Design of Hydraulic Brake system with variant bias using single piston master cylinder for All-Terrain Vehicle

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Abstract
Hydraulic Brake system is provided for All Terrain Vehicle that includes optimization of single piston master cylinder and fixed caliper inputted in self customized outboard wheel assembly. As variant torque is need in front and rear wheels, hence designing variable bias Hydraulic Brake system, optimizing components helps to reduce weight, cost and manufacturing and to increase braking efficiency. Key points of wheel assembly components are hollow front stub, tapered section hub and optimized slotted disc, slotting helps disc to cool down at much faster rate. A dual Piston Fixed caliper has been designed from material Al-7050 that helps against corrosion and other atmospheric effects with easy mounting on knuckle. Sintered metallic pads are used that has fewer tendencies to wear out easily.

Keywords: brake caliper, single piston master cylinder, wheel hub assembly, ATV

1. Introduction
Braking system of any ATV consists of a hydraulic disc brake or drum brake. Disc brake consist of a disc which is a part of the wheel hub assembly, caliper which is mounted on the knuckle, master cylinder which will generate the amount of pressure that we required to stop ATV. The main target that needed to be kept in mind is what amount of torque is need for car.

Brakes used in the past car consisted many types of system but the most efficient type was drum brake, drum brake generally consist of a drum in which brake shoe will expand with the help of mechanical spring and when brakes are not actuated the spring gets to its normal position and the brake shoe will also come to its position.

There are various disadvantages of this type of braking system if the spring gets affected then the brake shoe will not get back to its normal position. The efficiency of drumbrake is low and it requires service and update very frequently. Hydraulic disc brakes are comparatively more efficient than drum brake. Disc brake consist of a master cylinder with a reservoir in which hydraulic fluid is kept, then the brake lines which will connect the master cylinder to the various brake calipers, brake caliper is the most important part of the whole disc brake system it is mounted on disc which is connected to the wheel hub assembly. When the driver applies the brakes then the master cylinder gets actuated then from the master cylinder the oil with pressure goes into the brake lines forwarded to the caliper and then the caliper gets activated and the brake pads will move towards the disc and it will stop the vehicle.

Outboard configuration of braking is also a very efficient technique but the disadvantages of it are the brake lines, calipers. Brake disc are exposed while mounting it in this configuration which lead to damage from obstacles such as rocks and often debris. It also required more space for the mounting of caliper’s and ultimately it overall required more space for designing of wheel hub assembly’s. Inboard configuration is also very effective it reduces the weight of the braking system and reduces manufacturing cost & time. In inboard configuration the brake disc is mounted on the final drive.
2. Design of braking system

The main objective of any braking system is to retard the motion of any vehicle or you can say to stop any vehicle. Deceleration is one of the most important parts as the vehicle starts decelerating it will tend to stop at any period. The braking system works on converting kinetic energy into heat energy and thus motion of the vehicle stops. The main objective of the braking system is to stop a ATV with the configuration of

**Weight**: 160 kg (352.74 lbs)

**Speed**: 60 km/hr or 16.66 m/s

Any type of condition (dynamic, static)

Pedal must be directly actuating the master cylinder through rigid link. Brakes are mounted on the final drive axle. Design of pedal must be mounted with good ergonomics as driver can easily access the pedal and we have taken consideration of every size of driver. In our braking system consist of two independent hydraulic systems, each with their own fluid reserves

### 2.1 Brake Pedal Design

Design of pedal starts with calculation of leverage considering enough leverage for brake actuation i.e. 6:1 and hence, getting overall length of pedal as 9”. We have designed it as per to get the perfect I shaped so that it will give superior bending strength.

### 2.2 Design of Master Cylinder

A single piston master cylinder has been designed to get the maximum braking efficiency while decreasing weight to strength ratio this will increase the braking efficiency as the weight is reduced and we can generate the maximum braking force required to lock all four wheels. This master cylinder is compatible of using DOT 3,4,5,5.1.
The various forces acting on master cylinder is

- Pedal force acting on mounting of the master cylinder
- Force due to piston inside of master cylinder
- Force of spring acting to return of piston
- Pressure exerted by master cylinder to get the required braking pressure.

2.3 Design of Wheel hub Assembly

As shown in the figure the Wheel Assembly consists of the following Components.

1. Spindle-(1)
2. Knuckle-(1)
3. Hub-(1)
4. Bearings
   a. Deep Groove Ball Bearing-Front/Rear
5. Nut-(1)
6. Cotter/Split Pin-(1)

Before understanding the procedure it is important to understand how all these components are assembled. Firstly the spindle is taken. The Knuckle is press fitted on the spindle using Hydraulic press. The hub is taken and the outer race of the bearing is press fitted in the hub. Mounting disc on hub disc flanges using tapered bolts. Then the hub is positioned on the bearing and then the second bearing’s inner race is press fitted on the spindle. Then the nut is tightened on the spindle and a split pin is inserted into the hole made in spindle for positively locking the Wheel Assembly. Finally caliper is fitted on knuckle.

2.3.1 Design of Stub

Firstly the spindle is designed on which other components such as knuckle, bearings and hub will be fitted. At this stage we cannot decide the actual length of the spindle, so we just consider the tentative length of the spindle.

Syt = 654 N/mm²

Endurance Limit = 412 N/mm²

It consists of following steps:

1. Determining the forces acting on the spindle:

   The forces acting on the spindle are as follows

   1. Weight of the vehicle:

   During static and dynamic conditions a constant force of the self-weight is acting on the spindle at the part inside the knuckle. The weight on the one wheel is

   Weight in the front portion = 150 kg

   Weight on one tire = 150/2 = 75 kg

   Force due to weight of the vehicle = 75 × 9.81 = 735.850 N

   Let us consider this weight to be 1000 N.

   2. Bump force on the tire:

   At the time of a bump in the surface a force will act on the portion of the spindle which is inside the spindle. This force is obtained from the wheel rate.

   Bump Force = Wheel rate × Travel due to bump

   3. Torque on the spindle:

   Torque = mass on the spindle × g × radius of wheel

   = 129.44 N
Considering all these forces we studied FEA of stub as

**Stress**: 354.9 Mpa
**Deformation**: 1.401 mm
**FOS**: 1.4171

![Image 1](image1)
![Image 2](image2)

**Figure 8**: FEA of Front Stub Fitted into Knuckle and hub respectively and result description

### 2.3.2 Design of Hub

Concept of tapered design has been implemented for hub flanges to improve stress distribution resulting in sturdier design of hubs. Hub flanges are designed as per providing proper tapering to prevent it from torsion failure and keeping in mind the adequate distance from the brake caliper. Wheel and disc petal are designed as to get the perfect weight to strength ratio and disc is mounted as the optimal way with only three mounts. Furthermore all the mounts are calculated through shear stress theory.

The following forces are acting on the hub

- Torque on the brake disc petal.
- Loads on bearing.
- Torque acting on wheel petals.
- Force due to side impact.

Studying FEA of Hub we get results as follows

**Stress** (f/r): 238.3 / 226.2 mpa
**Deformation** (f/r): 0.1415 / 0.0954 mm
**FOS** (f/r): 2.1108 / 1.2189

![Image 3](image3)

**Figure 9**: FEA of front and rear hub and result description

### 2.3.3 Design of Disc

To reduce brake fade, slotting of brake discs was performed and optimized via an iterative method by compromising between disc strength and heat produced. Optimal design of slots for efficient cooling and adequate contact-effective disc area calculated based on wheel torque and retarding torque has been considered for optimisation.

The various forces that are acting on the disc are as follow

- Tangential force between pad and disc
- Braking torque acting on it
- Clamping force

**Stress**: 196.72
**Deformation**: 0.54
**FOS**: 1.72

**Thermal analysis**
- Max. Temperature: 112.35˚c
- Total heat flux: 1, 72,850 w/m²

**Figure 10**: FEA of disc and result description
2.3.4 Design of brake caliper

The fixed calipers were selected for higher braking efficiency due to the larger clamping force generated by one piston on either side of the disc.

A caliper consist of the various things as shown below

- Caliper body
- Mounting bracket
- Piston
- Retracting seal
- Frictional pads
- Bleed point
- Benjo point
- Fluid inlet

The piston diameter of 1” was selected and designed the brake caliper body according to perfect mounting of the caliper to the wheel hub assembly.

![CAD model of brake caliper](image)

Figure 11: CAD model of brake caliper

Various forces acting on the brake caliper are

- Reaction on caliper due to the pressure applied at the back of the piston
- Reaction on the caliper body due to clamping force
- Frictional force on pad, transmitted to the frictional pad mounting.

![FEA result of the brake caliper](image)

STRESS (F/R): 196.72
DEFORMATION (F/R): 0.54
FOS (F/R): 1.72

Figure 12: FEA result of the brake caliper and result description

3. Material Selection

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<th>Parameter</th>
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</table>

Table 3. Properties of selected materials

4. Conclusion

The paper shows studies in detail, conceptual design, analysis and optimization of a braking system. We have designed braking system with maximum braking efficiency and with much lesser weight.

- Wheel hub assembly was optimized by using FEA analysis and theoretical calculations.
- Single Master Cylinder was designed keeping in mind the required braking force.
- Design of caliper was carried out by also taking into considerations various clearances, proper mount and various other things.

5. Reference