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The Pneumatic Actuators As Vertical Dynamic Load Simulators On Medium Weighted Wheel Suspension Mechanism

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Abstract. Almost all of road damage can be caused by dynamic loads of vehicles that fluctuate according to the type of vehicle that passes through. This study aims to calculate the vertical dynamic load of the vehicle actually occurs on road construction by the mechanism of vehicle wheel suspension. Pneumatic cylinders driven by pressurized air directly load the spring and shock absorber installed on the wheels of the vehicle. The load fluctuations of the medium weight categorized vehicles are determined by the regulation of the amount of pressurized air that enters into the pneumatic cylinder chamber, pushing the piston and connecting rods. The displacement that occurs during compression on the spring and shock absorber, is substituted into the equation of vehicle dynamic load while taking into account the spring stiffness constant, and the fluid or damper gas coefficient. The results show that the magnitude of the displacement when the compression force works has significant influences to the amount of vertical dynamic load of the vehicle that overlies the road construction. The presence of dynamic load of vehicles that fluctuates and repeats, also affects on the reduction of road ability to receive the load. Experimental results using pneumatic actuators instead of real dynamic vehicle loads illustrate the characteristics of the relationship between work pressure and dynamic load. If the working pressure of P_2 (bar) is greater, the vertical dynamic load F_t (N) that overloads the road structure is also greater. The associated graphs show that the shock absorber has a greater ability to reduce dynamic load vertically that burden the road structure when compared with the ability of screw spring.

Keywords: Pneumatic Cylinder, Dynamic load, Pressurized air, Suspension, Road

1 Introduction

A number of four or more wheel type vehicles that pass over the surface of the highway at any time result in a number of dynamic loads that fluctuate. In addition to being obtained from dynamic load variation, DLV, this fluctuating loading can also be caused by overload, OL, and repetition loads (RL) [1]. The effects of transfer the fluctuating load (FL), OL and RL will decrease the capability/stability of the road structure in the form of hollow or bumpy surface deformations. The ability of the road structure to receive the vehicle's vertical dynamic load is dependent on the type of surface layer, the elastic foundation layer and the sliding foundation layer.

Variations in the weight of vehicles: light, medium and heavy, that pass over the road surface will simultaneously affect much the ability of the elastic foundation layer of the road in receiving such loads. Based on these problems, it is necessary to study the some influencing variables that both naturally direct and indirect. Fluctuated loading is influenced by the variables of weight of wheel axis and vehicle. The conditions of repetitive loading, RL, are also strongly influenced by the repetitive flow of traffic, the average volume of traffic flow (amount of vehicles/hour) generated from each vehicle and the length of the vehicle passing through the road. An attempt was made to examine the dynamic load of the medium weight vehicles that cross the road. This needs an experiment on the loading of a quarter part of a vehicle centered on a front wheel of a vehicle. This innovative study is based on a basic knowledge of the mechanism of vertical load transfer through a wheel suspension system consisting of spring work and shock absorber.

A study of dynamic loads transformed through the mechanism of suspension work on the vehicle wheels towards the road aims to know the form of formula and the magnitude of the vertical dynamic load of each type of vehicle weight passing the road, knowing the characteristics of the capability of the road in receiving repetitive loads, RL, and over loads, OL, and resulting in a relationship/comparison between vehicle vertical dynamic load and the capability of the road in the form of dimensionless parameters.A recentness element targeted in this study is to utilize pneumatic actuators on test equipment/ experiments as a replacement for dynamic loads of vehicles when loading the road surface. Pressurized air from the compressor provides compression forces variedly to the spring and shock absorber contained in the suspension system.

The passive suspension mechanism and the condition of a quarter vehicle loading structure are shown in Figure 1.1, [2]. The weight of the vehicle (*mass sprung*), m_2, with the stiffness of the spring, k_2, and the damping coefficient, c, will overload the axis of vehicle wheel (*mass un sprung*), m_1, furtherly gives an action force to the contour of the road surface[3].For light categorized vehicles : have axis load $m_1 = 400$ kg, and vehicle weight, $m_2 = 835$ to 1394 kg. Medium categorized vehicles : have axis load, $m_1 = 480$ to 600 kg and vehicle weight, $m_2 = 1185$ to 1990 kg. While heavy weight vehicles: have axis load, $m_1 = 525$ to 850 kg, and vehicle weight, $m_2 = 5200$ to 8730 kg (source: P.T. Astra International, 2014. The over loading conditions, OL, depend on the $\boldsymbol{k}$and axis load $\boldsymbol{m_1}$ (kg, ton) for each vehicle type. The value of $\boldsymbol{k}$ for a single axis : k = 1, the double axis : k = 0.086 and the triple axis : k = 0.031.

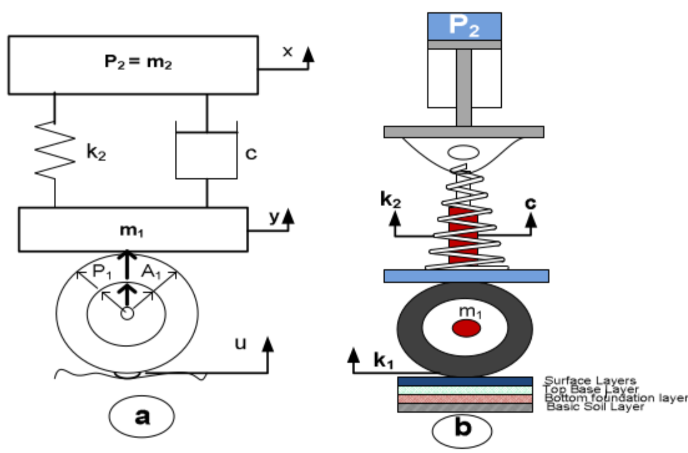

Figure 1.1. (a) Model of passive suspension. (b) Suspension unit, shock absorber, axis and a wheel on the structure of road layer.

The reaction force of the road contour to the tire will be distributed in the direction of u through the tire elasticity constant, $\boldsymbol{k_1}$. The magnitude of the vertical dynamic force by the equivalent

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pneumatic actuator in the weight force of the vehicle body (2) is described in equation (1.1). Compression displacement as far as x_2 (cm) will vary according to the magnitude of the working pressure P_2 (bar) that is varied from 1 bar to 8 bar.

$$\left.\begin{array}{c} F_{p2} = F_{ef} = F_k - R_f = F_k - 0.1F_k = 0.9F_k \\ \sum F_{v=0} \\ F_{ef} - (F_{k2} + F_{c2}) = 0 \\ 0.9\,F_k - (k_2 + c)x_2 = 0 \\ F_k = \frac{(k_2+c)x_2}{0.9} \\ F_{p2} = F_k = 1.1(k_2 + c)x_2 \end{array}\right\} \text{(N)} \qquad (1.1)$$

If the force F_{p2} works together with the axis force on the wheel (1) then the relationship is obtained as :

$$\left.\begin{array}{c} F_{t1} = F_{p2} + F_{r1} \\ F_{t1} = 0.9F_k + (m_1.g) \end{array}\right\} \text{(N)} \qquad (1.2)$$

If the piston diameter, D = 100 mm (0.100 m), k_2 = spring constant, c = damping coefficient, m_1 = weight of wheel axis, gravity acceleration g = 10 m/s^2 and push force of the pneumatic cylinder piston is $F_k = \frac{\pi}{4} D^2 P_2$, then equation (1.2) becomes :

$$F_{t1} = 785\,P_2 + 10m_1 \text{ (N)} \qquad (1.3)$$

The effective force, $\mathbf{F_{ef}}$ (N) of the piston cylinder in the intake stroke is the difference between the theoretical force, F_k (N) and frictional force $\mathbf{R_f}$ (N) [4, 5]. If the friction force $\mathbf{R_f}$ is set to $10\,\%\,x\,F_k$ (N) then the overall load transfer mechanism on the asphalt road structure refers to the following Free Body Diagram (FBD) as shown in Figure 1.2.

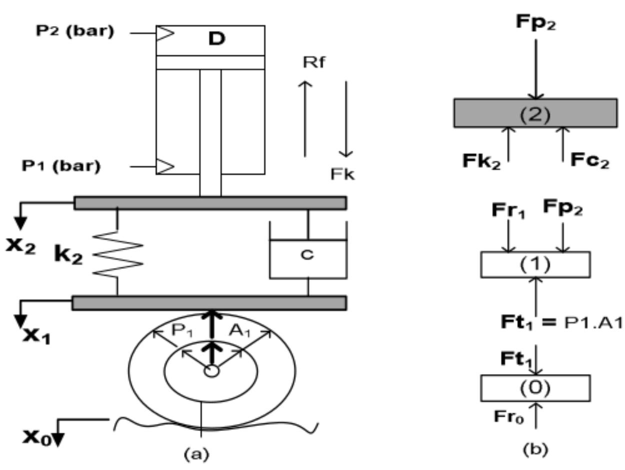

Figure 1.2. The mechanism of experimental loading of pneumatic system.

If the spring and shock absorber are subjected to varying loads of pressure P = 1 to 8 bar, there will be a deviation toward the compression as far as x (mm)[6]. Based on the action-reaction law, the load applied to the spring is proportional to the magnitude of the deflection multiplied by the spring constant.The magnitude of average displacement on the optimized suspension system x = 0.009264 m with maximum vertical acceleration is 15.571 m/s^2. In this condition it is obtained the coefficient of stiffness of the suspension spring $\mathbf{k_s}$ = 41821 N/m, and the suspension damper coefficient $\mathbf{c_s}$ = 98574 Ns/m [5] and $\mathbf{c_s}$ = 1920 J/kg.K . The suspension prototype tested by [7] has spring constant $\mathbf{k_s}$ = 10581.292 N/m, shock damping coefficient, $\mathbf{c_s}$ = 96.073 Ns/m and tire elastic constants, $\mathbf{k_e}$ = 98041.246 N / m. A preliminary study of the relationship between piston diameter D and hole diameter $\mathbf{d_i}$ has been carried out [5, 8] in the form of equation (1.4).

$$d_i = 0.065713\, D \tag{1.4}$$

The dimension of air duct to be used is adjusted to the dimension of the selected pneumatic cylinder piston.Based on the specifications of tires/wheels for light and medium vehicles it is used standard wind pressure within tires of **2 bar**, and **5.86 bar** for heavy vehicles. If the size of the tire/wheel used has dimension of 215/60/16 which means, width of tire S = 215 mm, height T = 60% x S (mm) = 129 mm = 0.129 m, and wheel diameter, D_1 = 16" (inches) = 16 x 25 mm = 400 mm = 0.4 m, and the air pressure within the tire is P_1 = 2 bar = 200000 N/m^2, and the tire area $A_1 = \pi[r_o^2 - r_i^2] = 3.14[0.102^2 - 0.020^2] = 0.031412\ m^2$,then the inner force of the tire/wheel in holding the vehicle's vertical load is $F_{t1} = P_1 \times A_1$ = 6282.4 N.The magnitude of the vehicle dynamic load coefficient is formulated [9] as a comparison between the average dynamic load and the static load as follows :

$$DLC = \frac{Average\ of\ dynamic\ loads}{Static\ load} = \frac{FD_{rms}}{F_s} \tag{1.5}$$

For vehicles with hydro-pneumatic suspension, the dynamic load can be reduced by 20%. Under this condition Dynamic Load Coefficient (DLC) becomes

$$DLC = \frac{(100-20)\%}{100\ \%} = 0.80. \tag{1.6}$$

When the wheel of quarter vehicle is rolling over the road surface, then the vertical dynamic load of the vehicle is formulated as follows :

$$\left.\begin{aligned} F_{DV} &= 0.8\ x\ F_{t1} \\ &= 628P_2 + 8m_1 \le F_{A0} \end{aligned}\right\} \text{(N)} \tag{1.7}$$

2 Research Method

2.1 Experiments

Experimentally the loading to the road foundation structure is carried out by equivalenting the total weight of the vehicle body m_1 (kg) and the weight of wheel axis m_2 (kg), with the compressive force of pneumatic cylinder piston, $\mathbf{F_{ef}}$. (N) as an actuator at a working pressure P_2 = 1 to 8 (bar). The research that is oriented to simulations of pneumatic cylinder piston force identified by [10]as real dynamic vehicle loads is shown in Figure 2.1. If the compressive force of the pneumatic cylinder piston presses the spring and the shock absorber then there will be a compression process indicated by the designation of the pointer x at the displacement scale (mm).

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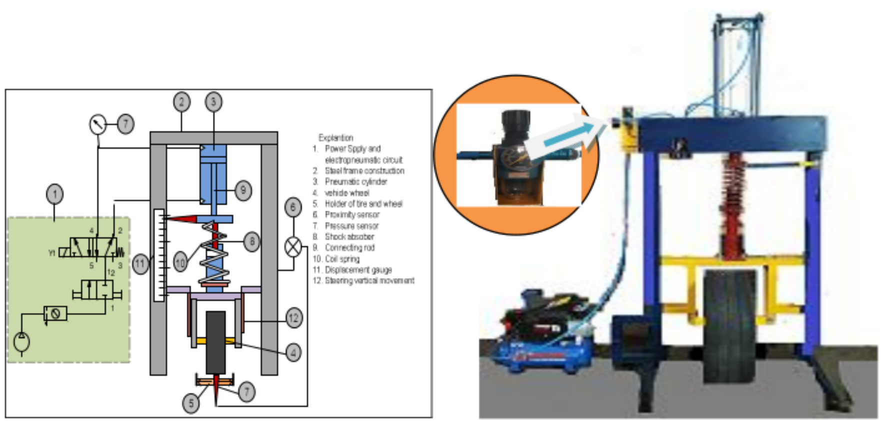
2.2 Collecting Data

Based on the loading simulation, the experimental data collection is done by reading the scale (11) pointer reveal/dial indicator of the displacement, x (mm) a while after compression on the spring (10). The magnitude of the change in displacement is determined by the amount of air pressure, P_2 (bar) set from 1 (bar) to 8 (bar). In order that the measurement results $x\ (mm)$ is closer to the real state then it is necessary to measure x (mm) 5 times at every working pressure setting by calculating the average value of x (mm)[11, 12].

2.3 Data Analysis

The magnitude of the mean displacement x (mm) obtained is substituted into equations (1.1) and (1.3) as vehicle weight force, Fp_2 (N) and the vehicle's real vertical dynamic force Ft_1 (N) to the road construction. With the help of Mat-Lab/Simulink program analysis, the magnitude Fp_2 (N) and Ft_1 (N) can be obtained. The loading characteristics done to the road construction can be shown through graphic curves.



(a) (b)

Figure 2.1. (a) Design of motion control simulation with pneumatic actuators. (b) Test equipment of loading on pneumatic system wheel suspension.

3. Results And Discussion

3.1. Experiment of Pneumatic System

The dynamic load simulation of vehicles played by pneumatic cylinders/actuators results in the magnitude of the dynamic load of vehicles, loading the road structure with refers to equation (1.3). If the working pressure, P_2 instead of the load of m_2 is varied from 1 bar to 8 bar, then the working characteristic of the dynamic load to the working pressure is shown in Figure 3.1.

The graph of the relationship between the working pressure of P_2 (bar) and the vertical dynamic that loads road structure represents a significant increase in dynamic load with the total vehicle load increase. This significance condition is shown in the graphic figure as a straight line.

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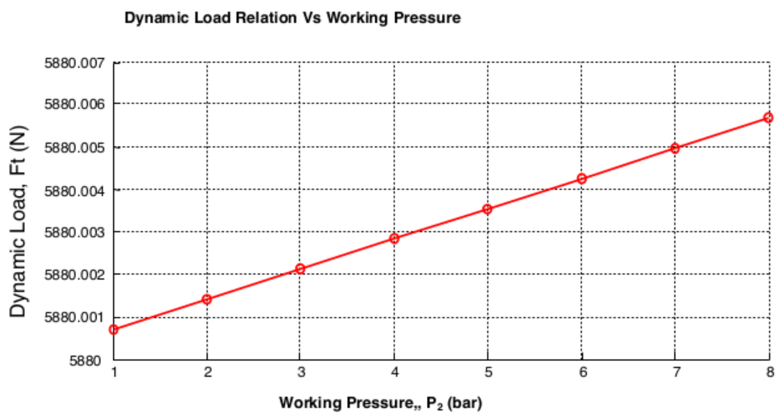


Figure 3.1. Dynamic load characteristic of pneumatic system

The dynamic load characteristics re obtained from the relationship between the operating pressure and the spring constant k_2. Pressing force of pneumatic cylinder piston, F_{p2}, shock absorber damping, c_2 and the magnitude of the vertical dynamic load that burdens the road structure, F_{t1},are shown in Figure 3.2 (a). The effect of attenuation by the shock absorber gives a huge influence on the dynamic load burdening the road structure. Such a condition causes the dynamic load of F_{t1} (N) according to Figure 3.2 (b) to be around 10000 (N) or equivalent to 1000 kg.

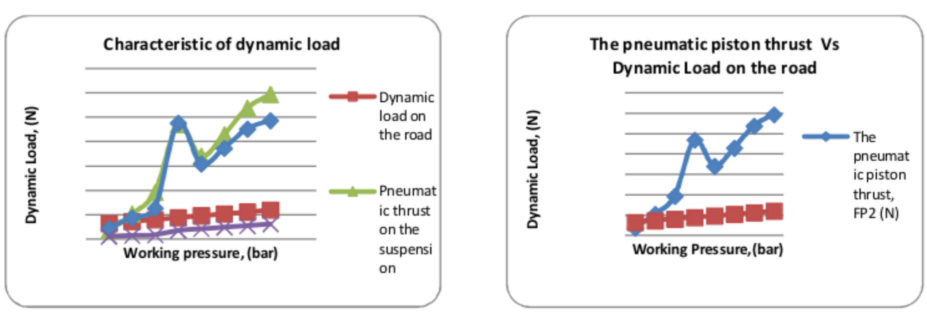
Hence, if the medium weight categorized vehicle being tested has the weight of wheel axis m_1 = 600 kg, body weight m_2 = 1665 kg and total/net weight m_t = 2265 kg according to the data in Table 3.1 then it is obtained the reduced dynamic vehicle load that is $m_r = m_t$ - 1000 Kg = 2265-1000 = 1265 kg.

The percentage of dynamic load drop burdening the road structure due to the attenuation of the shock absorber is $\frac{2265}{1265} x100\% = 55.85\ \%$.

3.2. Vertical Dynamic Load of Vehicle

Figure 3.3 (a) shows a fairly fantastic picture that the attenuation of the shock absorber attached to the vehicle suspension mechanism provides a damping value of **c (Ns/cm)** to a very large dynamic load that is between 4523.729 Ns/cm and 48702.041 Ns/cm.

The smallest effect of attenuation that is also used in the suspension system of the test vehicles is the contribution of the attenuation of threaded spring $\mathbf{k_2}$ **(N/cm)** whose values range between 1330.508 N/cm and 6408.163 N/cm.



(a) (b)

Figure 3.2. (a) Dynamic load characteristics by piston force, F_{P2}, to spring and shock absorber. (b) Relationship between piston force, F_{P2}, and dynamic load, F_{t1}, burdening the road structure .

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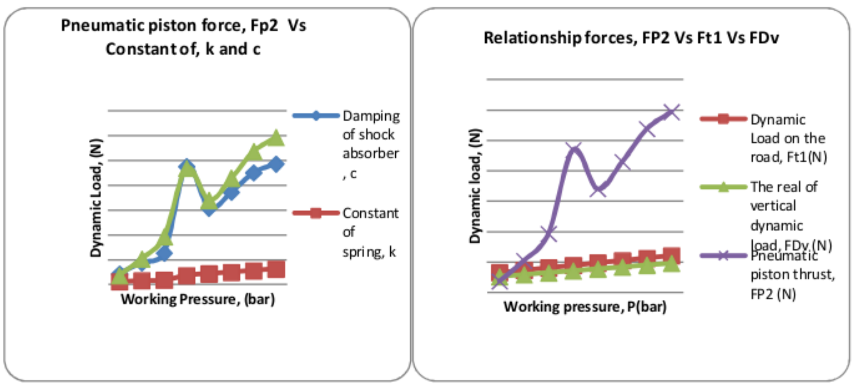
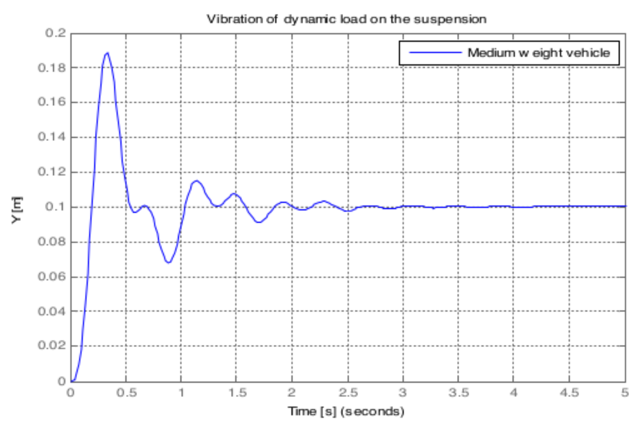
The gap value which occurring between the shock absorber and the threaded spring, indicates that the shock absorber plays an enormous role in reducing the vibrations generated by the vehicle's vertical dynamic load.Figure 3.3 (b) describes the relationship characteristics between the dynamic load of the experimental results and the actual dynamic load that occurs. By using the Dynamic Load Coefficient (DLC) value as 20% acts for vehicles with hydro-pneumatic suspension then the actual vertical vehicle dynamic load transformation follows the equation (1.5) with a value between 5332 (N) and 9728 (N) or less than the weight value of 10000 (N).

A number of important data information obtained from several formulas for experimental test vehicles are shown in Table 4.1, which can also present the results of dynamic load analysis using equations (1.2), (1.4) and equations (1.6). The magnitude of the vertical dynamic load, F_{Dv} (N) as contained in Table 4.1 can be identified as the normal force, F_N (N) acting in a perpendicular direction to the horizontal force, F_H (N) and the tangential force, F_T (N).



(a) (b)



(c)

Figure 3.3. (a) Relationship of piston force, F_{P2} (N), with shock absorber and threaded spring.(b) Relationship of pneumatic cylinder piston force, F_{P2} (N), with dynamic load of test vehicle, F_t (N), and the real vertical dynamic load, F_{Dv} (N). (c)Vibration dynamic load on the suspension mechanism

Table 3.1 Analysis results of vertical dynamic load of medium weight categorized vehicle.

Working pressure P_2(bar)	Wheel Axis weight $W1=m_1.g$	Vertical dynamic load $Ft_1=Fr_0$ (N)	Real Vertical dynamic load F_{Dv} (N)	Thrust force of pneumatic cylinder piston Fp_2 (N)
1	5880	6665	5332	3799.400
2	5880	7450	5960	10534.700
3	5880	8235	6588	19428.750
4	5880	9020	7216	46974.400
5	5880	9805	7844	34108.250
6	5880	10590	8472	43002.300
7	5880	11375	9100	53796.050
8	5880	12160	9728	59408.800

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4. Conclusion

Characteristics of the suspension mechanism on the quarter vehicle wheel of medium weight vehicle type experiences longest displacement of 0.18 m with a duration of 0.35 seconds. In an interval of 2.5 seconds later, the vibrations begin to shrink and eventually disappear in the last 3 seconds.

Medium weight categorized vehicle with a total weight : 2265 kg > 1942.8 kg obtains a dynamic vertical load that is greater than 658.8 kg. The percentage of the dynamic load decrease that burdens the road structure due to the attenuation of the shock absorber is 55.85%.

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