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Yaw Controller and Independent Braking System

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***Abstract*— This paper deals with the innovation of an add on device which enhances the performance of an automobile. The add on device which is used consists of the use of electronically operated solenoid valve. The valve is placed between the flowline of brake hose and it is manually controlled by the driver. So when the switch is operated any of the flowlines in the brake can be connected and disconnected based on this. This operation is made use in the braking of any of the four wheels while the vehicle is still in acceleration. This method can be used as an alternate for traction control system in a cheaper way. This can also be used in racing events like FSAE or SUPRA and NASCAR racing or in off road cars which is used in Baja. This also reduces the understeer and oversteer problems which is faced by most of the racing cars while cornering. Any failure in design of roll center can be compensated by this. Another main advantage of this system is that, the yawing motion which is occurs in sports car and race cars due to crosswinds and vehicle instability can be controlled by this system by getting input from yaw motion sensor and controlling the straight ahead motion of the vehicle by braking independent wheels.**

Keywords— ***Understeer and oversteer, minimize lap timing, traction control system, yaw motion sensor.***

I. INTRODUCTION

The braking system deals with the stopping of the car or any vehicle from a certain speed. It generally converts kinetic energy into heat energy. The energy and/or power absorbed by a brake system can be substantial during a typical maximum effort stop. The energy absorbed is the kinetic energy of motion for the vehicle, and is thus dependent on the mass. The power absorption will vary with speed, being equivalent to the braking force times the speed at any instant of time. Thus, the power dissipation is greatest at the beginning of the stop when the speed is the highest [1]. Over the entire stop, the average power absorption will be the energy divided by the time to stop. Calculation of power is informative from the standpoint of appreciating the performance required from a brake system. The forces on a vehicle producing a given braking deceleration may arise from a number of sources. Though the brakes are the primary source, the other sources are rolling resistance, aerodynamic drag, driveline drag, grade. Brake factor is the one which multiplies the braking effort and is the mechanical advantage that can be utilized in drum brakes to minimize the actuation effort required. The braking decelerations achievable on a vehicle are simply the product of application level and the brake gains (torque/pressure) upto the point where lockup will occur on one of the axles. Lockup reduces the brake force on an axle, and results in some loss of ability to control the vehicle. It is well recognized that the preferred design is to bring both axles up to the lock point simultaneously. Yet this is not possible over the complete range of operating conditions to which a vehicle will be exposed. Balancing the brake outputs on the front and rear axles is achieved by “proportioning” the pressure appropriately for the foundation brakes installed on the vehicle. Proportioning then adjusts the brake torque output at front and rear wheels in accordance with the peak traction forces possible. The first order determinants of peak traction force on an axle are the instantaneous load and the peak coefficient of friction. During braking, a dynamic load transfer from the rear to the front axle occurs such that the load on an axle is the static plus the dynamic load transfer contributions. The maximum braking force is dependent on the deceleration, varying differently at each axle. Attempts at braking on an axle above the boundary value results in lockup on the axle [2].

This system utilizes the concept of pascal’s law that pressure at all points are equal [6] .To advance the braking system and to prevent lockup and increase the efficiency, the development of ABS (Anti-Lock Braking) system came. It generally doesn’t allow the wheels to lockup, leading to avoid in increase of skid coefficient. Rather than attempt to adjust the proportioning directly, Antilock Braking Systems (ABS) sense when wheel lock up occurs, release the brakes momentarily on locked wheels, and reapply them when the wheel spins up again. Modern antilock brake systems are capable of releasing the brakes before the wheel goes to lockup, and modulating the level of pressure on reapplication to just hold the wheel near peak slip conditions [4].

Recognizing that braking performance of any vehicle will vary according to the friction of the road surface on which it is attempted, the concept of braking efficiency has been developed as a measure of performance. Braking efficiency may be defined as the ratio of the actual deceleration achieved to the ‘best’ performance possible on the given road surface. The braking efficiency concept is useful as a designer tool for the designer to assess success in optimizing the vehicle braking system. Braking efficiency is determined by calculating the brake forces, deceleration, axle loads, and braking coefficient on each axle as a function of application pressure[1].

Nowadays, brake has become an important factor in racing especially FORMULA 1, NASCAR, SUPRA where the brake determines the major control of the vehicle. Braking when applied during cornering decelerates all the wheels, thereby reducing the overall speed to avoid slipping in turn.

In this study, it mainly concentrates on the race cars which faces under steer and over steer problems due to the shifting of roll centers. This method also decreases the lap timing by just locking the inner rear wheel based on the turn. This enhances turning of the car with an increased speed, leading to increase in lap timing. It makes use of components like electronic solenoid actuator, manual control switch. This system requires a knowledge of skilled driver. So this system offers better advantage in race cars. It can also be used as a manual traction control system.

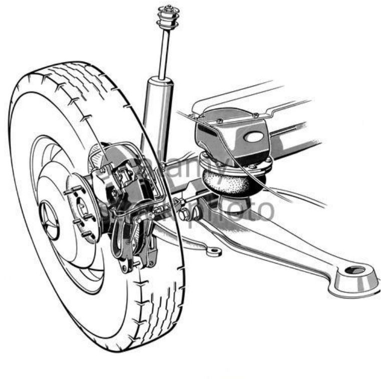

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Fig 1. View of brake system

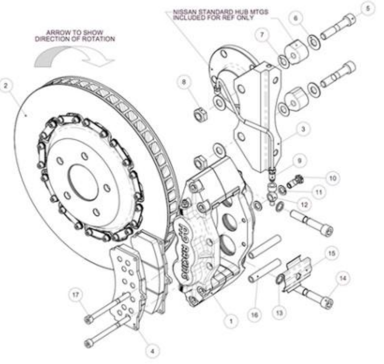


Fig 2. Dissected view of quarter brake system

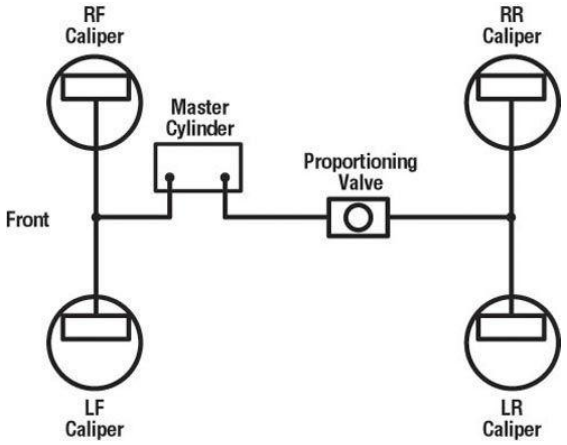


Fig 3. Normal braking system

Fig 4. Dissected view of caliper and discs.

II. BRAKE SYSTEM MODEL

This system enhances the use of controlling the flow of fluid in brakes so that ease in steering can be achieved and at the same time, traction control can be achieved manually by locking any one of the rear wheels by braking and by accelerating at the same time. And the yaw motion can also be controlled by locking the front wheels, when the vehicle is in motion. Suppose if the yaw tends the vehicle to rotate in anticlockwise direction, the brakes can be applied to the outer front wheel by getting information from the yaw sensor. The yaw sensor actually controls another set of solenoid valves and it is done automatically by the information from the yaw sensor. This system enhances the use of decrease in lap timing, thereby controlling the dynamics of the vehicle by the use of skilled driver. Sports car and other racing cars generally overtakes when they enter a corner in the race track. Suppose if the vehicle enters a tight corner without applying brake, the centrifugal force tends to pull the car away from the track, leading to failure in turning. This system acts as a three-point steering system i.e., while entering a corner, the driver should select the valves to be closed, so that the valve which is open allows the fluid pressure to go to calipers while braking. This applies brake to the inner rear wheel, depending on the turn. So this enhances the turning of the whole vehicle without decrease in overall speed.

A situation when a vehicle enters a corner is shown in Fig 6. In this assuming that the wheel takes a left turn. The driver who is riding the car should actuate the switch, such that the rear left wheel gets locked. So this left wheels acts as a fixed point, making the whole vehicle to move about a point, so that the vehicle turns itself, without decrease in overall speed thus decreasing the overall lap timing of the driver.

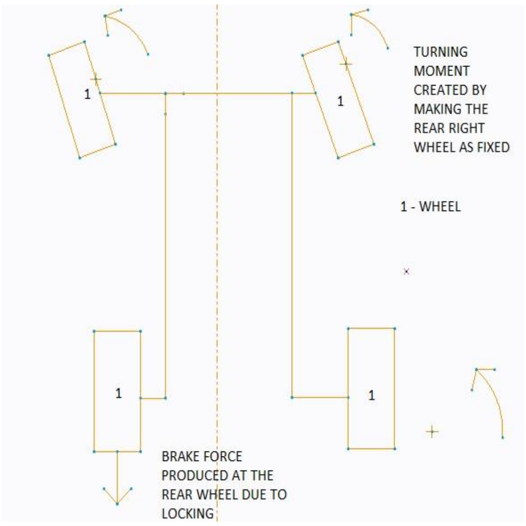


Fig. 5 Reaction occuring during a turn

The vehicle is turning a left turn, so in the inner rear wheels, the brake is applied, leading to the closing of solenoid valves in the other wheels. So, the turning moment produced along with the steer angle, makes the whole vehicle to turn leading to decrease in turning circle radius.

This method utilizes the rear wheel track, and if brake is applied in one of the wheel, it makes that wheel as a fixed point, and taking the length of the rear wheel track as radius, it makes a turn. So compared to Ackermann steering concept, this design utilizes the wheel track, along with wheel base, instead of only wheel base, leading to decrease in turning circle radius.

This system can also be used as an alternate for traction control system, and limited slip action can be brought by this method. . If an ordinary differential is used, then the scenario is worst, if it gets stuck in a mud. So, this system can be used where it locks one of the rear wheel, depending upon the situation, so that it is easy for the driver to get the vehicle out of the mud. It is used as an alternate traction control system.

In Fig. 7 it is assumed that the left rear wheel is stuck in mud, and the right rear wheel is in an asphalt road and needs traction and torque from the differential to come out from the mud. In these situations, the left wheel can be applied to braking pressure, by locking the solenoid valves of the other three wheels, and acceleration can be given by applying the brakes.

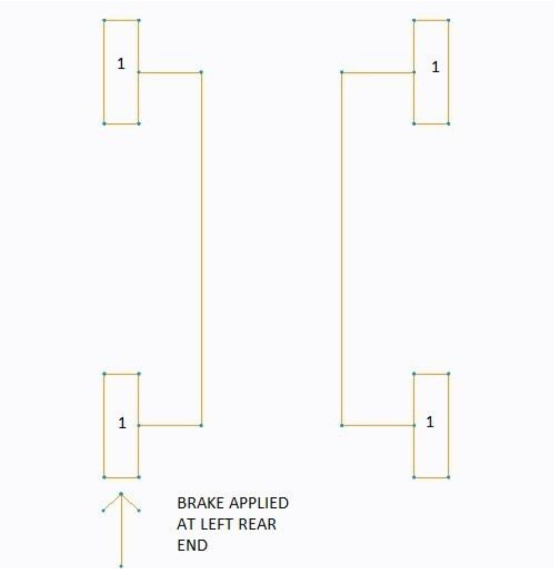


Fig. 6 Braking force applied at rear wheel

Understeer and oversteer are two major problems which is faced by any racing car while taking a shift. This problem can be precisely controlled by locking the rear wheels or front wheels depending on understeer and oversteer condition. A situation of understeer if occurred can be controlled by locking the rear wheels in the turn, so that car turns easily. Similarly, if oversteer occurs brake can be applied to front wheels only by energizing the solenoid of the rear wheels.

III. CALCULATION

The design of entire brake system for the vehicle has been calculated and the selection of solenoid valve is also done.

A.<u>VEHICLE ASSUMPTIONS:</u>

Mass = 330 kg

W → Weight of the vehicle

${}^{W}/_{g}\ .\ a_x$ → Inertia force acting at the center of gravity opposite to the direction of acceleration.

W_f → Dynamic weight carried on the front

W_r → Dynamic weight carried on the rear

F_{xf} → Front Tractive Force

F_{xr} → Rear Tractive Force

R_{xf} → Braking force and rolling resistance forces (Front)

R_{xr} → Braking force and rolling resistance forces (Rear)

D_a → Aerodynamic force acting on the body of the vehicle

h_a → Height at which the D_a acts

Rh_z → Vertical forces acting at the hitch point when the vehicle is towing a trailer

Rh_x → Longitudinal forces acting at the hitch point when the vehicle is towing a trailer.

B.CALCULATION OF LOADS:

The Fig. 8 represents the reactions for a vehicle in a gradient. Assuming clockwise direction as positive torque and taking moments about A,

$$w_f.L + {}^{W}/_{g}.a_x.h + w.\sin\theta.h - w.\cos\theta.c + Rh_z.d_H + Rh_x.h_h + D_a.h_a = 0$$

$$w_f = \frac{w.\cos\theta.c - Rh_x.h_h - {}^{W}/_{g}.a_x.h - w.\sin\theta.h - Rh_z.d_H - D_a.h_a}{L} \rightarrow (1)$$

Taking moments about B,

$$-w_r.L + w.\cos\theta.b + w.\sin\theta.h + {}^{W}/_{g}.a_x.h + D_a.h_a + Rh_z(d_h + L) + Rh_x.h_h = 0$$

$$w_r = \frac{w.\cos\theta.b + w.\sin\theta.h + w_g.a_x.h + D_a.h_a + Rh_z(d_h + L) + Rh_x.h_h}{L} \rightarrow (2)$$

Aerodynamic force = 0

Trailer hitch point force = 0

$a_x = 0$

Substituting the above in equation (1) and (2),

$$w_f = \frac{w.c - 0 - 0}{L}$$

$$w_f = \frac{w.c}{L} \rightarrow (3)$$

$$w_r = \frac{w.b - 0 - 0}{L}$$

$$w_r = \frac{w.b}{L} \rightarrow (4)$$

Assuming a load distribution of 33% and 67% in front and rear,

Load = 330 kg

At front,

w_f = 330 * 0.33

= 108.9 kg

w_r = 330 * 0.67

= 221.1 kg

Wheel base fixing as 200cm = 2000mm

From equation (3),

$$c = \frac{w_f.L}{w}$$

$$= \frac{108.9 * 2000}{330}$$

$c = 660mm$

From equation (4),

$$c = \frac{w_r.L}{w}$$

$$= \frac{221.1 * 2000}{330}$$

$c = 1340mm$

This vehicle consists of brakes attached to 4 wheels, so

F_{xf} = Braking force provided by the front wheels

$= \mu.W_f$

F_{xr} = Braking force provided by the rear wheels

$= \mu.W_r$

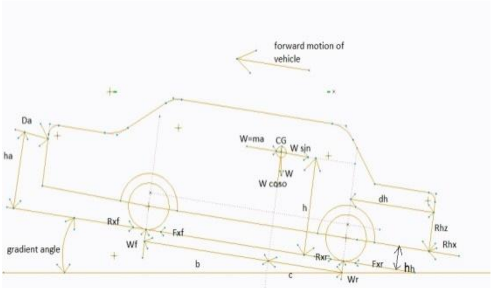


Fig .7 Reactions for a vehicle in gradient

Resolving the forces parallel to the plane. During braking inertia changes direction,

$$F_{xf} + F_{xr} + w.\sin\theta = {}^{W}/_{g}.a_x \rightarrow (5)$$

Resolving the forces perpendicular to the plane,

$R_f + R_r = w.\cos\theta$

Taking moments about G, the center of gravity of the vehicle

$(F_{xf} + F_{xr}).h + R_r.c = R_f.b$

Substitute,

$F_{xf} = \mu.W_f$,

$F_{xr} = \mu.W_r$,

$W_r = W.\cos\theta - W_f$

$\mu(W_f + W_r).h + (W.\cos\theta - W_f).c = W_f * b$

$\mu(W_f + W.\cos\theta - W_f).h + (W.\cos\theta - W_f).c = W_f * b$

$\mu W\cos\theta.h + W\cos\theta.c = R_f(b + c)$

$\mu W\cos\theta.h + W\cos\theta.c = R_f.L$

$$W_f = \frac{W\cos\theta(\mu.h + c)}{L}$$

$W_r = W\cos\theta - R_A$

$$= Wcos\theta - \frac{wcos\theta(\mu.h + c)}{L}$$

$$= Wcos\theta(1 - \frac{\mu.h+c}{L})$$

From,

$$\mu.W_f + \mu.W_r + W.sin\theta = {}^{w}/_{g}.a_x$$

$$\mu(W_f + W_r) + W.sin\theta = {}^{w}/_{g}.a_x$$

$$\mu(Wcos\theta) + W.sin\theta = {}^{w}/_{g}.a_x$$

$$a_x = \frac{\mu g(wcos\theta) + wgsin\theta}{w}$$

$$= \mu gcos\theta + gsin\theta$$

$$a_x = g(\mu cos\theta + sin\theta)$$

When vehicle moves on a level track,

$\theta = 0°$

So,

$$R_f = \frac{w(\mu.h + c)}{L}$$

$$= \frac{330*9.81(0.6*661+660)}{2000}$$

$$R_f = 1710.26N$$

$$R_r = w(1 - \frac{\mu.h + c}{L})$$

$$= 330 * 9.81\left(1 - \frac{0.6 * 661 + 660}{2000}\right)$$

$$R_r = 1527.03N$$

$a = \mu.g$

In g units,

$Deceleration, a = \mu$

Coefficient of friction between road and tire is 0.65 (asphalt road)

a_x = 0.65 (g units) [5]

Deceleration, a_x = 0.65*9.81

Maximum Deceleration, a_x = 6.375 m/s^2

Cg height is calculated as 661 mm.

C. DESIGN OF BRAKING:

$$F_f + F_r = w_a - k_r.w - k_a.A.v^2$$

F_f → Tractive force at front

F_r → Tractive force at rear

Resistance supports during braking. Neglecting the effect of resistance,

$$F_r.R = F_1.r.2$$

$$(\mu_R.R_{rdyn}).R = F_1.r.2$$

μ_R = Friction between ground and tire

D. MAXIMUM BRAKING FORCE:

$$F_f = \mu.W_{f\,dyn}$$

= 0.6*1710.26

F_f = 1026.156N

$$F_r = \mu.W_{rdyn}$$

= 0.6*1527.03

F_r = 916.218N

E. BRAKING TORQUE AT THE WHEELS:

R = 11''

R = 0.2794m

$$T_{Bf} = F_f.R$$

= 1026.156 * 0.2794

= 286.707 Nm

$$T_{Br} = F_v.R$$

= 916.218*0.2794

= 205.99 Nm

Also, at the disc

$$T_B = F_T.r_e$$

where,

F_T = Tangential force

F. EFFECTIVE RADIUS OF DISC:

$$r_e = \frac{r_1 + r_2}{2}$$

$$= \frac{63.5+88.9}{2}$$

= 76.2 mm

$$T_B = F_T.r_e$$

$$F_T = F_c.2\mu$$

μ = Friction between pads and disc

$$T_B = F_c.2\mu.r_e$$

$$F_c = \frac{T_B}{2\mu.r_e}$$

$$F_{cf} = \frac{236.707}{2 * 0.4 * 0.0762}$$

= 4703.19 N

$$F_{cr} = \frac{255.99}{2 * 0.4 * 0.0762}$$

= 4197.83 N

G. MASTER CYLINDER AND CALIPER:

Diameter of the caliper = 1''

= 25.4 mm

Area = $\frac{\pi}{4}.d^2$

= 506.707 mm

Pressure developed in the caliper, P = $\frac{F_{cal}}{n*A_{cal}}$

$$= \frac{4703.19}{2*506.707}$$

P = 4.64 N/mm^2

$F_1.a = F_2.b$

$200\ (\frac{a}{b}) = F_2$

$F_2 = 1200\ N$

According to Pascal’s law, pressure at all points is same so,

$P_{master} = P_{calliper}$

$F/_A = 4.64\ N/mm^2$

$1200/_A = 4.64$

$A = 258.6\ mm^2$

$\pi/_4\ d^2 = 258.6$

$d = 18.15\ mm$

$d^2 = \frac{258.6*4}{\pi}$

$d = 18.14mm$

$d = 1.8cm$

Master cylinder diameter = 1.8cm

H. STOPPING DISTANCE:

$s = \frac{v^2}{2f}$

Maximum speed of 60 km/hr = 16.66 m/s^2

$s = \frac{(16.66)^2}{2*0.6*9.81}$

$s = 23.57\ m$

IV. INDEPENDENT BRAKING SYSTEM

The entire braking system is designed and the placing of solenoid valves between the hoses must be made and switches to control the system must be placed. The solenoid valve used is shown in Fig. 9 .

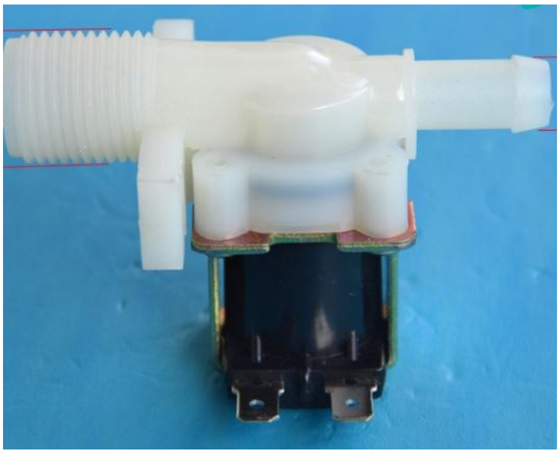


Fig . 8 Electronic solenoid valve

The placing of a motor operated solenoid valve can be used to restrict the flow of the brake fluid and to send the fluid to the calipers.

The complete layout of this system is shown in Fig. 10. It makes use of solenoid valves and brake hoses and manual switches, to precisely control the braking of wheels, thereby controlling the dynamics of the vehicle.

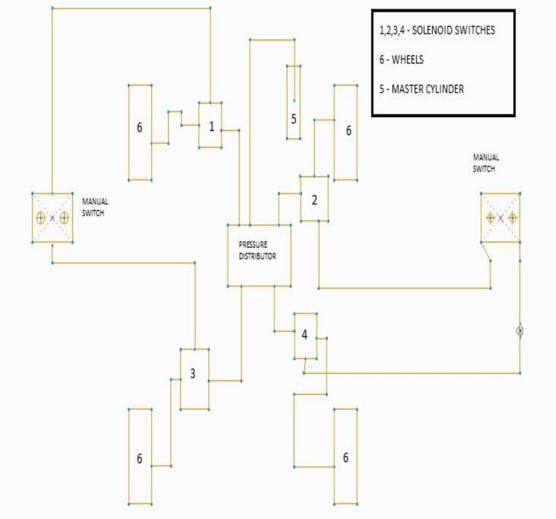


Fig . 9 Layout of the system

V. YAW CONTROLLER

The yaw motion controller can be done with the help of a sensor which detects the yawing motion and it is sent to the ECU and according to the response the brakes are applied at different wheels to lock it. It is shown in Fig. 14 .

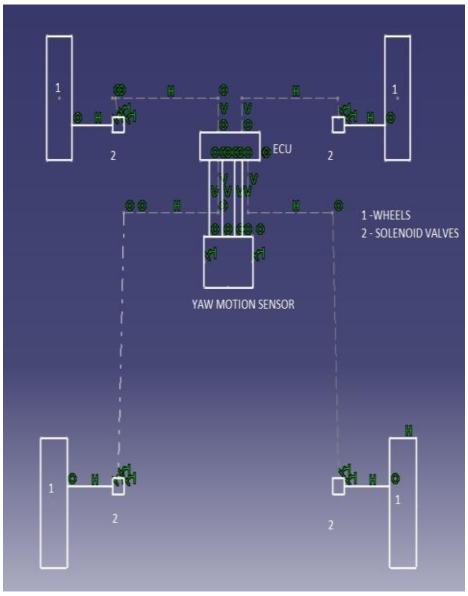
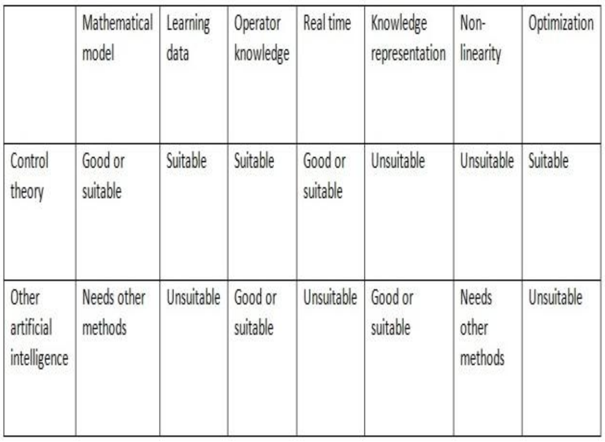


Fig. 10 Yaw controller system

In the present survey we explored the techniques of solution procedures of different control policies such as classical and intelligent control strategies.

TABLE 1.Comparison of capabilities of different adaptive methodologies:



	Mathematical model	Learning data	Operator knowledge	Real time	Knowledge representation	Non-linearity	Optimization
Control theory	Good or suitable	Suitable	Suitable	Good or suitable	Unsuitable	Unsuitable	Suitable
Other artificial intelligence	Needs other methods	Unsuitable	Good or suitable	Unsuitable	Good or suitable	Needs other methods	Unsuitable

VI.CONCLUSION

This concept proved well about controlling the dynamics of the vehicle and improving the lap timings. This concept can be well applied to cars like FSAE and SUPRA to get maximum efficiency during cornering and decreasing the lap timing. If a skilled driver is there, then maximum control of the vehicle can be done by him, leading to increase in speed of the car. The Matlab results have been generated for braking forces for various coefficient of friction values [3].

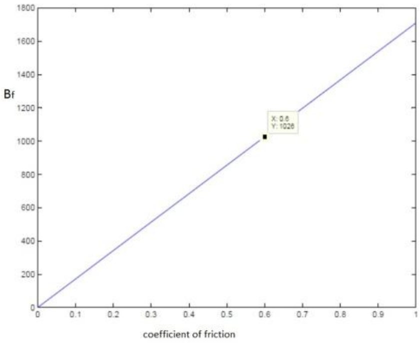


Fig . 11 front axle braking force

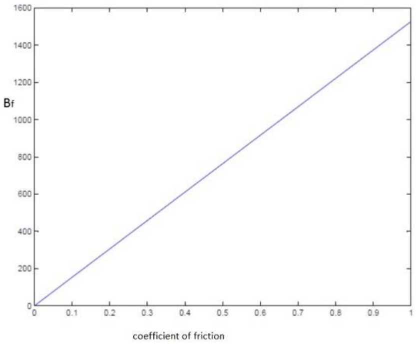


Fig . 12 rear axle braking force

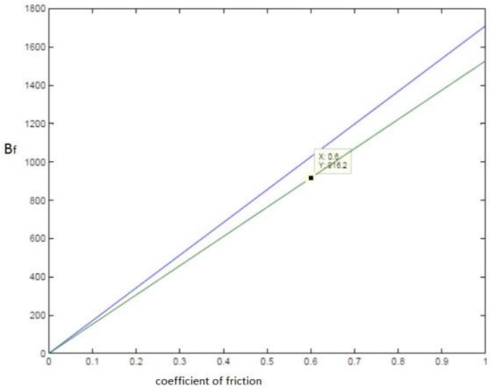


Fig . 13 Variation of front axle and rear axle braking force

In this the B_f represents braking force. This graph will be useful for predicting the braking force for different values of friction [3].

Brake control to handle the car is highly a difficult control problem for a non-skilled driver due to the complicated relationship between its components and parameters. The researches were carried out in broad range of design issues and challenges.

Acknowledgment

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