Lightweight 6-Piston Caliper Optimization Using Generative Design for Enhanced Performance and Safety

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Abstract - *This paper looks at how a redesigned 6-piston brake caliper can improve braking efficiency, reduce weight, and enhance performance in mid-size SUVs, which typically weigh between 1800–2700 kg. By using generative design software Fusion 360, we created a new brake system with a 6-piston fixed caliper that offers better clamping force and heat management. The brake disc was also optimized to reduce weight and improve heat dissipation. The new caliper is light weighted and reduces weight from the vehicle's unsprung weight. This weight reduction improves suspension performance, making the vehicle more responsive and stable while also reducing stopping distance.These changes lead to safer, more efficient braking.*

Key Words: Generative Design,6-Piston Caliper, Braking Efficiency, Weight Reduction

1.INTRODUCTION

The braking system is essential for vehicle safety, especially for mid-size SUVs like the Ford EcoSport, Hyundai Tucson, and Toyota Fortuner, which typically weigh between 1800–2700 kg. This study focuses on redesigning the brake system by changing the floating caliper to a fixed 6-piston caliper using advanced generative design technology. The goal is to make the braking system lighter, more efficient, and improve its performance. A 6-piston caliper design provides better braking force and heat management, which is important for heavy loads and high-speed braking. The brake discs were also improved with features like fins and holes to help cool the system and reduce weight. The result of using a lighter caliper is a decrease in the overall weight of the braking system, which enhances vehicle handling and safety by improving suspension performance and reducing the stopping distance.

2. 6-Piston Brake Caliper and brake disc

A 6-piston brake caliper is an upgrade from the common 2- or 4-piston systems typically found in compact and mid-size SUVs, like the Ford EcoSport, Hyundai Tucson, and Toyota Fortuner, which weigh between 1800–2700 kg. These calipers have three pistons on both the inboard and outboard sides in a fixed-position design, providing improved clamping force and even pressure distribution across the brake pad. This design is ideal for handling heavier loads, towing, and aggressive high-speed braking, offering better heat dissipation for consistent and reliable performance.

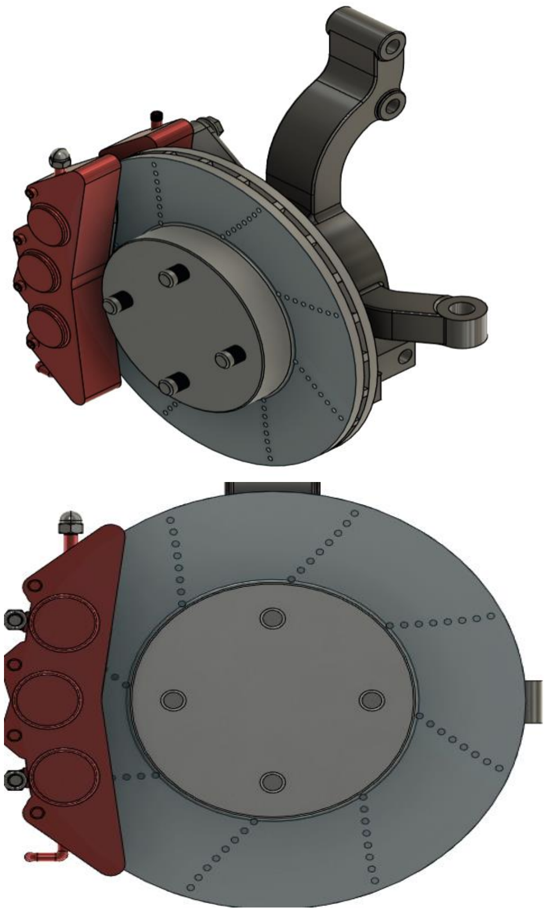

Fig -1: 6 piston brake caliper and brake disc

brake disc

The brake disc is crucial in braking as it dissipates heat and provides a rough surface for better braking performance. Features like fins between the plates and patterned holes enhance heat dissipation, ensuring smoother braking. The disc must withstand the high clamping force of a 6-piston caliper, making material optimization essential. By reducing its weight from 9.5 kg to 7.8 kg and increasing thermal conductivity compared to conventional materials, the disc becomes lighter and more efficient while maintaining durability and performance.

Conventional model	Redesigned model
Rotor •Mass – 9.5 kg •Material-Cast Iron •Thermal Conductivity-8.5053.3w/m.K	**Rotor** •Mass – 7.807 kg •Material-MS •Thermal Conductivity-51.9w/m.K

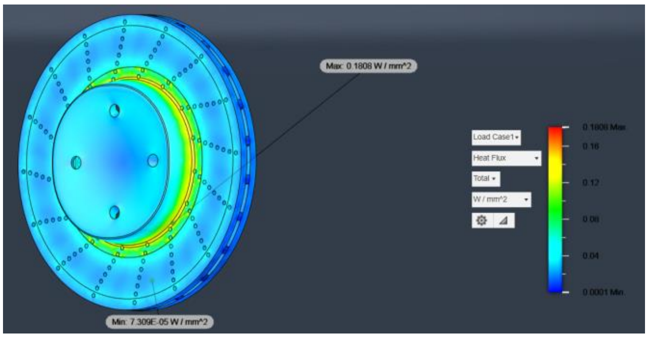

Fig -2: brake disc heat flux

3. Calculations

We take weight of the car is 2500kg approx. Toyota Fortuner's weight and take highest speed of 160km/h. we use our 6 piston cylinder brake caliper in this SUV with the disc size of 350mm

Vehicle Weight (m): 2500 kg.

Speed (v): 160 km/h = 44.44 m/s.

Deceleration (a): Assume braking system achieves a deceleration of **0.8g (7.84 m/s^2)** under optimal conditions.

Friction Coefficient (μ): Typical value for a dry road is **0.8** (can vary).

1. **Brake Rotor Radius (r): 0.175 m (350 mm rotor diameter).**
2. **Six-Piston Caliper Details:**
   - Total number of pistons: 6.
   - **piston diameter = 40 mm** for calculations.
3. **System Pressure (P):** Assume **100 bar = 10 MPa** (braking line pressure).

The **stopping distance** is derived from the equation:

$d=v^2/2a$,

$d=44.44^2/2*7.84$

So, the stopping distance is approximately **126 meters.**

Clamping force

$A_p=\pi\times(\text{diameter}/2)^2\approx0.001256m^2$.

The total clamping force depends on the hydraulic pressure and caliper piston area.
For a six-piston caliper, with three pistons on each side:
Total piston area

Total area for six pistons: $A_t=6\times0.001256\approx0.00754m^2$

The clamping force (F_c) is: $F_c=P*A_t$

$F_c=10^7*0.00754$

The total clamping force is approximately **75.4 kN.**

With the formula $Fb=\mu*Fc*r/R$

μ: Friction coefficient between the brake pad and rotor.

Fc : Clamping force applied by the brake caliper.

r: Effective radius of the brake rotor.

R: Wheel radius.

Doubling the clamping force approximately doubles the braking force.

And it halves the stopping distance

$d\propto 1/F_c$

Increasing the **clamping force** increases the braking force, which improves deceleration and reduces stopping distance.

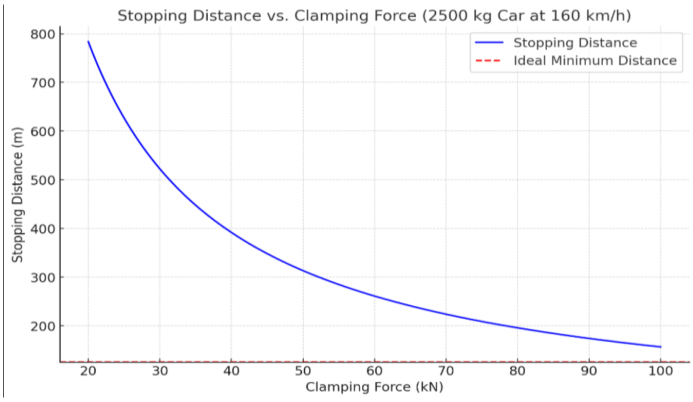

Fig -3: stopping distance vs clamping force graph

4. Generative design of brake caliper:

Generative design is a modern engineering process that uses AI and tools like Fusion 360 to create optimized designs based on specific goals and constraints. The workflow begins by defining preserve geometries, which are areas that must remain intact, and obstacle geometries to prevent material from being added in clearance zones. Design objectives, such as reducing weight or improving strength, are then set, followed by the application of real-world forces and constraints to ensure practical performance. Material selection, considering factors like weight, thermal conductivity, and manufacturability, plays a critical role in achieving the desired outcome. The software generates and tests numerous design iterations, and the best option is chosen for refinement and validation through simulations. This process delivers innovative, efficient designs tailored to real-world applications.

Preserve Geometries: Preserve geometries are essential shapes that are critical for the design to function properly. These are typically simple, basic shapes chosen to define the dimensional limits and ensure all necessary clearances are met. The preserve geometries outlined below adhere to both the dimensional and clearance constraints established by the original swing arm design.

Obstacle geometries: space where you any material or mass will render the component dysfunctional. Other than that, obstacle geometries could also be used as clearance space to access preserve Obstacle geometries are basically the sections of the design space where you any material or mass will render the component dysfunctional. Other than that, obstacle geometries could also be used as clearance space to access preserve geometries as well as clearance for bolts and shafts.

Material and manufacturing process selection: Material selection is one of the most important part of design process followed by selection of manufacturing processes. Both of these criteria are deeply intertwined with each other and are critical to the structural and mechanical properties of a component. With generative design, the manufacturing process usually narrows down to additive manufacturing and other unconventional manufacturing methods as the geometries produced by generative design are harder or impossible to produce using conventional means of manufacturing. For this study, additive manufacturing is selected as the manufacturing method and wide arrays of materials from “Fusion 360 additive material library” are selected and further compared with each other.

In this design, the piston holes and fluid lines are kept as preserve geometries, meaning they remain unchanged. The surrounding areas are filled with the necessary material, which is then optimized to handle the required load. This approach reduces unnecessary weight, making the caliper lighter while still maintaining its strength and functionality. The result is a more efficient and sustainable design.

Generative design solutions: Various different solutions which meet the applied load, dimensional and structural constraints are produced with different design philosophies and material selections. Each design features its own set of design iterations from which a design could be refined and adjusted according to the particular parameters. Optimum design is selected according to the parameters like total mass, FOS (factor of safety), estimated manufacturing costs, material properties, material availability etc.

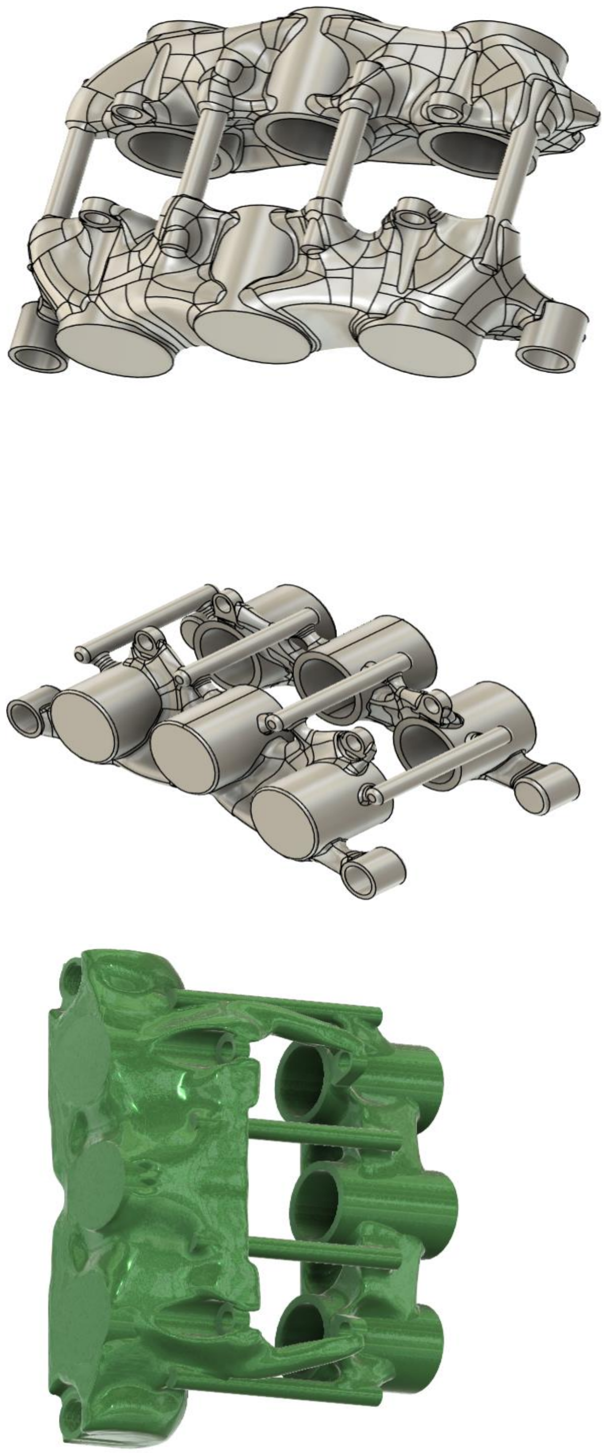

Fig -4: possible solutions

The new brake caliper weighs 2 kg, which is much lighter than the previous 4.2 kg caliper. We reduced its weight without compromising its strength or performance, using the same material.

By reducing the caliper's weight, we also lower the vehicle's unsprung weight. This helps improve suspension performance, allowing the tires to maintain better contact with the road, which can increase braking stability and efficiency.

Fig -5: finalized generative design

4.1 improvements through generative design

The reduction in mass means less energy is required to move and stop the caliper itself, which can make the braking system slightly more responsive.

Original unsprung weight per wheel: $W_{original}$= 4.2 kg

New unsprung weight per wheel: W_{new}= 2.0 kg

Reduction per wheel: $\Delta W = W_{original} - W_{new}$= 4.2kg−2.0kg = 2.2kg

For four wheels: Total reduction= 4*2.2kg = 8.8 kg

This 8.8 kg reduction leads to **better road contact**, as the suspension can respond more quickly to road irregularities.

stopping distance (d) depends primarily on the deceleration (a), which is affected indirectly by the reduced unsprung weight improving tire-road contact.

Stopping Distance
Reduced unsprung weight improves road grip, potentially increasing the effective deceleration. Assume deceleration improves from 7.84 m/s^2 to 8.03 m/s^2 approximatly 2.5% increases

$d_{orignal}=44.44^2/2*7.84 \approx 126m$

$d_{new}=44.44^2/2*8.2 \approx 123m$

The stopping distance reduces by approximately 3m, improving safety.

Because of the reduction of material it reduces overall cost of braking system in mass production car.

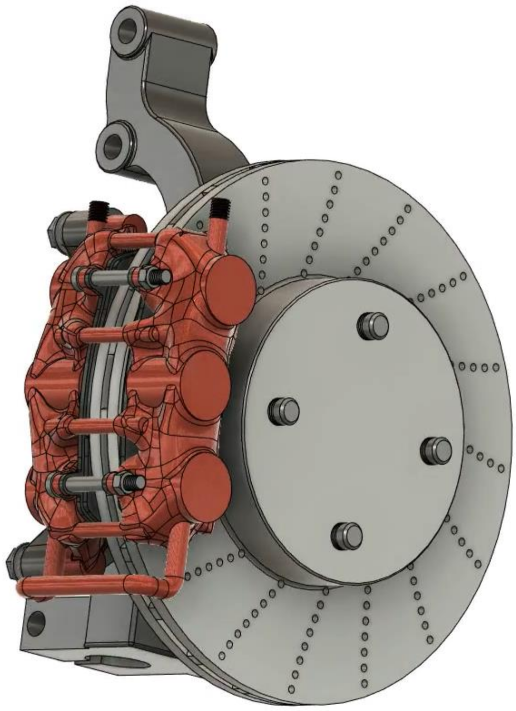

Fig -6: final combined brake disc and new caliper

3. CONCLUSIONS

The study highlights the transformative potential of generative design in optimizing automotive components, focusing on the development of a lightweight and high-performance six-piston brake caliper for crossover SUVs. By leveraging Autodesk Fusion 360's generative design capabilities, the research achieved a significant 52.38% reduction in the caliper's weight, from 4.2 kg to 2 kg, without compromising its structural integrity or braking efficiency.

This substantial weight reduction enhanced vehicle dynamics, including better suspension performance, improved tire-road contact, and a shorter stopping distance by approximately 3 meters.

Moreover, the integration of innovative material selection and thermal optimization resulted in improved heat dissipation and increased durability under real-world conditions. The application of generative design principles, including the definition of preserve and obstacle geometries and precise loading conditions, demonstrated the ability to create advanced, manufacturable designs tailored to specific performance goals.

This research underscores the potential of generative design as a revolutionary tool in engineering, capable of balancing performance enhancement with sustainability and cost-efficiency. It offers a forward-looking approach to modern vehicle design, setting a benchmark for future studies in automotive innovation and manufacturing technologies.

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