Design of Effective Hydraulic Braking System for Formula Motorsport Car

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Abstract. The design of an effective braking system plays a major role in high performance formula cars since the stopping distance and speed control during cornering are the important part of any race. Everyone wants their car to go fast, but the braking system should be capable to stop immediately and safely. Any car with highly effective braking system fills confidence in the driver. It also increases driving pleasure.

1. Introduction

Braking system is the device which brings the moving vehicle into rest by converting kinetic energy of the vehicle to frictional energy interns heat energy which is dissipated to atmosphere [7]. Brakes helps to slow down or stop the vehicle in the shortest possible time as per the driver requisite and also at the time of driving down the hill and to obtain a better traction control in different terrains [2].

There are various types of braking systems available such as drum brakes and disc brakes based on the components involved [6] and also hydraulic and wire actuated brakes and these brake actuation systems converts drivers force into frictional force at the rubbing surface [4].

Usually drum brakes are used in heavy weight transportation vehicles since the friction area is more which intern helps to control larger momentum easier and this entire system is completely closed, brake operation will not be affected by any other foreign particles like dust, mud and sand [1] when driver applies force on the brake pedal due to hydraulic actuation or wire actuation driver’s force will be transmitted to the actuating member inside the drum which intern pushes the brake shoes against the internal surface of the drum resulting reduction of velocity of the vehicle [5].

Disc brakes are commonly used in high speed racing cars because of no time operations [8]. In this type when driver applies force on the brake pedal either by the use of hydraulic actuation or wire actuation driver force will be transferred to the calliper which intern rubs the ceramic brake pads against the rotating disc resulting the vehicle deceleration [3]. Disc brakes are simple in construction since number of sub components are less compared to the drum brakes.
2. Design of Braking System.

2.1 Selection of brakes
choice for all type of racing conditions due to its effective and efficient operations and it uses hydraulic fluid for the actuation with the viscosity standard DOT-4 (department of transfer) since it has less viscosity coefficient. In formula cars all four wheels will have the individual rotating disc with the diameter of 200mm, patterned holes are provided for the rapid ventilation to the disc. and the brake pedal is designed to withstand the maximum load of 2000N with the pedal ratio of 6:1. For this particular type Suzuki swift tandem master cylinder with two outputs. In order to increase the lifecycle of the brakes metallic hoses are used inside the chassis for the fluid flow and rubber hoses are used between the chassis and brake calliper due to its flexibility. And 4 high performance endurance callipers which consists dual piston with two ceramic brake pads at the rubbing surface. And total pressure is distributed with the help of X split (diagonal) hydraulic circuit by providing 40% of hydraulic pressure to the front brakes and 60% in the rear. The main advantage of this X split is if the one of the hydraulic circuit get fails to operate another circuit will be able stop the vehicle by locking either the front left wheel and rear right wheel or front right wheel and rear left wheel so this circuit assures more safety to the driver.

2.2 Working of hydraulic braking system
Hydraulic brake works on Pascal law which states that “pressure acting in an enclosed system is same in all the directions”. According to this law when the pressure is applied on a fluid will travel equally in all the directions hence the uniform braking action is applied on all four wheels.

When the driver applies force on the brake pedal say 100N, the master cylinder experiences 600N at the piston rod due to the pedal ratio of 6:1 which causes the movement of piston inside the master cylinder chamber results to pressurize the fluid with 6.21MPa, fluid rushes towards the brake caliper hence the pistons in the calliper experiences the pressure of fluid which intern makes the pistons to push the ceramic brake pad against the rotating disc with the brake force of 6.9KN hence the kinetic energy of the vehicle is converted into heat energy and dissipated to the environment resulting the vehicle to stop from 105kmph to 0kmph within the stopping distance of 72.26m, stopping time of 4.9sec with the deceleration of -5.88m/sec^2.

2.3 Brake calculation
Speed of the Vehicle = 105kmph = 29.1666/sec

Weight of the vehicle including Driver = 300 kg

Vehicle momentum:

Kinetic energy of the vehicle is calculated by

KE=1/2mv^2

KE = 1/2(300 * 29.1666^2) = 127598.3334 N = 127.5983 KN
KE = 127598.334 \text{ kgm}^2/\text{sec}^2

Stopping distance:

Stopping distance is calculated by dividing whole equation by force acting on the wheel by gravity (Coefficient of friction between tire and road $\mu = 0.6$)

\[ F = \mu mg = 0.6 \times 300 \times 9.81 = 1765.8 \text{ N} \]

Stopping distance \( d = \frac{v^2}{2\mu g} \)

\[ d = \frac{29.1666^2}{(2 \times 0.6 \times 9.81)} = 72.26 \text{ m (theoretical)} \]

Or

Stopping distance \( d = \frac{KE}{\mu mg} \)

\[ d = \frac{127598.3334}{(0.6 \times 300 \times 9.81)} \]

\[ d = 72.26 \text{ m} \]

Deceleration:

\[ V^2 = u^2 + 2as \]

\[ 0^2 = 29.1666^2 + 2 \times a \times 72.26 \]

\[ a = -\frac{29.1666^2}{2 \times 72.26} = -5.88 \text{ m/sec}^2 \text{ (negative sign indicates the deceleration)} \]

Stopping time:

\[ V = u + at \]

\[ 0 = 29.1666 + \frac{-5.886}{t} \]

\[ t = \frac{-29.1666}{-5.886} = 4.9 \text{ sec} \]

Braking force:

\[ F_{\text{brake}} = ma = 300 \times 38.5586 \times 0.6 = 6940.548 \text{ N} \]

Brake torque:

\[ T_{\text{brake}} = F_{\text{brake}} \times \text{effective radius of rotor} \]
\[ T_{\text{brake}} = 6940.548 \times 0.1 \text{m} \]
\[ T_{\text{brake}} = 694.054 \text{ N-m} \]

If we give 66.1386 lbs. (nearly equal to 30kg) of force on to brake pedal with pedal ratio 6:1

Piston force on the cylinder = pedal ratio * applied load in kg

\[ F_{\text{piston}} = 6 \times 30 = 180 \text{ kg} = 1765.1970 \text{ N} \]

To find the diameter of disc:

\[ T_{\text{brake}} = 2 \times \mu \times F_{\text{piston}} \times R \]

\[ R = \frac{694.054 / 2 \times 0.45 \times 6940.548}{110 \text{ mm}} \]

Diameter of the disc \( d = 110 \times 2 = 220 \text{ mm} \)

pulsar bike’s brake discs with diameter of 200mm are used.

Pedal travel:

The master cylinder used here is Bajaj bike’s BYBRE calliper of bore diameter = 19.02mm and piston travel = 25.4mm with pedal ratio 6:1.

\[ \text{Pedal Travel} = \text{piston travel} \times \text{pedal ratio} \]

\[ \text{Pedal Travel} = 25.54 \times 6 = 153.24 \text{ mm} \]

Master cylinder pressure:

Piston Area of the master cylinder = \( \frac{\pi}{4} \times d^2 \)

\[ P_{\text{area}} = \frac{\pi}{4} \times 19.02^2 \times 284 \text{ mm}^2 \]

\[ P_{\text{area}} = 2.84 \times 10^{-4} \text{ m}^2 \]

Piston Pressure of the master cylinder = \( F / A \)

\[ = 1765.19 / 2.84 \times 10^{-4} \]

Piston pressure = \( 6.21 \times 10^6 \) Pa = 6.21 MPa

For BYBRE calliper disk width = 4 mm Area of the calliper piston = \( 5.07 \times 10^{-4} \text{ m}^2 \)
Force acting on each piston of the calliper:

\[ F = \text{Pressure} \times \text{area} \]
\[ F = 6.21 \times 10^6 \times 5.07 \times 10^{-4} \]
\[ F = 3.14 \text{ KN} \]

Mean braking radius:

Mean braking diameter = (disc diameter – (pad plate height/2))/2

\[ R = \frac{(200 - (25.4/2))}{2} \]
\[ R = 93.6 \text{ mm} \]

2.4 Brake Assembly

\[ \text{Figure 1. X Split or Diagonal hydraulic circuit} \]

\[ \text{Figure 2. Brake pedal and master cylinder assembly. a brake pedal is designed to withstand a maximum force of 2000N.} \]
3. Conclusion

As discussed above the braking system is designed and fabricated, the system will be able to slow down and stop the car from 105kmph to 0kmph with the practical stopping distance of 4.8m by performing linear braking within the shortest braking time of 2.3 seconds without skidding the vehicle.

Even in the case of vehicle launch in the races, during the starting the brakes are partially engaged and released to get a good launch or acceleration. And in traction control the sequential or pulsating engagement of particular wheels is achieved with traction controller module which also make use of anti-lock braking system. As the rules of the competition doesn’t permit the use of boosted brakes neither electronically nor hydraulically, which makes the normal disc brake, the exact option of use for the open wheel race cars.

References

[1]. Smith C. (1984), Tune to win, St. Paul, MN, USA, Motorbooks.
[2]. James Walker, The Physics of Braking Systems, 2005 StopTech LLC.
[3]. Milliken, W.F. (1995). Race Car Vehicle Dynamics Warremdale, PA, USA: Society of Automotive Engineers Inc.
[4]. Gillespie, T. D. (1992) Fundamentals of Vehicle Dynamics Warremdale, PA, USA: Society of Automotive Engineers Inc.
[5]. CMTI, Machine Tool Design Handbook, Tata McGraw Hill Education (India) Private Limited.
[6]. Automotive Engineering Fundamentals by Richard Stone and Jeffrey K. Ball
[7]. Paul S Grit, brakes system, SAE
[8]. How It Works - Racing Cars + Reveled the Engineering Redefining