Stiffness analysis of passenger car tire using Nitrogen

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Abstract- The objective of this paper is to compare vertical stiffness of inflation fluid air and nitrogen to increase capacity of tire normal force and then improve vehicle stability. Tire Stiffness is important to provide comfortable ride for passenger and also prevent damage to the working parts. The stiffness of Tata Nano car tire having size P135/70R12 in the radial [or vertical] direction is measured. This information is based on the measurement of single tire at inflation pressure [1.3, 1.7, 2, 2.4 and 2.7bar] and vertical load range [300 400,500,600,700 and 800kg] for different inflation fluid inside the tire. Experimental verification of vertical stiffness is done for P135/70R12 tire by using load-deflection test conducted for different inflation pressure, inflation fluid and load under static condition. To design mathematical model of undamped spring mass system under harmonic force. The minimum vertical amplitude is obtained from theoretical analysis at given load and pressure for different fluid.

Index Terms- Amplitude, Inflation pressure and fluid, load-deflection characteristics, Tire vertical stiffness, undamped system.

I. Introduction

An effective performance of car tires depends on tire size, tire pressure, vehicle load, resistance to aging, resistance to wear etc. The tires must be large and strong, enough to support the vehicle on road the tire must absorb by deflecting part of the shock from road irregularities. Stiffness of a tire plays an important role for a comfortable ride for passenger also protecting the chassis and other working parts from getting damaged due to road irregularities. A small radial ply drive tire was chosen for rolling and non-rolling test at different inflation pressure[1].The maximum change in area about 70% was observed in the range of pressure from 1 bar to about 2 bar deflection. Taylor (1996) examined potential equations to describe the relationship between load and deflection[2].Efficiency of tire tube development in integrating, analysis and simulation into design, testing and manufacturing process. The analysis of tire tube fluid dynamic properties by study and simulation using CFD tools. The various properties taken into account are static pressure, dynamic pressure and radial velocity[3]. The stiffness of the tire when it is stationary is usually greater than when it is rolling. Stationary tire stiffness is more dependent other factor such as amplitude and frequency than rolling tire stiffness[4].The quasi-static behavior stationary automobile tire vertically loaded against a horizontal surface was successfully investigated using LS-DYNA3D simulation[5]. static and dynamic tire test was conducted the tire carcass shape was measured and the footprint dimension of the tire were determined at various tire inflation pressure and normal loads using cleats with different dimensions the modal analysis was also determined the vibration mode and natural frequencies of the tires[6,8].

The objective is to determine the vertical stiffness of a P135/70R12 passenger TATA Nano car drive tire using the Load-deflection method. This measurement is to establish value of tire stiffness which could be used for vehicle simulation and to observe the value changed under different conditions. Compare the stiffness characteristics of tire at different inflation pressure and different static load and different inflation fluid e.g. compressed air and nitrogen. The compressed air inside a tire expands when heated and contracts when cooled. Nitrogen will not fluctuate as much.

Nitrogen provides constant pressure and is less susceptible to diffusion caused by changing temperatures [3]. In present work design a mathematical model for response of undamped spring mass system under harmonic force and response of undamped system under harmonic motion of the support.

In the present work P135/70 R12 passenger car tyre is used where P indicates for passenger vehicle, 135 identifies the section width in millimeters, 70 identifies the ratio of the tyre cross-sectional height (The distance between the tip of the tread to the bead seat) to that of the section width (the outermost distance between the tire walls), R indicates a radial tire and 12 identifies the wheel rim diameter in inches.

II. MATHEMATICAL MODELING

A) Response of an undamped system under Harmonic Force:

An undamped system subjected to a harmonic force

F (t) = $F_0 \sin wt$ acts on mass *m* of an undamped system

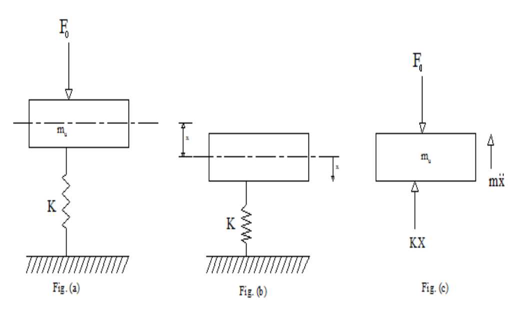


Fig.(a) Equilibrium position Fig.(b)-Displacement position Fig.(c)- F.B.D.

The equation of motion

$$m\ddot{x} + kx = F_0 \sin wt \qquad (1)$$

The solution of equation

$$x_c = c_1 \cos\omega_n t + c_2 \sin\omega_n t \qquad (2)$$

$$x_p = X \sin\omega t \qquad (3)$$

X= Maximum Amplitude of x_p

$$(X) = \frac{F_0}{K - m\omega^2}$$

$$(X) = \frac{\delta_{st}}{[1-\left(\frac{\omega}{\omega_n}\right)^2]} \qquad (4)$$

The Total solution of equation (1) becomes,

$$X(t) = c_1 \cos\omega_n t + c_2 \sin\omega_n t + \frac{F_0}{K - m\omega^2} * \sin\omega t$$

Using initial condition, $X(t=0)=x_0$ and $\dot{x}(t=0) = \dot{x}_0$

$$2x(t) = [x - \frac{F_0}{K - m\omega^2}] \cos\omega n\, t + (\frac{\dot{x}_0}{\omega_n}) \sin\omega n\, t + [\frac{F_0}{K - m\omega^2}] \sin\omega t \qquad (5)$$

This equation (5) obtained complete solution by superposition of transient and steady state vibration.

B) Response of an undamped system under Harmonic motion of the Support:

The tire is modeled as a linear spring without damping. The support is excited by a sinusoidal motion $y=Y \sin\omega t$

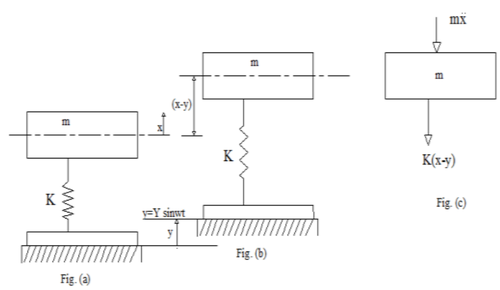


Fig.(a)- Equilibrium position Fig.(b)- Displacement position Fig.(c)- F.B.D.

x=Displacement of mass 'm' from its equilibrium position
y= Displacement of support

$$y = Y \sin\omega t \qquad (6)$$

The differential equation of motion is

$$m\ddot{x} + Kx = Y\ K \sin\omega t \qquad (7)$$

The equation (xi) is known as Differential equation of motion an undamped system which is similar to a linear second order differential equation of motion

For Steady State Amplitude (X)

$$(X) = \frac{Y}{[1-\left(\frac{\omega}{\omega_n}\right)^2]} \qquad (8)$$

X = Steady state Amplitude
Y = Amplitude of Sine curve (m)

III. EXPERIMENTAL ANALYSIS

A small passenger Nano car tire P135/70R12 was selected for this study, a pivoting test frame was constructed with a length L of 1235mm from the pivot to the Axle center. For vertical deflection test consisted of a mild steel base plate with an inverted u-shaped bracket to support the axle. The distance from the base plate to the tabs was 450mm, which placed the axle center 470mm from the base plate.

Fig.1 Experimental Setup

1. Hydraulic jack, 2.vernire height gauge, 3.Tested tire, 5.hydraulic pump, 6.pressure gauge 4, 7 supporting frame

Vertical load applied by using hydraulic jack at different inflation pressure. A vernire height gauge having least count 0.02mm was used to measure vertical displacement from the axle. Test is conducted at five pressure (1.3, 1.7, 2, 2.4 and 2.7bar) by increasing the static load and measuring static loaded radius (SLR) as the tire rested on a smooth metal The vertical load (300,400,500,600,700 and 800kg) applied on the test frame for fluid Air and Nitrogen.

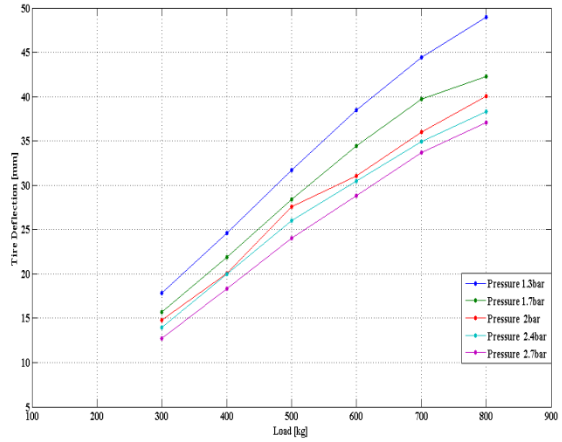
IV. RESULT ANALYSIS

The experimental results are obtained by varying stiffness parameters as follows

A) Effect of change in inflation fluid Air

Load [kg]	Tire Deflection [mm]				
	1.3 bar	1.7 bar	2 bar	2.4 bar	2.7 bar
300	17.8	15.7	14.8	14	12.72
400	24.6	21.9	20.10	20	18.34
500	31.7	28.44	27.6	26	24.02
600	38.5	34.4	31.09	30.50	28.84
700	44.4	39.7	36.04	34.90	33.7
800	49	42.30	40.05	38.30	37.10

Table1. Effect of change in inflation fluid (Air)



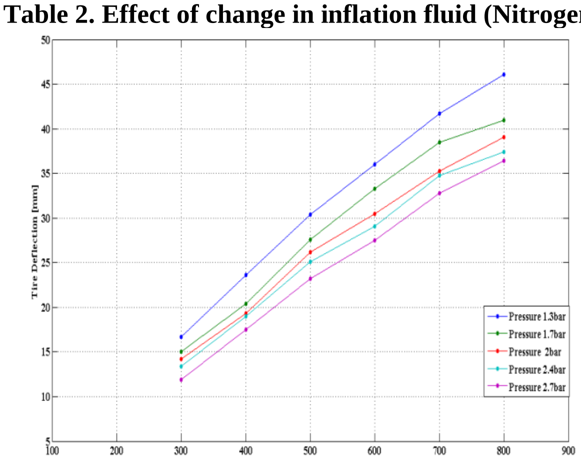
Graph 1.Combined effect of tire deflection versus load for Air

Graph shows at constant pressure, when load is increasing then tire deflection increases linearly. Pressure 1.3bar shows more deflection at all load values. Tire deflection gradually decreases when increasing tire pressure at any constant load value.

B) Effect of change in inflation fluid Nitrogen

Load [kg]	Tire Deflection [mm]				
	1.3 bar	1.7 bar	2 bar	2.4 bar	2.7 bar
300	16.7	15.02	14.2	13.35	11.9
400	23.6	20.4	19.32	19	17.5
500	30.4	27.6	26.2	25.12	23.20
600	36	33.3	30.5	29.08	27.54
700	41.7	38.5	35.24	34.8	32.82
800	46.10	41	39.08	37.40	36.4

Table 2. Effect of change in inflation fluid (Nitrogen)



Graph 2.Combined effect of tire deflection versus load for Nitrogen

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Graph shows at constant pressure, when load is increasing then tire deflection increases linearly. Pressure 1.3bar shows more deflection at all load values.

C) Effect of inflation pressure on Stiffness for Air:

Tire Stiffness value determined at different inflation pressure is the ratio of applied load on the tire to the deflection. Inflation pressure of tire increases then stiffness of tire is increases. Shows stiffness values at different pressures at inflation fluid as Air

Pressure 1.3bar		
Load kg	Def. mm	Stiffness N/mm
300	17.8	165.33
400	24.6	159.51
500	31.7	154.73
600	38.5	152.88
700	44.4	154.66
800	49	160.16

Pressure 1.7 bar		
Load kg	Def. mm	Stiffness N/mm
300	15.7	187.45
400	21.9	179.17
500	28.44	172.46
600	34.4	171.10
700	39.7	172.97
800	42.3	185.53

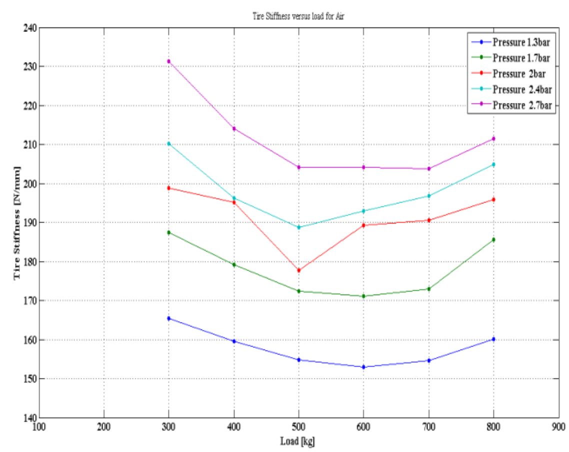
Pressure 2 bar		
Load kg	Def. mm	Stiffness N/mm
300	14.8	198.85
400	20.1	195.22
500	27.6	177.71
600	31.09	189.32
700	36.04	190.53
800	40.05	195.95

Pressure 2.4bar		
Load kg	Def. mm	Stiffness N/mm
300	14	210.21
400	20	196.2
500	26	188.65
600	30.5	192.98
700	34.9	196.76
800	38.3	204.90

Pressure 2.7bar		
Load kg	Def. mm	Stiffness N/mm
300	12.72	231.36
400	18.34	213.95
500	24.02	204.20
600	28.84	204.09
700	33.7	203.76
800	37.1	211.53

Table 3. Effect of inflation pressure on Stiffness for Air

Graph shows the combined effect of all load values on Tire stiffness when inflation fluid as Air in tire



Graph 3. Tire stiffness versus load for Air

At constant load Inflation pressure increases then tire stiffness is also increases.

D) Effect of inflation pressure on stiffness for Nitrogen:

Inflation pressure of tire increases then stiffness of tire is increases. Shows stiffness values at different pressures at inflation fluid as Nitrogen

Pressure 1.3bar		
Load kg	Def. mm	Stiffness N/mm
300	16.7	176.22
400	23.6	166.27
500	30.4	161.34
600	36	163.5
700	41.7	164.67
800	46.1	170.23

Pressure 1.7bar		
Load kg	Def. mm	Stiffness N/mm
300	15	195.93
400	20.4	192.35
500	27.6	177.71
600	33.3	176.75
700	38.5	178.36
800	41	191.41

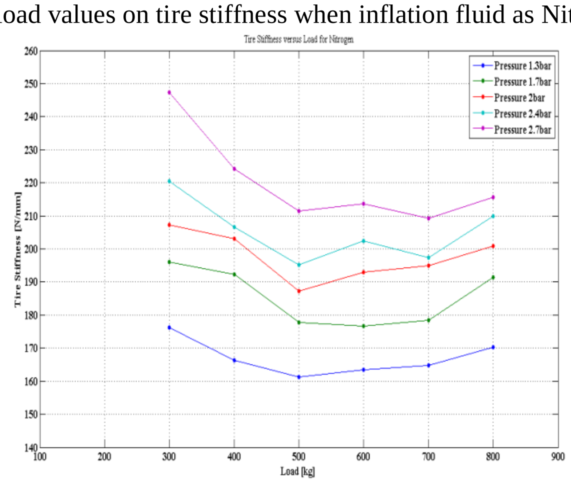
Pressure 2bar		
Load kg	Def. mm	Stiffness N/mm
300	14.2	207.25
400	19.3	203.10
500	26.2	187.21
600	30.5	192.98
700	35.2	194.86
800	39.0	200.81

Pressure 2.4 bar		
Load kg	Def. mm	Stiffness N/mm
300	13.3	220.44
400	19	206.52
500	25.1	195.26
600	29	202.40
700	34.8	197.32
800	37.4	209.83

Pressure 2.7bar		
Load kg	Def. mm	Stiffness N/mm
300	11.9	247.31
400	17.5	224.22
500	23.2	211.42
600	27.5	213.72
700	32.8	209.23
800	36.4	215.60

Table 4. Effect of inflation pressure on Stiffness for Nitrogen

Graph shows the combined effect of all load values on tire stiffness when inflation fluid as Nitrogen in tire



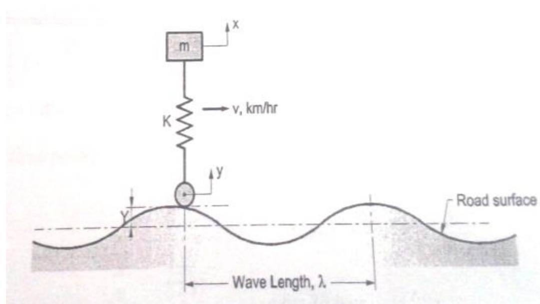
Graph 4. Tire stiffness versus load for Nitrogen

At constant load Inflation pressure increases then tire stiffness is also increase. At pressure 2.7bar tire stiffness is more compare to the other pressure values.

E) Theoretical analysis for vertical amplitude of vibration (X):

Consider a TATA Nano car moves over a road surface having sinusoidal profile with a wavelength of 4m and amplitude of 0.15m.

m= Mass of tire (kg) = 14kg
K= Tire stiffness (N/m)
λ = wavelength of sine curve (m) = 4m
Y= Amplitude of sinusoidal surface (m) =0.15m
ω_n = Natural circular frequency of the system (rad/s)
ω = circular frequency of external exciting force (rad/s)
V = speed of vehicle (km/hr) = 100km/hr
V = (100 * 1000)/3600 = 27.77m/sec



Vertical Amplitude of vibration (X):

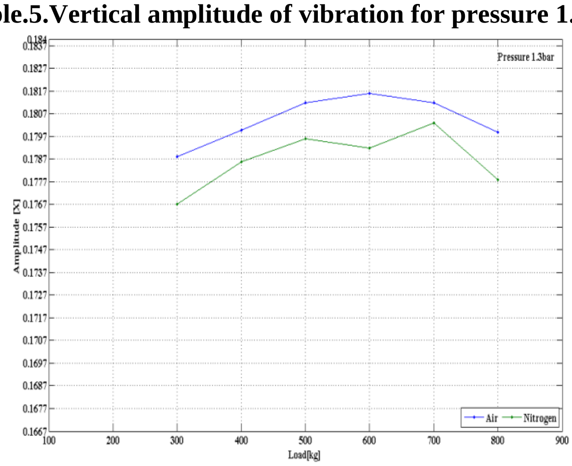
Steady state amplitude due to excitation of support

$$\omega_n = \sqrt{K/m} \qquad \text{(i)}$$

$$(X) = \frac{Y}{\left[1-\left(\frac{\omega}{\omega_n}\right)^2\right]} \qquad \text{(ii)}$$

For inflation fluid: Air			For inflation fluid: Nitrogen		
Pressure 1.3bar			Pressure 1.3bar		
Load (kg)	W_n (rad/s)	X (m)	Load (Kg)	W_n (rad/s)	X (m)
300	108.67	0.1788	300	112.19	0.1767
400	106.74	0.1800	400	108.97	0.1786
500	105.12	0.1812	500	107.35	0.1796
600	104.49	0.1816	600	108	0.1792
700	105.10	0.1812	700	106.4	0.1803
800	106.95	0.1799	800	110.26	0.1778

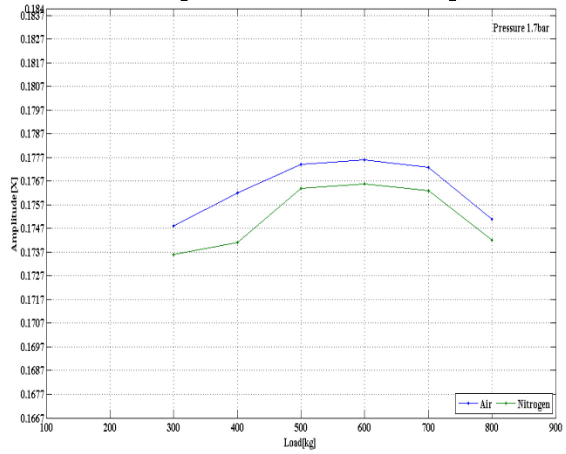
Table.5.Vertical amplitude of vibration for pressure 1.3bar



Graph 5.comparison of amplitude of Air and Nitrogen at pressure 1.3bar

For inflation fluid: Air			For inflation fluid: Nitrogen		
Pressure 1.7bar			Pressure 1.7bar		
Load (kg)	W_n (rad/s)	X (m)	Load (Kg)	W_n (rad/s)	X (m)
300	115.71	0.1748	300	118.3	0.1736
400	113.13	0.1762	400	117.2	0.1741
500	110.99	0.1774	500	112.66	0.1764
600	110.55	0.1776	600	112.36	0.1766
700	111.15	0.1773	700	112.87	0.1763
800	115.11	0.1751	800	116.92	0.1742

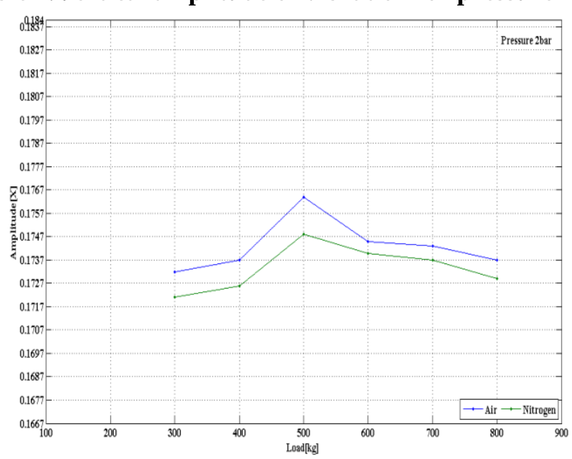
Table 6.Vertical amplitude of vibration for pressure 1.7bar



Graph 6.comparison of amplitude of Air and Nitrogen at pressure 1.7bar

For Inflation Fluid: Air			For inflation fluid: Nitrogen		
Pressure 2bar			Pressure 2bar		
Load (kg)	W_n (rad/s)	X (m)	Load (Kg)	W_n (rad/s)	X (m)
300	119.17	0.1732	300	121.67	0.1721
400	118	0.1737	400	120.44	0.1726
500	112.66	0.1764	500	115.63	0.1748
600	116.28	0.1745	600	117.4	0.1740
700	116.66	0.1743	700	117.97	0.1737
800	118	0.1737	800	119.8	0.1729

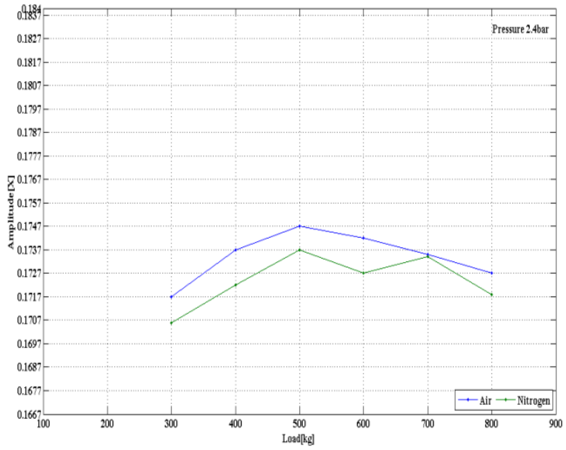
Table 7.Vertical amplitude of vibration for pressure 2bar



Graph 7.comparison of amplitude of Air and Nitrogen at pressure 2bar

For Inflation Fluid: Air			For inflation fluid: Nitrogen		
Pressure 2.4bar			Pressure 2.4bar		
Load (kg)	W_n (rad/s)	X (m)	Load (Kg)	W_n (rad/s)	X (m)
300	122.53	0.1717	300	125.48	0.1706
400	118	0.1737	400	121.45	0.1722
500	116	0.1747	500	118.09	0.1737
600	117	0.1742	600	120.23	0.1727
700	118.55	0.1734	700	118.72	0.1734
800	120.17	0.1727	800	122.42	0.1718

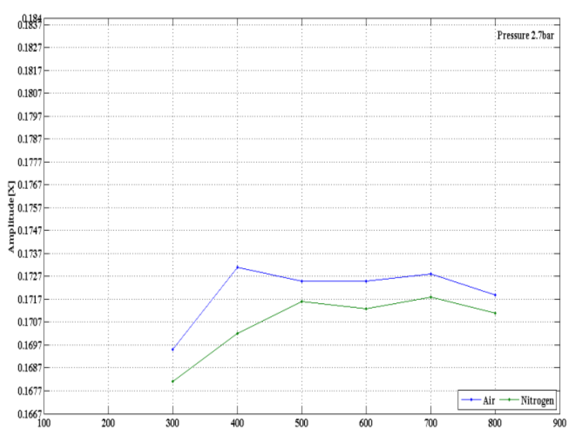
Table 8.Vertical amplitude of vibration for pressure 2.4bar



Graph 8.comparison of amplitude of Air and Nitrogen at pressure 2.4bar

For Inflation Fluid: Air			For inflation fluid : Nitrogen		
Pressure 2.7bar			Pressure 2.7bar		
Load (kg)	W_n (rad/s)	X (m)	Load (Kg)	W_n (rad/s)	X (m)
300	128.55	0.1695	300	132.9	0.1681
400	123.62	0.1731	400	126.55	0.1702
500	120.77	0.1725	500	122.88	0.1716
600	120.64	0.1725	600	123.55	0.1713
700	120	0.1728	700	122.24	0.1718
800	122	0.1719	800	124.09	0.1711

Table 9.Vertical amplitude of vibration for pressure 2.7bar



Graph 9.comparison of amplitude of Air and Nitrogen at pressure 2.7bar

V. CONCLUSION

Vertical Radial stiffness of passenger car tire P135/70R12 is successfully investigated using load deflection method under a static condition by using experimental test frame setup. Tire deflection for fluid Nitrogen is less compare to Air for all pressures. The Inflation pressure directly influences the stiffness of the tire as inflation pressure increase, the stiffness of the tire also increases. From theoretical analysis the minimum vertical amplitude is obtained at given load and pressure condition for a fluid Nitrogen compare to Air. This indicates that minimum bump in the road is transmitted to the chassis and the passenger of the car

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