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Review Article

PARAMETRIC STUDY AND EXPERIMENTAL EVALUATION OF VEHICLE TIRE PERFORMANCE

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The purpose of this review paper is to study of effect of the different tire operating parameters on tire performance and review of testing setup to test these tire performance parameters. The testing of tire performance parameters by experimentally is help to designer to correlate the relationships of parameters and to design the tire, hence it is need to testing of tire. Knowledge about dynamic properties of tires is an essential for any kind of research and development activities on vehicle dynamics. The main purpose of laboratory testing is to separate the properties of the tire from the vehicle, achieve high rate of reproducibility and to optimize the cost. This review paper gives the information regarding of different researcher's works on inter laboratory tire testing setup for measuring tire performance parameters and also this review paper helps to understand the factors on which tire performance parameters is depends.

Keywords: Inter laboratory, Review, Tire parameters, Tire performance

INTRODUCTION

The pneumatic tire plays an increasingly important role in the vehicle performance of road. However, this status is achieved because of more than one hundred years' tire evolution since the initial invention of the pneumatic tire by John Boyd Dunlop around 1888. Tires are required to produce the forces necessary to control the vehicle. As we know that the tire is the only means of contact between the road and the vehicle but they are at the heart of vehicle handling and performance (Nicholas, 2004). The inflated rubber structure provides comfortable ride for transportation. With the growing demand for the pneumatic tire, many improvements have been made based on the initial conception, such as the reinforcement cords, the beads, the vulcanization, the materials and the introduction of the tubeless tire. The relationship between human and tire and environmental surrounding play an important role for developing of tire technology. These concerns include traffic accidents caused by tire failure, the waste of energy due

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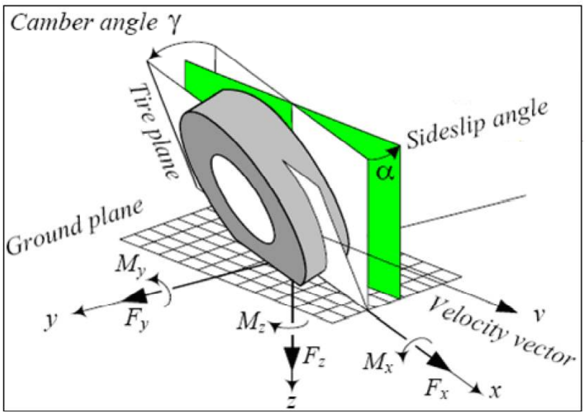
to bad tire conditions, the pollution through the emission of harmful compounds by tires, and the degradation of road surfaces related to tire performance, etc.

Tire as one of the most important components of vehicles requires to fulfill a fundamental set of functions are to provide load-carrying capacity, to provide cushioning and dampening against the road surface, to transmit driving and braking torque, to provide cornering force, to provide dimensional stability, to resist abrasion (Mir Hamid, 2008). Tires have ability to resist the longitudinal, lateral, and vertical reaction forces from the road surface without severe deformation or failure. Tire performance is depends on the tire rolling resistance, cornering properties, tire traction, tire wear, tire temperature, tire noise, tire handling and characteristics, etc. There are various losses associated with the vehicle that affect its fuel economy as it is being operated. These losses include engine, driveline, aerodynamic and rolling losses, while the rolling loss is associated with the vehicle tires. This papers tells about the theoretical study about the tire background, tire axis terminology, tire performance parameters, experimental setup available for this parameters, and survey on tire testing setups available for tire testing.

TIRE AXIS TERMINOLOGY

It is need to understand some of the basic terminology for tire, especially regarding the systems of coordinates, orientations, velocities, forces, moments. Nomenclature and definitions based on the SAE standard as shown in Figure 1 X-axis is the intersection of the wheel plane and the road plane with positive direction forward. The Z-axis perpendicular to the road plane with positive direction downward. The Y-axis in the road plane, its direction being chosen to make the axis system orthogonal and right hand. There are several forces, moments and angles that prove to be very important in tire behavior. All these forces can be seen as the forces and moments acting on the tire from the road. First, there are two main angles to consider, the camber angle and the slip angle. The camber angle is the inclination angle from its vertical position while the slip angle is the difference in wheel heading and direction.

Figure 1: Tire Axis Terminology



Forces include the longitudinal force in the X direction, the lateral force in the Y direction and the normal force in the Z direction. Longitudinal force (F_x) is the result of the tire exerting force on the road and becomes negative during braking. The lateral force (F_y) is the resultant of the forces produced by a non-zero camber angle and by a non-zero slip angle during cornering. Normal force (F_z) can also be viewed as the negative of the upward vertical force. Moments include the overturning moment, the rolling resistance moment, the wheel torque and the aligning moment. The overturning moment (M_x) is caused by a lateral shift of the vertical load during cornering. Rolling resistance (M_y) is created by various factors that lead to a loss of energy. The aligning moment (M_z) also known as the self-aligning torque, produces a restoring moment on the tire to realign the direction of travel with the direction of heading when the slip angle is non-zero. It should also be noted that there is also a moment produced by the axle on the wheel (Nicholas, 2004).

PERFORMANCE PARAMETERS

Tire performance is affected by the rolling resistance, tire wear, tire noise, tire temperature, cornering properties.

Rolling Resistance

When a tire rolls on the road, mechanical energy is converted to heat as a result of the phenomenon referred to as rolling resistance. Effectively, the tire consumes a portion of the power transmitted to the wheels, thus leaving less energy available for moving the vehicle forward. Rolling resistance therefore plays an important part in increasing vehicle fuel consumption. The rolling resistance of tires on hard surfaces is primarily caused by the hysteresis in tire materials due to the deflection of the carcass while rolling. Friction between the tire and the road caused by sliding, the resistance due to air circulating inside the tire and the fan effect of the rotating tire on the surrounding air also contribute to the rolling resistance of the tire, but they are of secondary importance (Berng, 2011). Available experimental results give a data of tire losses in the speed range 128-152 km/h (80-95 mph) as 90-95% due to internal hysteresis losses in the tire, 2-10% due to friction between the tire and the ground, and 1.5-3.5% due to air resistance. Fuel consumption is the most important topic of discussion in the automotive industry today. Tire energy losses are responsible for about 25% of the total fuel consumption of a typical passenger car. The coefficient of rolling resistance of the first tires in 1900 was approximately 0.025. This value was reduced by 50% to 0.013 with the introduction of radial tires in 1946. The introduction of silica fillers in 1992 further reduced resistance to 0.008. Rolling resistance is the effort required to keep a given tire rolling. Its magnitude depends on the tire used, the nature of the surface on which it rolls, and the operating conditions inflation pressure, load and speed. Rolling resistance has historically been treated as a force opposing the direction of travel, like a frictional force. A more general concept is in terms of the energy consumed by a rolling tire. Driving resistances can be divided into two categories one is steady-state resistances and second is dynamic resistances. Steady-state resistances occur when a vehicle is running at a constant speed, rolling resistance, aerodynamic drag and climbing resistance fall in to this categories. Dynamic resistance occurs when vehicle is accelerating, this type of resistance occurs due to the vehicle inertia (Berng, 2011). The rolling resistance of a wheel (F_R) is made up of four components. The sum of these components is equal to the total rolling resistance Components such as Tire rolling resistance (F_R, T),Road rolling

$$F_R = F_R, T + F_R, Tr + F_R, \alpha + F_R, fr \qquad ...(1)$$

Resistance (F_R, Tr) Resistance due to tire slip angle (F_R, α) Resistance due to bearing friction and residual braking (F_R, *fr*) (Berng, 2011). Tire rolling resistance is depends upon the following parameters.

Tire Temperature

The temperature of the tire has significant effect on rolling resistance of tire. Increasing of rolling resistance of tire is due to the deflection and energy loss in the material.

Tire Inflation Pressure and Load

Tire inflation pressure determines the tire elasticity and combination with load, determines the deflection in the sidewalls and contact region. The overall effect of rolling resistance is depends on the elasticity of the ground. On the soft surfaces like sand, high inflation pressure results in increased ground penetration work and therefore higher coefficients while the lower inflation pressure decreasing ground penetration. Thus the optimum pressure depends on the surface deformation characteristics.

Speed of Vehicle

The rolling resistance is directly proportional to speed because of increasing of flexing work and vibration in the tire body. Influence of speed becomes more important when combines with lower inflation pressure.

Tire Material Design

The material and thickness of both the tire sidewalls and the tread determines the stiffness and energy losses in the rolling tire. The cord material in the sidewall has only a small effect, but the cord angle and tire belt properties have significant influence on rolling resistance of tire.

Tire Slip Angle

Wheels Tractive and braking forces shows higher effects on rolling resistance due to the wheel slip angle. At a few degree of slip the rolling resistance coefficient may nearly double in the magnitude (Thomas, 1992).

Tire Wear

The wear performance of a tire is its ability to reach high mileages. One way of evaluating this wear performance is consider the duration of tire service life, which is the mileage after which a point on the tread has reached the legal limit of the wear indicator. The duration of a tire's Service life depends on the mass loss from the tread, which is usually expressed in g/100 km, and by the transverse worn profile which enables the wear shape of the tread to be qualified. The duration of a tire's service life depends on the condition in which the tire is used, that is the type of driver and the geographical area. Wear is depend upon many parameters, which gives designer to modification tire force applied on tire or changes in rubber or ground surface (Olivier *et al.*, 1998).

Road Surface and Styles of Driving

Depending upon the route and the style of driving, the acceleration levels reached by the vehicle may vary. These acceleration levels modify the forces applied to the tire. The system of loads causing wear in the contact patch (sliding, stresses) is directly proportional to these forces. The effect of the style of driving can be quantified by measuring the tire wear on the same vehicle driven by different drivers over the same course (Olivier *et al.*, 1998).

Tire

The tire is the link between the vehicle and the ground and therefore has a major effect on wear. The most important tire parameters acting on wear are the first one is to different stiffness which determine the shape, stress and slip in the contact patch second one is the rubber volume available for wear, which is correlated to geometrical characteristics of both tire (width, diameter) and tread (rubber thickness and the tread pattern percentage) and third one is the material characteristics of the tread such as friction and abrasion. Hence, the facts that tire size choice and inflation pressure are first order parameters for the wear performance of the tire. This difference is due to the variation in rubber volume and stiffness between the two tires. The inflation pressure of the tires also has a great influence on wear and worn profile. It acts on the shape of the contact patch and on the tire's stiffness (Olivier *et al.*, 1998).

Seasonal Effects

Environmental parameters such as temperature and humidity are very season-dependent. These parameters have a very substantial influence on the rubber/ground interface characteristics and therefore on wear (Olivier *et al.*, 1998).

Vehicle Weight

When the vehicle is travelling on the road weight of the vehicle is acts as force and it directly applied on tire. The average life of tire may vary within the range of 50% or the depending upon the vehicle characteristics. The vehicle characteristics of the greatest influence are weight, suspension and steering geometry. The axle geometry factor such as toe and camber angle is influence on mass loss and worn profile of tire (Olivier *et al.*, 1998).

Tire Noise

When the tread of a tire rolls into contact the void areas in the tread pattern compress and air force out of the voids take place, when the tread element leave contact the voids expands and air rushes in back in due to this repetitive compression and expansions of the tread voids known as air pumping and it can cause significant tire noise. Tire or road noise contributes the maximum percentage of noise is 30% after the engine noise 34%. It is understand that the effect of roughness of road surface, effects of exciting force due to pattern such as lug grooves in tread surface, effects of driving torque of tires under an accelerating period etc. are considered as the exciting force generating tire/road noise (KejirioIiwao and Ichiro, 1996). It is found the sound pressure level is depends upon roughness of the road surface. Tire/road noise dependant not only upon exciting force due to the tread pattern and roughness of the road surface, but also largely depends upon the structure of tire such as thickness of the tread blocks (KejirioIiwao and Ichiro, 1996).

Cornering Properties

One of very important function of a tire is to develop the lateral forces necessary to control the direction of the vehicle, generate lateral acceleration in corner or for lane changes, and to resist the external force such as wind energy and road cross-slope. These forces are generated either by lateral slip (slip angle) of the tire, by lateral inclination (camber angle) or the combination of two angles. When a rolling tire is subjected to a lateral force, the tire will drift to the side so therefore there angle will be created between the direction of tire heading and the direction of travel this angle is known as a "slip angle". When the tire travels forward tread of tire come in contact with the road but they are undeflected from their normal position and therefore it unable to developing lateral force. But as tire travels forward at some angle direction of travel, the tread elements remain in the position of their original contact with the road and therefore deflected sideways with respect to the tire, by this process the lateral force is developed. The lateral force behavior of rolling tire is characterized only in the steady state that is at constant load and slip angle. When the slip angle is zero the lateral force is zero, at the slip angle is going to increase the lateral force developing rapidly and linearly. At the large slip angle behavior of wheel is locked, which has a lateral force equal to the sine angle resultant of the sliding coefficient friction (μ_s), times the vertical load (F_Z). The ratio of lateral force (F_Y) to the slip angle ($\propto$) is called the "cornering stiffness".

$$C_{\propto} = \frac{F_Y}{\propto} \quad \text{...(2)}$$

From the following equation we get the central to drag force ratio which reduces with slip angle, higher cornering stiffness is. The reason for this is that a given central force will be achieved at smaller slip angles and therefore results in lower tire drag force. The central/drag ratio is given as follows:

$$\frac{Fs}{Fd} = \frac{C_{\propto} \cdot \alpha \cdot \cos(\alpha)}{\mu_R \cdot F_V + C_{\propto} \cdot \alpha \cdot \sin(\alpha)} \quad \text{...(3)}$$

Cornering force at the given slip angle rises with the vertical loading on tire but It's doesn't rise proportionately with load while, the maximum cornering force per unit load occurs at the lightest loads. Due to inflation pressure carcass stiffness is increases but simultaneously reduces the contact length of the tire it influences on cornering stiffness of tire. Tread rubber acts as a series spring in the generation of lateral force with respect to slip angle. Therefore tread design has a potential influence on cornering stiffness. Cornering stiffness is influenced by one factor is "aspect ratio" is nothing but the section height to section width, as the increasing the width and decreasing the height of the tire there is increasing cornering stiffness is proved by experimentally in currently used tire. The cornering stiffness is dependent upon on many variables like tire size and type, number of plies, cord angle, wheel width, and tread design (Thomas, 1992).

Tire Temperature

Tire behavior is largely dependent upon tire temperature. Temperature of tire is affect on tire's adhesion, ride comfort, wear, and rolling resistance, hence it is important to measure tire temperature during testing and include temperature effects in any simulations of tire behavior. There is also a direct relationship between tire temperature and the power loss in the tire. The effects listed above depend mainly on the temperature of the rubber in the tire's tread surfaces. This temperature can be measured using various methods ranging from simple insertion measurements at the end of a test run to complex high speed infrared cameras. Another temperature measurement technology, developed at TUV Sud Automotive and known as T3M, uses a microsensor embedded in the rubber of the tire's tread surface. These measured values can be evaluated and modeled with respect to the tire's adhesion, durability, and wear properties (Berng, 2011).

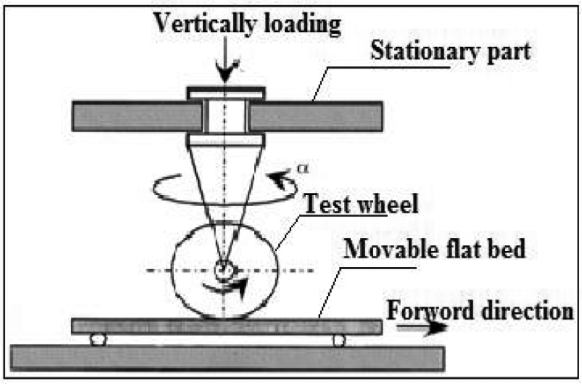
EXPERIMENTAL SETUP FOR TESTING TIRE PARAMETERS

Different research centers and researchers have used following tire test machine for measuring tire forces and moments, rolling resistance, braking and traction efforts, and cornering characteristics.

Flat Bed Tire Testing Machine

The test surface is travelling table. Due to limited stroke, the test speed is considerably lower than actual tire operating speed and the steady state working conditions cannot be achieved as seen following Figure 2. This construction is very useful in determination of the static elastic properties of tires and is used by researcher for years (Ergin and Samim, 2001).

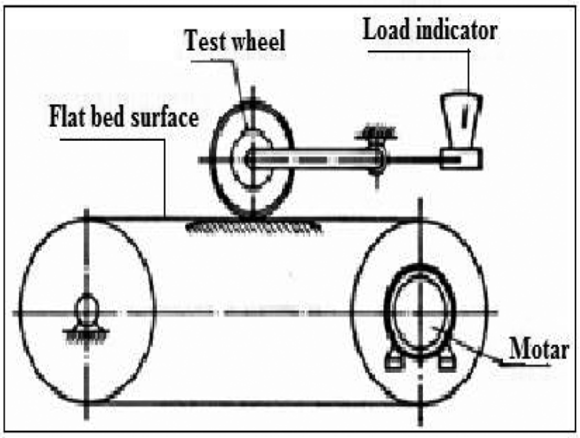
Figure 2: Flat Bed Tire Testing Machine



Flat Surface Tire Testing Machine

Flat bed tire testing machine is probably caused by limited stroke of the table to overcome this problem there is use of infinite belt as seen Figure 3. Due to the high force

Figure 3: Flat Surface Testing Machine

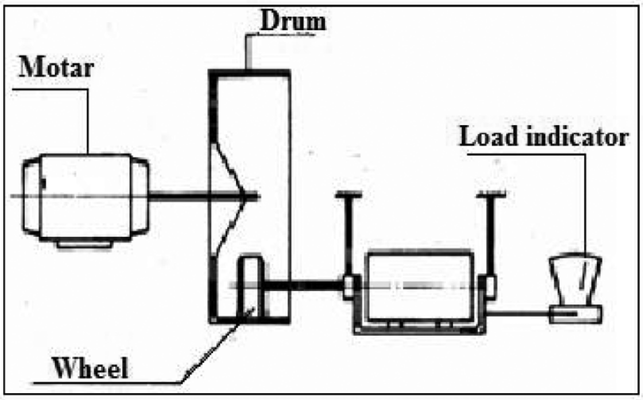


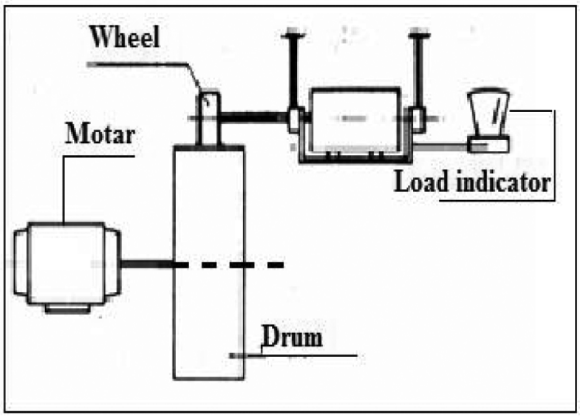
generated by the test tire, a bearing to support the belt used. To control the belt tension and position one of the drum carrying the belt is positioned by a feedback control system. Some flat surface test machine may reach road speeds of 0-250 km/h, and the surface coating and temperature may be controlled to simulate different road condition. Flat surface test setup is used to test parameters like rolling resistance, tire wear, tire temperature, tire noise, cornering stiffness of tire (Ergin and Samim, 2001).

Drum Type Tire Testing Machine

Due to the complexity of flat surface test machine there is development of drum type tire testing machine as seen Figure 4. The test surface is either internal or external surface of drum. In both case contact patch is distribution is different than flat surface test machine. The test results are comparative among different tires and mostly cannot be extrapolated to flat surface. Drum type test machines are used to test the parameters like rolling resistance, tire wear, tire temperature, tire noise, cornering stiffness of tire (Ergin and Samim, 2001).

Figure 4: (a) Internal Drum Tire Test; (b) External Drum Tire Test

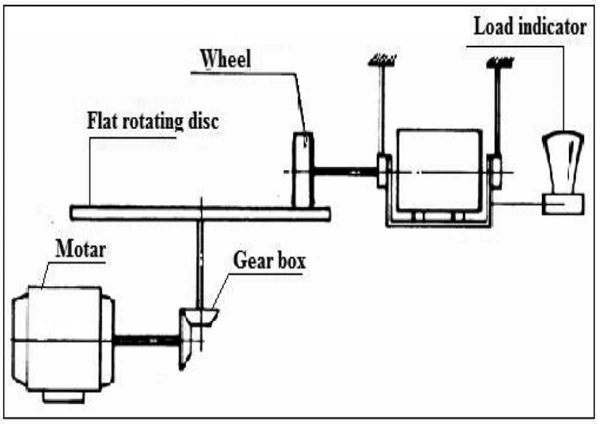




Flat Rotating Disc Type Tire Testing Machine

To eliminate the effects caused by drum curvature, a flat rotating disc was used as seen in Figure 5. However, due to the finite width of the tire tread, the rotational speeds of the inner and outer tread edges are different, which results in slip in the contact area

Figure 5: Flat Rotating Disc Type Tire Testing Machine



SURVEY ON TIRE TESTING SETUP

The main purposes of laboratory testing is to separate the properties of the tire from those of the vehicle, achieve a high rate of reproducibility and optimize costs. Laboratory testing can also be used to conduct tests of absolute strength, which cannot be performed during vehicle testing due to safety considerations. In this paper we discuess the three methods, these methods includes rolling drum type testing machine, Flat-Trac rolling machine and twin rolled test rig.

Ergin and Samim (2001) have studied on prediction of cornering force by finite element modeling and analysis. For the prediction of tire cornering force characteristics two distinct type of models analytical and empirical model and physical tire model have been developed. They observed that lateral cornering force developed by tire was strongly affected the direction control and stability of the vehicle, depends upon the slip angle at which tire is operating, inflation pressure, vertical tire loading. They discuses the methods available for tire testing which includes flat bed tire testing machine, flat surface tire testing machine and drum type tire test machine. For the experimentally verification they tested tire on drum type machine. For testing of tire they choose brand new tire 155 R13 on which up to 500 N load is applied and this test conduct on 0-60 km/h. Their study says that with the help of this finite element model the cornering force characteristics of a tire can be estimated without going to lengthy and expensive process of prototype manufacturing and testing.

Padmanabha (2004) have studied on effect of overload and inflation pressure on rolling resistance and fuel consumption for truck/bus tires. For the experimental verification they used 1.7 m cylindrical diameter drum and rolling resistance were measured according to SAE J1269. By adjusting tire load, pressure condition they finding the rolling resistance. This test is done on SAE J1269 for measuring rolling resistance. Through this research paper they found that a truck or bus tires carrying 100% load consumes more than twice the amount of fuel compared to normal load. They suggest the possible method for optimizing fuel consumption by adjusting load and pressure conditions.

Nikola *et al.* (2011) have studied on finite element analysis of a tire steady rolling on the drum and its results compared with experimentally. They developed a CAD model of rolling on the drum which was used to quickly find out the optimal tire design parameters. Equipment and methods have been used for experiment determination of braking and cornering characteristics of the tire as well as for experimental determination of friction of coefficient of tire tread. For experimental testing of tire parameters they used drum diameter 1219 m and uses maximum speed of 150 km/h. For the cornering test they vary slip angle from –10 degree to +10 degree. Through this research paper they found that the differences between experimental and numerical results were decreased after the calibration of friction has been performed and also they found that CAD model is help for designer to quickly find out the optimal values of tire design parameters.

Parmeet and Sid (1999) have studied on testing of tire rolling resistance according to the SAE J2452 and to compare results with the new parameters. The new parameters are Mean Equivalent Rolling Force (MERF) and Standard Mean Equivalent Rolling Force (SMERF) are mathematically derived and comparing with inter laboratory rolling resistance data as per SAE J2452. They told that SAE J2452 is the new test method for measuring rolling resistance on drum machine in the laboratory, this method is able to test rolling resistance at different load, speed and inflation pressure condition. They told that MERF and SMERF values are helpful to compare directly for two tire at given load and pressure.

Clark and Dieter (1998) have studied on inter laboratory test for tire rolling resistance. The major objectives of these test is to examine the rolling resistance equipment measuring device and to study the effect of test wheel diameter on rolling resistance. The test were organized a group of five types of passenger car tires. Texture surface were tested by four methods force, power, torque, cost- down time. They use conversion of drum type results in to flat track. They told that drum diameter is effectively affected on rolling resistance, as the decreasing the drum diameter rolling resistance is increases. From this experiment they conclude that tire type and tire pressure had strong effects on rolling resistance. The tire were tested on flat surface as well as on variety of drum and best correlation between rolling resistance and drum diameter were obtained.

CONCLUSION

From the literature survey we observed that tire performance is affected by rolling resistance, tire wear, tire temperature, cornering properties, tire noise, etc., from this parameters we conclude that rolling resistance having the major contribution in the tire performance and fuel economy of the vehicle. Tire performance parameters we can test by the drum type, flat-track type, flat bed type testing rig and flat rotating disc type from this above four type we observed that drum type is the simplest in construction, manufacturing and to design than the other test rig. Reactions at the tire affects the dynamic performance of the vehicle, hence it is need to test the tire performance parameters and to optimize those parameters for improvement in the fuel economy.

REFERENCES

1. Berng Heibing (2011), *Chasis Handbook*, *ATZ Technology*, 1st Edition, pp. 35-50.
2. Clark S K and Dieter J Schuring (1998), "Interlaboratory Tests for Tire Rolling Resistance", *Journals of SAE*, 780636, pp. 1-8.
3. Ergin Tonouk and Samim Unlusoy Y (2001), "Prediction of Automobile Tire Cornering Force Characterstics by Finite Element Modeling and Analysis", *Journals of Computers and Structures*, Vol. 79, pp. 1219-1232.
4. Hans B Packeja (2005), *Tire and Vehicle Dynamics*, 2nd Edition, pp. 472-476, Delft University Technology.
5. KejirioIiwao and Ichiro Yamazaki (1996), "A Study on the Mechanism of Tire/Road Noise", *Journals of Science Direct*, Vol. 17, pp. 139-144.
6. Mir Hamid Reza Ghoreishy (2008), "A State of the Art Review of the Finite Element Modelling of Rolling Tyres", *Iranian Polymer Journal*, Vol. 17, No. 8, pp. 571-597.
7. Nicholas D Smith (2004), "Understanding Parameters Influencing Tire Modeling", *Journals of SAE Dynamics*, pp. 1-22.
8. Nikola Korunoviæ, Miroslav Trajanoviæ, Miloš Stojkovic, Dragan Mišiæ and Jelena Milovanovic (2011), "Finite Element Analysis of a Tire Steady Rolling on the Drum and Comparison with Experiment", *Journals of Mechanical Engineering*, Vol. 57, pp. 888-897.
9. Olivier Le Maitre, Manfred Sussner and Cesar Zarak (1998), "Evaluation of Tire Wear Performance", *Journals of SAE*, 980256, pp. 43-48.
10. Padmanabha S Pillai (2004), "Effect of Tyre Overload and Inflation Pressure on Rolling Loss (Resistance) and Fuel Consumption of Automobile Truck/Bus Tyres", *Indian Journals of Engineering and Material Science*, Vol. 11, October, pp. 406-412.
11. Parmeet S Grover and Sid H Bordelon (1999), "New Parameters for Comparing Tire Rolling Resistance", *Journals of SAE*, 1999-01-0787, pp. 1-8.
12. Thomas D Gillespie (1992), *Fundamentals of Vehicle Dynamics*, pp. 335-337, Society of Automotive Engineering.

APPENDIX

Nomenclature			
F_X	Longitudinal force	F_α	Cornering stiffness
F_Y	Lateral force	α	Slip angle
F_Z	Normal force	F_R	Total rolling resistance
M_X	Overturning moment	F_R, T	Tire rolling resistance
M_Y	Rolling resistance moment	F_R, Tr	Road rolling resistance
M_Z	Aligning moment	F_R, α	Resistance due to slip angle
F_R, fr	Resistance due to bearing friction and residual braking	Fd	Drag force
		Fs	Force component perpendicular to travel