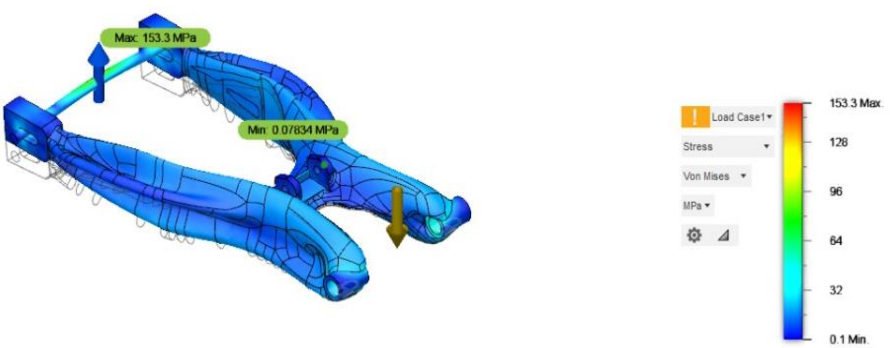

Fig. 9. Counter Part Load case 3(extreme)

4 Results And Justification

The following results are tabulated after studying the various load case analysis reports considered during static simulation of the original swingarm and counter swingarm.

Table 3. Simulation Results

S. No	Material	Maximum Displacement (mm)	Maximum Stress (MPa)	FOS	Weight (Kg)
1	AISI 1010 (Original Part)	3.332	268.3	1.285	12.005
2	Al 6061 (Counter Part)	1.288	153.4	1.350	7.575 (36.91%)
3	Al 6061 T6 (Counter Part)	2.247	150.0	1.380	7.575 (36.91%)
4	Al 7075 (Counter Part)	1.287	153.3	1.351	7.884 (34.32%)

- The factor of safety (higher FOS is desirable) of the counterpart has the least value of 1.350 for Al 6061 and the highest value of 1.380 for Al 6061 T6 as this variety has undergone precipitation hardening, Hence it has increased yield and tensile strength .

- The maximum displacement (low displacement is desirable) of the counterpart has the least value of 1.287 mm for Al 7075 and the highest value of 2.247 mm for Al 6061 T6. The density of Al 7075 is slightly higher when compared to Al 6061 T6.
- The maximum stress (low stress is desirable) on the counterpart has the least value of 150.0 MPa for Al 6061 T6 as it has relatively higher yield and tensile strength and the highest value of 153.4 MPa for Al 6061.
- The weight (lower weight is desirable) of the counterpart has the least value of 7.575 Kg for Al 6061 & Al 6061 T6 and the highest value of 7.884 Kg for Al 7075. Here the density of Al 6061 is low when compared to Al 7075.

5 Justification

Aluminum is the ideal light-weighting material. At 2,700 kg/m^3, the density of aluminium is one third of that of steel. But attaining such a weight reduction is rare since, for a large number of parts, it is necessary to increase the average thickness of aluminum compared to steel to achieve the same part characteristics.

However, the relationship between the material properties and the strength, stiffness and weight of a component is very complex and can be strongly influenced by the part geometry. Al 6061 T6 provides better formability, weldability and is corrosive resistant. All these properties pile up to justify the conclusions obtained in this project.

6 Conclusions

- The weight of the swing arm is reduced from 12.005 kg to 7.575 kg, as mentioned in table 7.
- The weight reduction achieved varied within the range of 34.32 to 36.91% by using Al 6061, Al 6061 T6, Al 7075 materials.
- It is also observed that Al 6061 T6 is the best suitable material for the newly designed CAD model of the swing arm for considered Motorcycle (Yamaha FZ-S V2) as it has higher FOS, i.e., 1.380 and lower maximum stress being 150.0 MPa in comparison when Al 6061 and Al 7075.
- Finally, it is concluded that Al 6061 T6 is an optimally suitable material with low maximum stress and high FOS for our newly designed swing arm for Yamaha FZ-S V2.
- This swing arm design involved economic utilization of material as it reflects the in the analysis through which induced stresses are minimized.

7 Future Scope

However, further study may be required to explore manufacturing feasibility. The future scope of swing arm design is correlated to the advancements achieved in vehicle configuration and performance; as the vehicle performance improves, the problems in the current design become more clear during Analysis, solutions can be predicted, which lead to further development in the swing arm part design. The Generative design technology provides scope for remarkable advancements in the design and development of components for the future of vehicles to make them lighter and more efficient.

The growth in the design technology and manufacturing advancements such as Additive Manufacturing allows the changes in the methodology of vehicle development completely, which were fundamentally impossible to imagine with the design practices and ways of the present manufacturing methods and take the outcomes to unexpected levels.

8 Acknowledgements

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References

1. Abdullah, S. H., Ahmed, M., & Rahman, W. A. (2018). Design of racing motorcycle swing-arm with shape optimisation. Int. J. Sci. Res. & Dev, 6, 179-183..
2. Krawczuk, M., & Palacz, M. (2021). Special Issue “Applications of Finite Element Modeling for Mechanical and Mechatronic Systems”., 5170.
3. Powar, A., Joshi, H., Khuley, S., & Yesane, D. P. (2016). Analysis and topological optimization of motorcycle swing-arm. Int. J. Curr. Eng. Technol, 270-274.
4. Swathikrishnan, S., Singanapalli, P., & Prakash, A. S. (2019). Design and analysis of swingarm for performance electric motorcycle. International Journal of Innovative Technology and Exploring Engineering (IJITEE), ISSN, 2278-3075.
5. Pabón Villamizar, D., & Roa Prada, S. (2019, November). Computer Aided Methodology for the Optimization of an Electric Motorcycle Suspension. In ASME International Mechanical Engineering Congress and Exposition (Vol. 59414, p. V004T05A028). American Society of Mechanical Engineers.
6. da Cal Ramos, J. D. (2016). Front and Rear Swing Arm Design of an Electric Racing Motorcycle.
7. Satyanarayana, K., Narendra, M., Pavan Sai, E., Harsha Sri, B. G., & Rao, M. (2020). Modelling and analysis of double sided monoshock swing-arm. J. Compos. Theory.
8. Jain, A. (2015). Design of an Aluminum Alloy Swingarm and its Weight minimization using Topology Optimization (No. 2015-01-1356). SAE Technical Paper.
9. Spanoudakis, P., Christenas, E., & Tsourveloudis, N. C. (2020). Design and structural analysis of a front single-sided swingarm for an electric three-wheel motorcycle. Applied Sciences, 10(17), 6063.
10. https://en.wikipedia.org/wiki/Swingarm
11. Swingarm Design by Jeffrey Diamond (Cantilever)
12. Auto Desk Fusion 360 Generative Design Workbench