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DESIGN AND OPTIMIZATION OF HIGH-PERFORMANCE MOTORCYCLE SWINGARM

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Abstract: - Grand Prix Motorcycle Racing (MotoGP) refers to the sport class of motorcycle used in motorcycle racing events under governing body of FIM (Fédération Internationale de Motocyclisme). Motorcycles having power of 260 bhp and that can go up to 355 kmph are used in this event. During high speed-cornering, the motorcycle is subjected to extreme loads; hence every component of motorcycle must be designed precisely and analysed in order to endure the extreme loading conditions. A swingarm allows connecting the rear wheel with the chassis which gives more space for rear suspension and while pivoting vertically, it absorbs bumps coming on the road. The focus of this research is to redesign a swingarm for MotoGP standard motorcycle by application of multiaxial forces and using manual Shape Optimization technique to reduce overall weight of the motorcycle. Since weight is the factor of consideration, Aluminium 7075 T6 material is selected for the swingarm as its structural rigidity and strength to weight ratio is most ideal for application. Structural analysis using ANSYS is performed on the model, to find stress concentration for applied loads. Aim is to achieve good strength to weight ratio.

Keywords: *Swingarm, Racing Motorcycle, Shape Optimization, Multiaxial Loads, Suspension, Strength, Weight*

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I INTRODUCTION

Grand Prix Motorcycle Racing is a sophisticated moto racing event held on racing circuits and approved by Fédération 'Internationale de Motocyclism'. GP motorcycles are special built machines that are generally unavailable for legally riding on public roads.1 These super motorcycles experiences extreme loads under powered-cornering, braking and acceleration; hence all component of these machine is meticulously designed to improve safety and performance of the machine. This research study is specifically focused on swingarm component of the motorcycle.

The swingarm should be strong enough to handle typical loads experienced in the field and stiff enough to increase the response and stability of the motorcycle. The weight of the swingarm should also be reduced to improve motorcycle performance and increase the road holding of the rear wheel. Most motorcycles use materials such as steel, aluminium and magnesium in their swingarm design.

1.1Swingarm

A swingarm is the most important component of the rear suspension of all modern racing or modified motorcycle. Its function is to connect the rear wheel with the chassis and also to allow for the space of the rear suspension, while pivoting vertically, to allow the suspension to absorb bumps in the road.1 Today we have swingarms of two main types: a traditional two arm and a single arm. Traditional swingarm is usually a symmetric structure, with a two parallel beams/pipes connecting the rear axle at one end and pivoting at the other end. The swingarm should be strong enough to handle typical loads experienced in the field and the torsional stiffness is enough to increase the response and stability of the motorcycle (B Smith, et al, 2015). The weight of the swingarm should also be reduced to improve motorcycle performance and increase ground contact of rear wheel. Most of the motorcycle are equipped with the swingarm design made of steel, aluminium and magnesium alloy.

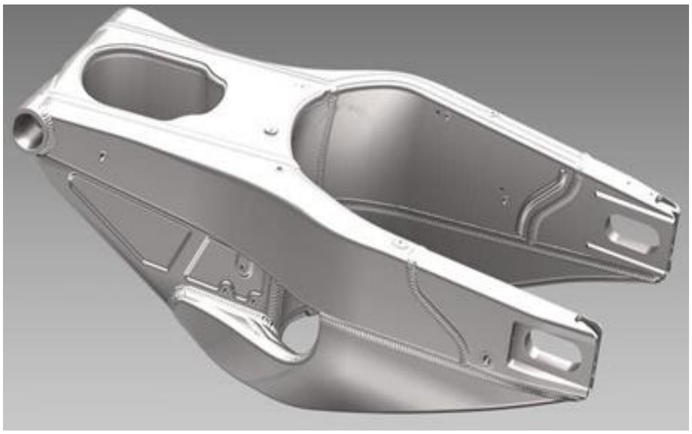
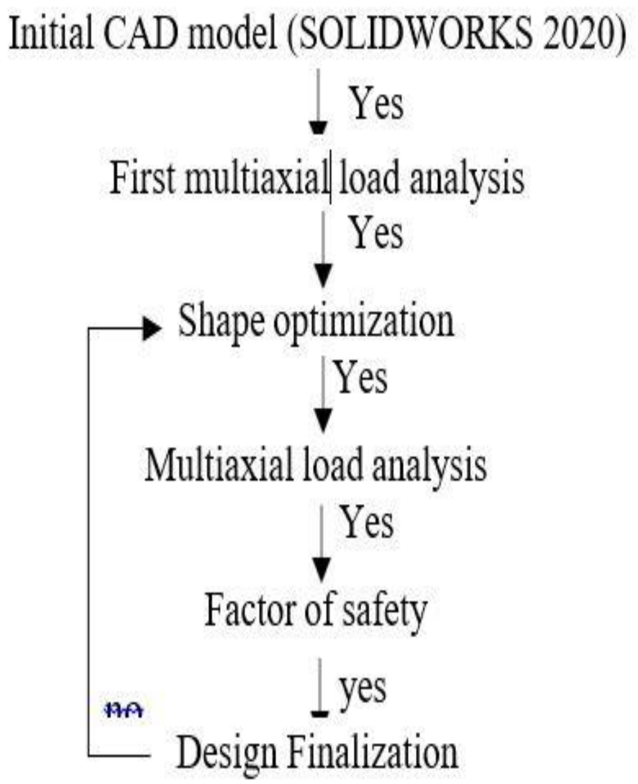


Figure 1. Swingarm Design of Honda RC213V

II METHODOLOGY

After studying the geometry and shape of existing part it is clear that a swingarm requires great structural strength along with good stiffness and more importantly the torsion moment. The structural rigidity and stiffness of the component is analysed by application of well-defined multiaxial loads using ANSYS 2020 software. Design constraints like shape and thickness of the component is changed untilsatisfactory results are not acquired. Stress Distribution on overall body is observed and multi-objective approach is followed. The solution that is considered ideal for the application is to have less weight and maximum torsional stiffness for the defined weight and stress values. The development and optimization process involves multiple design iterations and studying the result after application of same multiaxial loads over each iteration of model. This optimization and analysis process is continued until the targeted values are achieved for FOS and maximum displacement.



III.CALCULATIONS

Material Selection

Material of any individual structural component has a significant role in its performance characteristics. Performance characteristics for a motorcycle can be improved by utilizing a light material with high yield strength, rather than by altering the geometry in the design. Aluminium 7075 T6 alloy is being used in this particular study as it provides ease of machinability, high durability and high strength to weight ratio. Another great property of Al 7075 T6 is to transfer and distribute load during an impact.

Table 1. Mechanical Properties of Aluminium 7075 T6

Parameters	**Specification**
Density	2.81 g/cc
Ultimate Tensile Strength	572 MPa
Tensile Yield Strength	503 MPa
Modulus of Elasticity	71.7 GPa
Poisson's Ratio	0.33

Considered Parameters

Honda RC213V is selected as our primal motorcycle choice, as it is most popular motorcycle inMotoGP industry with one of the finest engines and maximum wins with riders of different attitude.

Table 4.1 Honda RC213V specifications

Parameters	**Specifications**
Kerb Weight	157 kg
Dimensions	L: 1.8m, W: 0.65m. H: 1.1m
Ground Clearance	1.1 m
Wheelbase	1.43m
Power	185 KW
Top Speed	355 Kmph

Multiaxial Loading

The loads on the swingarm are majorly result of high-speed manoeuvring. These loads are generated at the point of contact of the tire and road surface and acted on the connection points between tire and swingarm. The loading scenarios that are considered in this research study are cornering and braking. Foale (2002) suggested that centre of gravity of the motorcycle varies according to different loading scenarios subjected to manoeuvring, speed of the motorcycle. Mass transfer occurs from rear to front during braking; as inertia force acts at the centre of gravity. The loads acting on the rear wheel is given by the equation.

$$F_R = \frac{½*m*g*a_2}{L} - \frac{½*m*g*h*a}{\frac{L}{g}} \quad (1)$$

Here,

m = mass of the vehicle

g = acceleration due to gravity

a = acceleration of the vehicle (0.5g)

L = Wheelbase

h = C.G. Height

$a2$= longitudinal distance between C.G. and Rear wheel centre

The centre of gravity during braking will change significantly, the height will decrease by 12 to 15 % while the length will decrease by 20 to 25%.

At high-speed cornering conditions, motorcycle leans in and takes turn of particular radius of curve with respect to the centre, this results in shift of centre of gravity in lateral direction. The loading of swingarm is given by the equation:

$$m*g*L'+C.G._{height}*m*a= F_T*L' \quad (2)$$

During Cornering, both centripetal and centrifugal forces act on the motorcycle and since they are equal in magnitude, they will balance each other. But this balancing will not assure that there will be no load on the swing arm, hence a load WC will cat in the inward direction, given by the equation:

$$F_c=m*v^2r \quad (3)$$

Here

The shift in centre of gravity in the lateral direction is taken as 1.1 m, which is same as the height of the motorcycle, and the shift in height is 50% if the static value. (Syed Hassaan Abdullah, Mohd Ahmed, Wajahath Abdul Rahman, 2018).

IV .FINITE ELEMENT ANALYSIS

Swingarm failure occurs solely due to application of multiaxial load on connection point, during long service of the vehicle, thus, it's important to locate failure regions for better design optimizations. Ansys 20200 is used to carry out the structural analysis of the steering knuckle, as it provides information with stress concentration regions on applications of loads and variation of the materials.

4.1Load Applications

Three distinguishable forces act on the swingarm due to, braking and cornering. A new swingarm design was developed using geometry of existing structure and first analysis was conducted on models developed. The loading of the component is described in figure 3.

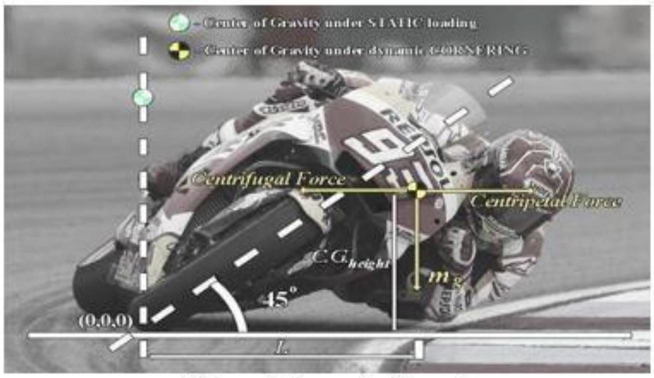


Figure 2. Cornering Scenario

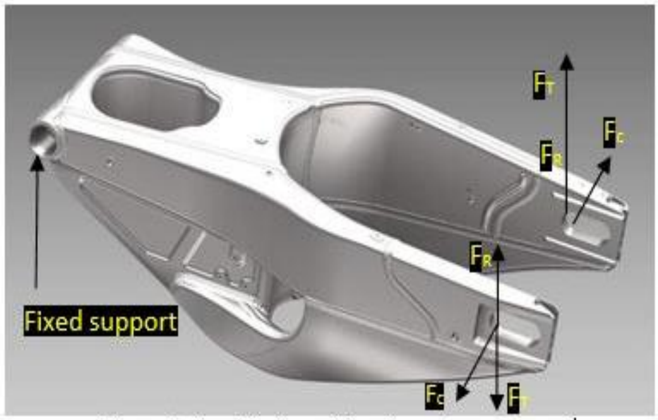


Figure 3. Application of loads on the swingarm

As while riding bike is inclined to particular angle. This angle is considered to be θ, hence the forces due to braking and cornering will change.

From equations (1) and (2) we get,

FT = FT $*cos(\theta)$ (4)

FR = FR $*cos(\theta)$ (5)

Where, the inclination θ is considered as 45∘ and the vehicle is said to take turn of 40m radius at velocity of 27.75 m/s, hence from equations (3), (4) and (5) we get the forces as:

Fc = 3.099kN FT = 2.94kN FR = 0.616 kN

V.FIRST ITERATION

The design for first iteration was based on the geometry of Yamaha R1M MotoGP bike. The design was developed in SOLIDWORKS 2020 and the meshing and analysis was done in ANSYS 2020. The load on the model were applied as describes in loading diagram while the bolting with chassis was assigned as fixed support. Weight of this iteration was 6.98 kg.

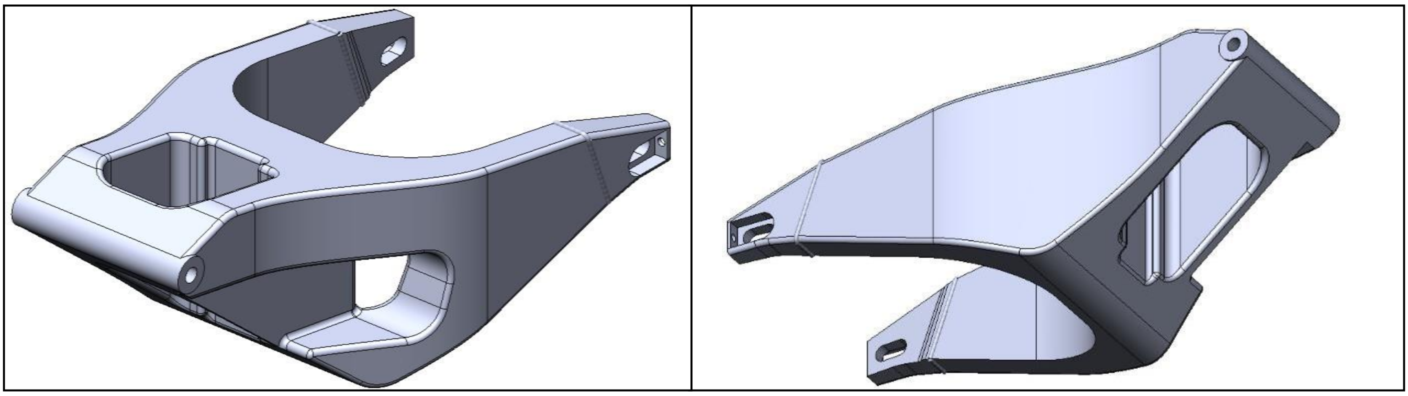


Figure 4. First design iteration

Result

The first iteration weight was 6.98 kg. Structural analysis performed showed that the maximum stress in the model was 151.24 MPa and the maximum displacement of 2.9 mm as shown in figure 5 and figure 6. Thus, iteration one was over design and it was possible to reduce the weight.

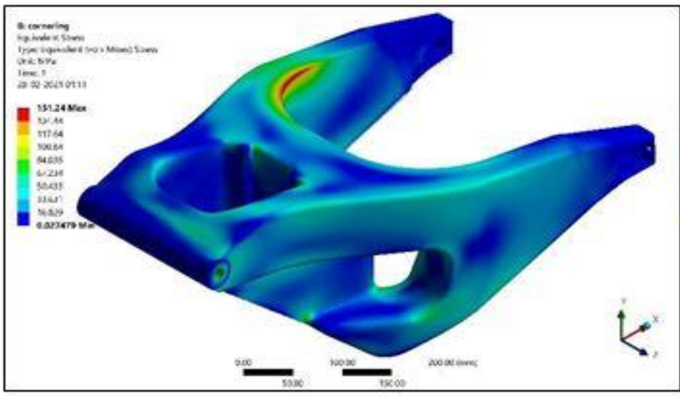


Figure 5. Max Stress in first iteration

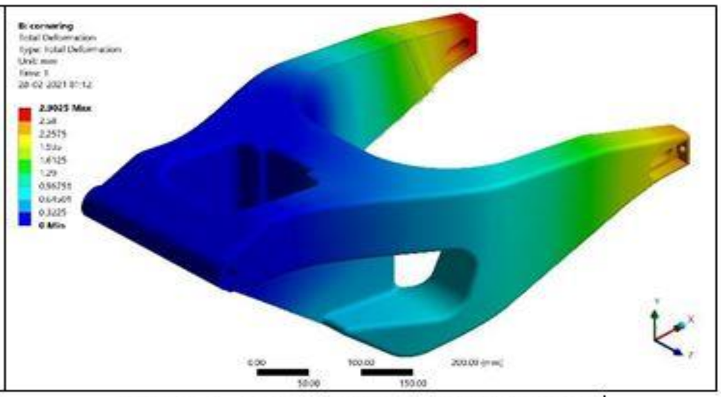
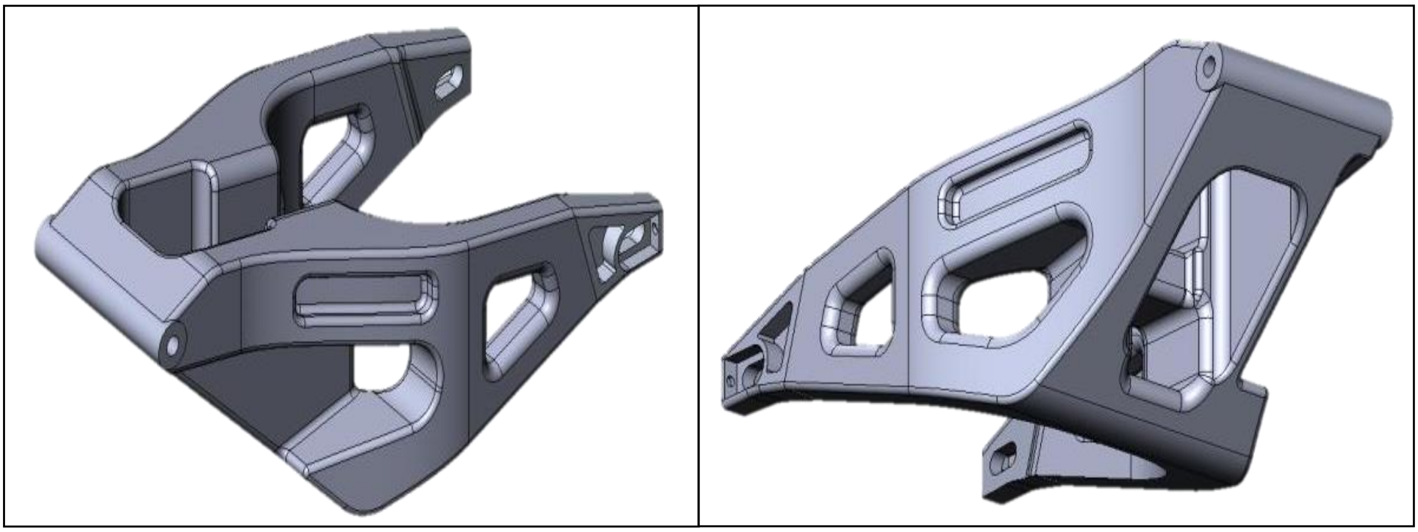


Figure 6. Deformation in first iteration

VI SECOND ITERATION

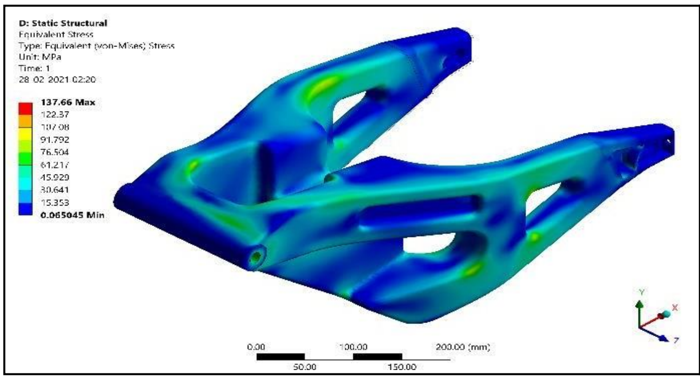
After studying the results from first iteration, shape of the swing arm design was modified inSOLIDWORKS and the new iteration i.e., the second iteration was meshed and analysed in ANSYS

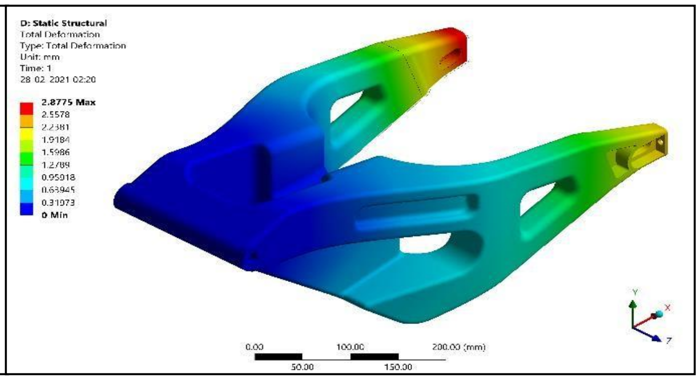


.Figure 7. Second iteration design

Result

After shape optimization the weight of second iteration was 6.1 kg. So, the reduction in the weight was 11.59%. Same structural analysis was performed on this model and the maximum stress was 137.66 MPa and the maximum displacement was 2.8 mm. Thus, comparing the with first iteration the max stress value in this iteration was lower and so was the max displacement value. This made us clear the manual shape optimisation was correct and now the goal was set to reduce weight keeping FOS of between 1.5 to 2.0





. Figure 8. Max Stress in second iteration

Figure 9. Deformation in second iteration

VII THIRD ITERATION

Further optimization was needed in the second iteration. Thus, the third iteration was developed after manual shape optimisation of the part. Weight of this iteration was 4.1 kg, and same multiaxialload analysis was performed on the new model. For model refer figure 10

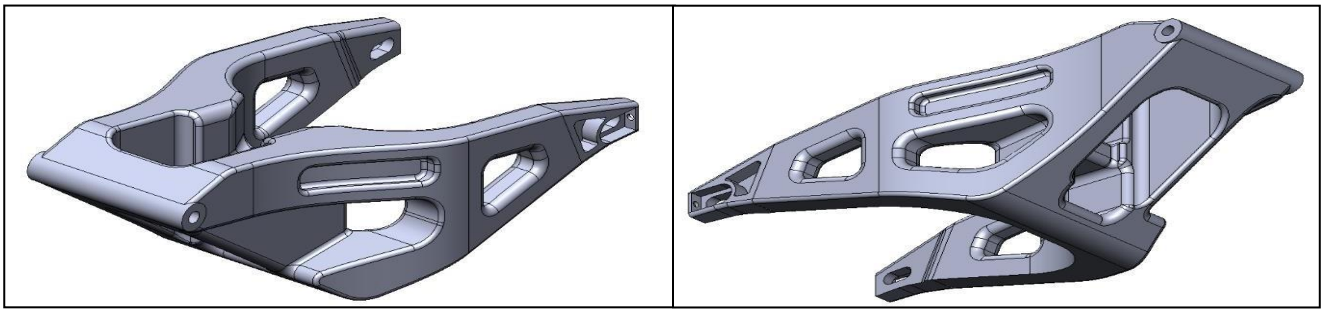
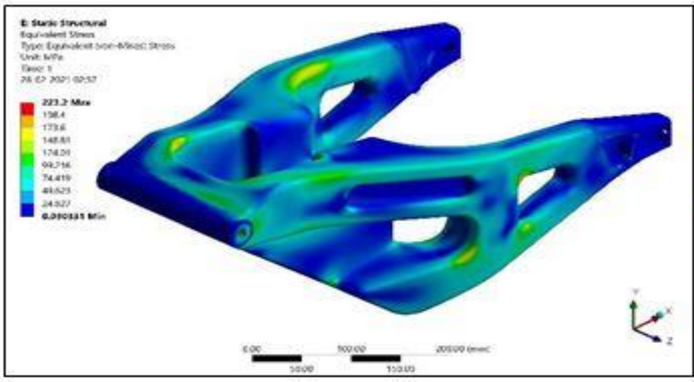


Figure 10. Third iteration design

Results

After shape optimization the weight of third iteration was 4.1 kg. So, the reduction in the weight was 32.78%. Same structural analysis was performed on this model and the maximum stress was 223.2 MPa and the maximum displacement was 5.44 mm. The calculated FOS was 2.5.



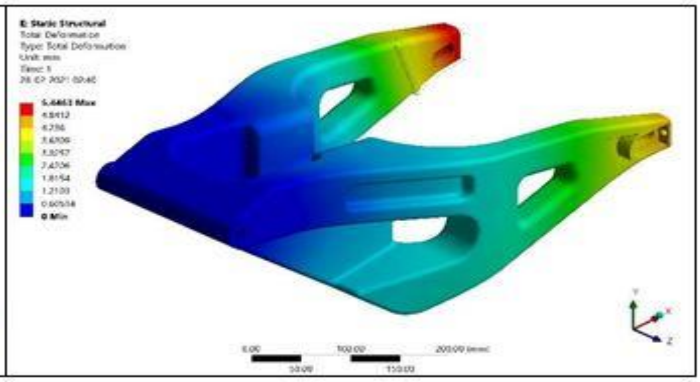


Figure 11. Max Stress in third iteration

Figure 12. Deformation in third iteration

Thus, comparing with second iteration the maximum stress value was higher and max displacement was also much higher. The max displacement value is important to achieve as it in in account to stiffness and directly affects the handling and performance of the bike. Now for the next iteration goal was set to reduce weight keeping FOS of between 1.5 to 2.0 and achieve max displacement of in the range of 6 mm to 9 mm.

VIII FOURTH ITERATION

A new model was developed after studying the results of third iteration. The aim while developing fourth iteration was to achieve max stress and max displacement values in desired range. The weight ofthis iteration was 3.38 kg. and the same multiaxial load analysis was performed

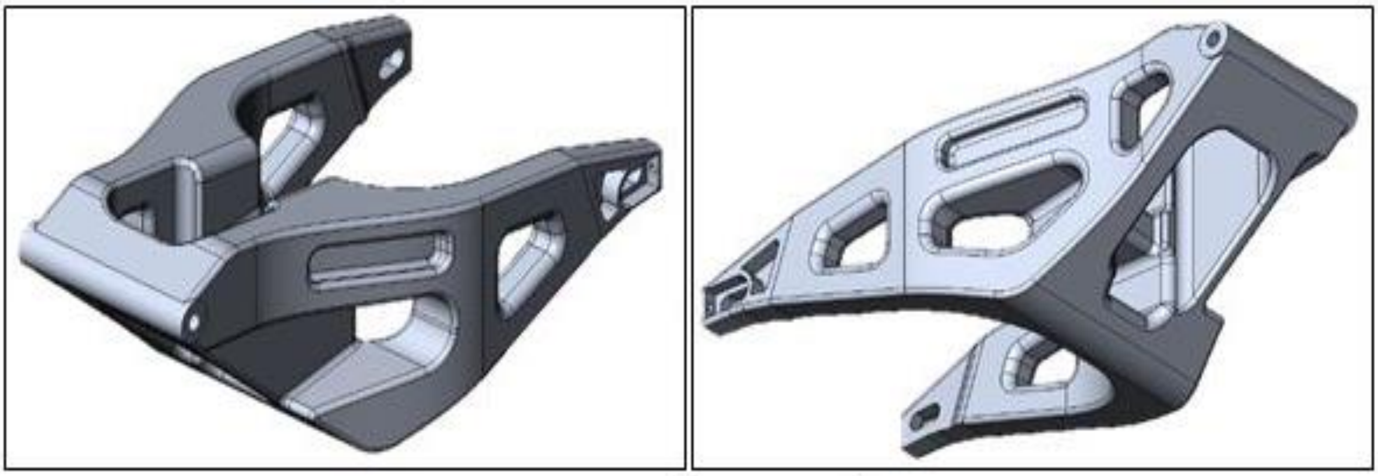


Figure 13. Fourth iteration design

8.1 Result

After shape optimization the weight of fourth iteration was 3.38 kg. So, the reduction in the weight with respect to third iteration was 17.56%. The results of multiaxial load analysis performed on this model were; the maximum stress value was 311.26 MPa and the maximum displacement was 8.18 mm. The calculated FOS was 1.83. Thus, the target was achieved i.e., to reduce weight keeping FOS of between 1.5 to 2.0 and achieve max displacement of in the range of 6 mm to 9 mm. So, the fourth iteration is considered as final iteration. Refer figure 14 and figure 15.

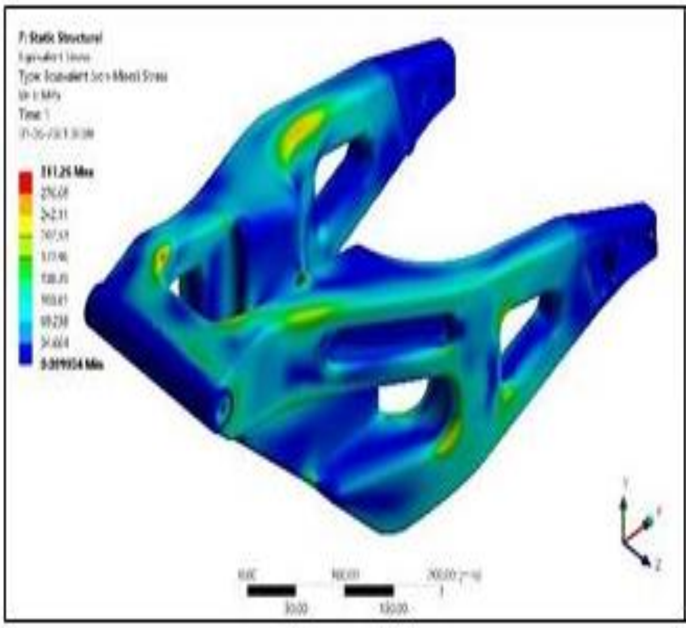


Fig.14 Max Stress in fourth iteration

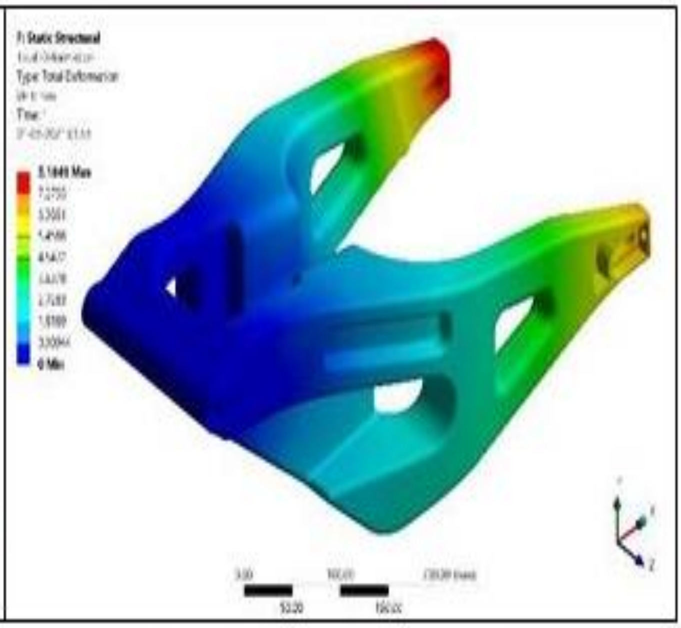


Fig.15 Deformation in fourth iteration

Result Table

Table 2. comparison of results in four iterations

Sr. No.	Iteration	Weight (kg)	Max Stress (MPa)	Max Displacement (mm)	FOS
1	First	6.9	151.24	2.9	3.78
2	Second	6.1	137.66	2.8	4.155
3	Third	4.1	223.2	5.44	2.55
4	Fourth	3.38	311.26	8.184	1.83

IX CONCLUSION

A successful manual shape optimization was performed and a complete new designed was developed. The reduction in the weight with respect to first iteration is 51.01% with maintaining factor of safety of 1.83. So, it clear that, using simulation data, the weigh on component (swingarm) can be reduced. The reduction in weight directly improves the performance and handling of the of the bike as MotoGP event is about speed and performance. Ultimately facilitating riders to achieve maximum potential of the machine and prove their calibre on the track. Further development of the part can be done implementing carbon fibre material for the swing arm.

X FUTURE SCOPE

Increasing competition makes this study imported to be at top in the championship. To meet the requirement faster and more precise riders, it is important to make the most important dynamic component ready for all the loading condition with favour to rider’s actions.

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