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Design and Application of Cutting Brake for ATV with Open Differential

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Abstract - *Braking is an essential aspect of vehicle safety and control, serving as the primary mechanism for slowing down or stopping a vehicle. It plays a crucial role in preventing accidents by allowing drivers to respond to obstacles, traffic, and emergencies effectively. Beyond safety, brakes contribute to overall vehicle handling and stability, distributing weight properly among the wheels and ensuring balanced braking. Efficient braking systems minimize stopping distance, reduce wear on other vehicle components, and enable drivers to maintain control during downhill descents.*

In modern vehicles, cutting brakes are used . to increase maneuvering characteristics of an ATV

***Key Words*:** Master Cylinder, Clamping Force, Cutting brakes

1.INTRODUCTION

Cutting brakes, commonly used in ATVs (All-Terrain Vehicles) and off-road vehicles, are a specialized braking system designed to provide increased maneuverability by allowing the driver to selectively brake individual wheels. In ATVs equipped with a front open differential, cutting brakes function by applying braking force to one wheel while allowing the other wheel on the same axle to spin freely.

1.1 WORKING

Installing a cutting brake on the front differential for off-road use could offer several advantages. By selectively applying the cutting brake to one side of the front differential, drivers can improve maneuverability, allowing for tighter turns and more efficient navigation around obstacles. Additionally, using the cutting brake to transfer power away from slipping or spinning wheels can enhance traction, aiding in maintaining control on challenging terrain. This capability also assists in correcting the vehicle's trajectory and regaining steering control in unstable conditions. Furthermore, the cutting brake can facilitate precise maneuvers in technical off-road situations, such as negotiating tight spots or traversing steep inclines. While not as common as hydraulic handbrakes in drifting, implementing a cutting brake on the front differential requires careful engineering and driver training to ensure safety, reliability, and compatibility with the vehicle's drivetrain components.

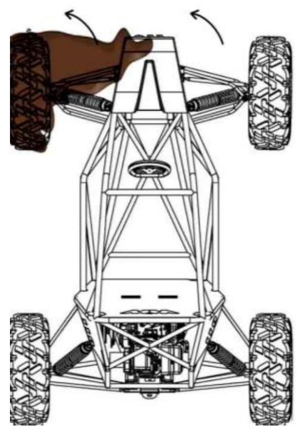


Fig -1: cutting brakes in different traction condition

In a 4x4 off road vehicle, the open differential in the front will provide more power to the wheel which has less resistance.

1.2 HIGH SPEED TURNING

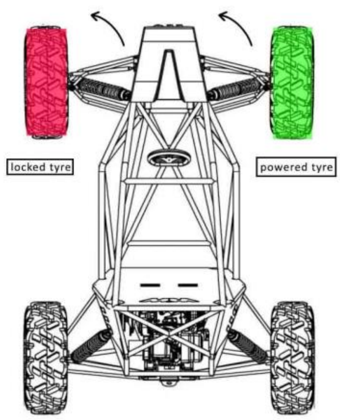


Fig-2: locking the left wheel

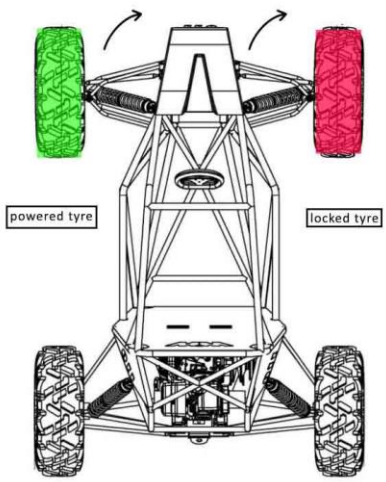


Fig -3: locking the right front wheel

Due to the bigger turn radius, the outside wheels of a high-speed turn naturally go a longer distance than the inside wheels. The wheels spin at different speeds as a result of the difference in distance traveled; the outside wheel spins more quickly than the inside wheel. The driver can efficiently limit the speed of the outer wheel by applying the cutting brake to it. This will promote a smoother rotation and minimize the tendency to understeer.

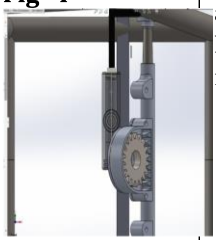
Moreover, properly employing the cutting brake may assist in creating oversteer, which is advantageous for making tighter turns or starting slower, controlled drifts at higher speeds. The car's front end can step out by briefly lowering power to the outside tire, enabling the driver to maintain a desired line around the turn while controlling weight transfer and vehicle balance.

2 DECISION MATRIX

Decision matrices are essential instruments for decision-making because they provide an organized method for assessing several possibilities or alternatives in accordance with predetermined standards.

Two separate design intents we were followed which was concluded by forming a decision matrix with various pointers such as the advantages and the possible failure method or the issues that were met while calculations or simulations following the decision matrix, the **IDEA 2** was chosen

Table -1: A decision matrix for the cutting brakes

Decision Matrix for the cutting brakes			
Sl. No.	**Design Features**	**Advantages**	**Issues faced**
IDEA 1 (Steering rack actuated set-up)	1. The linkage for actuating the cutting brakes are attached with the clevis of the steering rack. 2. The master cylinder is mounted just behind the steering assembly. **Fig -4** 	1. These cutting brakes are driver-independent. Whenever, wheels are steered more than 43.5° these brakes get actuated (based on calculations). 2. The design is compact and Brake line routing is simpler.	1. The steering effort increases by 65N whenever a turn of more than 43.5° is to be taken. 2. The wheels may steer more than 43.5° even during suspension events (ex: in booby tracks). In this case cutting brakes may get actuated unnecessarily
IDEA 2 (Mechanical lever similar to that seen in vehicles)	1. Either a lever just behind the steering wheel OR; 2. A mechanical linkage (wire) which will actuate the mc piston on pressing the paddle shifters towards the steering wheel. **Fig -5** 	1. Reliable and easiest to set up. 2. The design is simple and chances of error are low. 3. Human effort can be reduced as a lever ratio of 2-3 can be achieved.	1. Difficult to provide the necessary actuation force of 350N (min.) by just pressing the paddle shifters. 2. Moreover, it might cause hindrance during the entire course of steering wheel action.

3. CALCULATIONS

Given that :-

Weight Distribution = 45:55

Mass of Car = 140+85 = 225 kg

Center of gravity =21 inch

Wheel Base (b) = 57 inches

Position of C.O.G (front)= (40/100) * 57 = 25.65 inches

(rear) = (60/100) * 57 = 31.35 inches = l

Maximum Speed of Vehicle = 49 km/h = 13.61 m/s

DYNAMICS:

We calculated deceleration using an accelerometer instead of the physics formula, because the errors caused by factors like slippage and aerodynamics cannot be ignored.

Let Rf be the normal reaction between the ground area and the front wheel and Rr be the normal reaction between the ground and the rear wheels

$$Rf = W(l+\mu h/b)$$

$$Rr = W(b-l-\mu h/b)$$

Rf = (225*9.817) * [(31.35+ (0.7*12.5))/57] = 1784.498 N

Rr = (220*9.817) * [(57-31.35-(0.7*12.5))/57] = 424.327 N

Let Fr be the braking force produced at the rear wheel

Ff be the braking force at front wheels

Fr = μRr (limiting value) = 0.7*1784.498 = 1249.1487 N

Ff = μRf = 0.7*424.327 = 297.0288 N

Static Weight Distribution

Rf static = (45/100) * (225*9.817) = 993.971 N

Rr static = (55/100) * (225*9.817) = 1214.853 N

Stopping Distance: v2 – u2 = -2 Dx S

v = 0 m/s ; u = 13611 m/s

Dx = (0.7*9.817) = 6.872 m/s2

0-(13.61)2 = -2*6.872*S

S = 13.479m

For Rear

Brake Caliper: Wilwood PS1

No. of pistons: 2

Piston Area: 0.99 inch square

Piston Dia.: 1.12 inch

Since we have standard MC and caliper, we need to find an exact disc diameter.

We know, Braking Torque (BT) >= Overall torque at the rear axle to stop the vehicle.

Overall torque at rear axle = 19.6*7.72*3.75*0.99

= 561.746 Nm

Braking Torque = Pedal-force * Pedal-ratio *(Ac/AMC) * Reff * μp *μg

600 = 600 *6 * (1.2*10-3/1.98*10-4) * Reff * 0.45 * 0.7

600 / 7162.10 = Reff

Reff = 0.0895m

Reff = 3.521 inches

Reff = (2/3) * [((R)3 - (r3))/(R2-r2)]

Where; R = Disc outer radius

r = Disc radius – piston thickness (1.12/2)

6R2- (6Reff+3.36)R+1.68Ref+0.6272=0

On solving the quadratic equation; R = 3.79 inches

Hence rear disc diameter = 7.58”

Clamping Force (Cf)

Cf = Tb/(2*μp*Reff)

Cf = 600 / (2*0.45*(3.521*0.0254))

Cf = 7453.169 N

Brake line pressure

Pr = (Fp*Pedal-ratio) /Amc

Pr = (600* 5.5) / 0.3068

Pr = 2417.18 psi = 16.67 MPa

For Front

Brake Caliper: Wilwood PS1

No. of pistons: 2 and number of calipers = 4

Piston Area: 0.99inch square

Piston Dia.: 1.12 inch

Since we have standard MC and caliper, we need to find an exact disc diameter.

Braking Torque = Pedal-force * Pedal-ratio * (Ac/AMC) * Reff * μp *μg

We know, Breaking Torque (BT) >= Overall torque at the rear axle to stop the vehicle.

Torque on wheels: T = 2 * μg * (Rf/2) * Rwheel

= 2 * 0.7 * (1784.498/2) * 10.5 * 0.0254

= 666.296 Nm

Braking Torque = 600 * 6 * (2*1.2*10-3/1.98*10-4) * Reff * 0.45 * 0.7

Braking Torque >= Torque on wheels

700 = 600 *6 * (2*1.2*10-3/1.9*10-4) * Reff * 0.45 * 0.7

405 / 7162.10 = Reff

Reff = 0.07514m

Reff = 2.958 inches

Reff = (2/3) * [((R)3 - (r3))/(R2-r2)]

Where; R = Disc outer radius

r = Disc radius – piston thickness

6R2- (6Reff+3.36)R+1.68Ref+0.6272=0

On solving the quadratic equation; R = 3.23 inches

Hence, each front disc diameter = 6.46"

Clamping Force (Cf)

Cf = Tb/(2*µp*Reff)

Cf = 600/(2*0.45*(2.958*0.0254))

Cf = 10351.62 N

Brake line pressure

Pr = (Fp*Pedal-ratio) /Amc

Pr = (600* 5.5) / 0.4418

Pr = 1678.59 psi = 11.57 MPa

4. CAE ANALYSIS

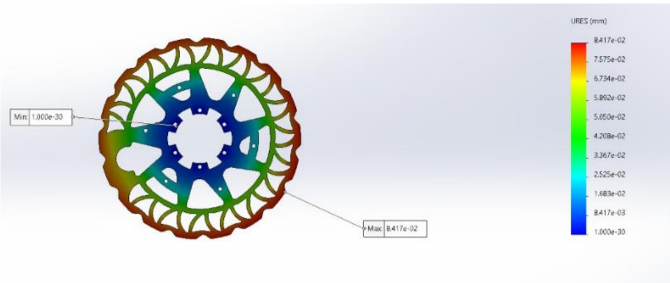


Fig -6: Displacement Analysis

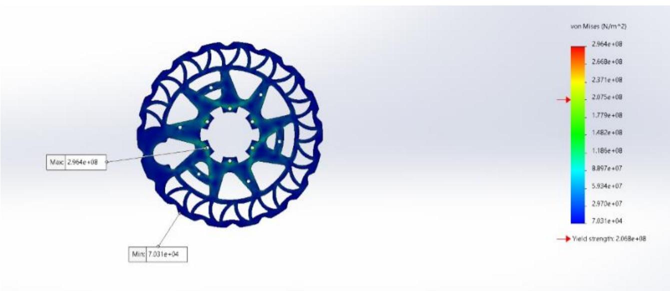


Fig -7: Stress Analysis

5. RESULTS

Various analysis were performed to check for the calculations and material selection for the braking setup ,

Transient Thermal heat analysis			
Side	**Diameter**	**Temperature**	**Validation results**
Front	7"	358 degree celsius	117 degree celsius
Rear	8"	298 degree celsius	112 degree celsius

CAE analysis also helped in material selection by evaluating different materials' properties and performance under specific conditions. Ultimately, displacement analysis and stress analysis streamlined the design process, reduced development time and costs, and ensured that components meet desired performance criteria efficiently and effectively across a range of industries.

6. CONCLUSION

The limitations of open differential are mitigated by installing cutting brakes on ATVs.

An open differential controls the differential in speed between the two wheels when the vehicle is turning. Cutting brakes are used to lock a wheel that becomes caught on a slick surface. This was used for improving the oversteering characteristics of the off road vehicle but creating a artificial RPM difference between the two front wheels of the ATV

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