

Driveline System - Suspension Interaction in a 6×6 Terrain Truck

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ABSTRACT

Normal and longitudinal dynamics of vehicles interrelates via the normal and longitudinal tire reactions. The normal reactions are supposed to be formed by characteristics of the suspension system and tires, and the longitudinal forces in the tire patches are produced by the driveline system by supplying torques to the drive wheels. Usually, the normal and longitudinal reactions, independently generated by the two vehicle systems, are considered to interrelate, but not to impact each other.

An analytical study presented in this paper showed that the normal tire reactions are formed not only by the design of suspension but also by the longitudinal tire reactions (circumferential wheel forces), which follow from the wheel torques supplied by the driveline system. A 6×6 vehicle with A-type suspension systems at all three axles exhibits different normal tire reactions at the drive axles during motion even when the static weight distribution is equal. The paper presents this analytical study of the influence of the circumferential wheel forces on the normal reactions at the wheels.

At the same time, the difference in the normal reactions leads to the different rolling radii of the tires; this generates a kinematic discrepancy in the driveline system that impacts the power distribution between the drive axles and changes the circumferential wheel forces. Thus, the two systems, i.e., the driveline and suspension, impact each other. The paper presents this study in detail, illustrates it with practical examples, and provides recommendations for engineering design.

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INTRODUCTION

Research and developments of suspension systems is a major field in vehicle dynamics and vehicle design, including ride comfort, handling, stability of motion and rollover, suspension and chassis design, etc. Two-body models of a quarter vehicle and multi-body mathematical models of vehicles used in such studies are based on vibration analysis of sprung and unsprung masses. Usually, the process of the reduction of actual suspensions to equivalent spring-damper systems is omitted in publications [1,2,3,4,5,6, etc.]. This leaves the engineering problem of the normal and longitudinal tire forces out of consideration.

Thus, less attention is given to the interaction between normal and longitudinal dynamics of vehicles. The latter is not included in the cornering analysis and suspension tuning (for example [7]). In references [8-9], traction dynamics and braking dynamics are considered with the use of reduced vibration diagrams of the sprung and unsprung masses. One of a few publications, [10], considers the interaction between the tire traction force and normal reaction in detail for various suspension designs. However, the consideration is limited to

the one drive wheel-suspension interaction or one drive axle-suspension interaction depending on the type of suspension. The only publication, known by the author of this paper, on the interaction of two drive axles and the leaf-suspension of the tandem of a 3-axle automobile is [11]. As shown, the torque of the forward rear axle T_{w2} turned out to be 1.5-fold greater than the torque of the reward rear axle T_{w3} in uniform rectilinear motion of the automobile. Under steady turning conditions the torque turned out to be higher at the rear axle and the ratio of torques T_{w2}/T_{w3} was approximately 0.5. This data prompts a necessity of a detailed analytical study of the multi-wheel driveline system and suspension system. The outcomes of such study are presented in the paper.

NORMAL REACTION ANALYSIS

Fig. 1 presents a free-body diagram of a 6×6 truck in which the second and third axles form a tandem. The truck has A-type suspension at all three axles. The forces, reactions and dimensions are apparently clear from Fig. 1.

Using the diagram, the normal reactions of the axles will be determined and further analyzed in the paper. The

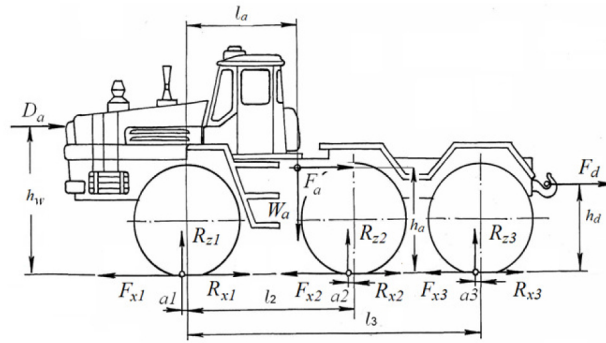


Figure 1. A free-body diagram of a 6x6 truck with A-frame type suspension.

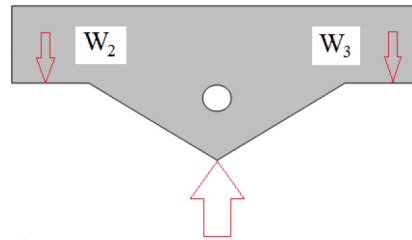


Figure 2. Tandem diagram with equal normal loads on the axles

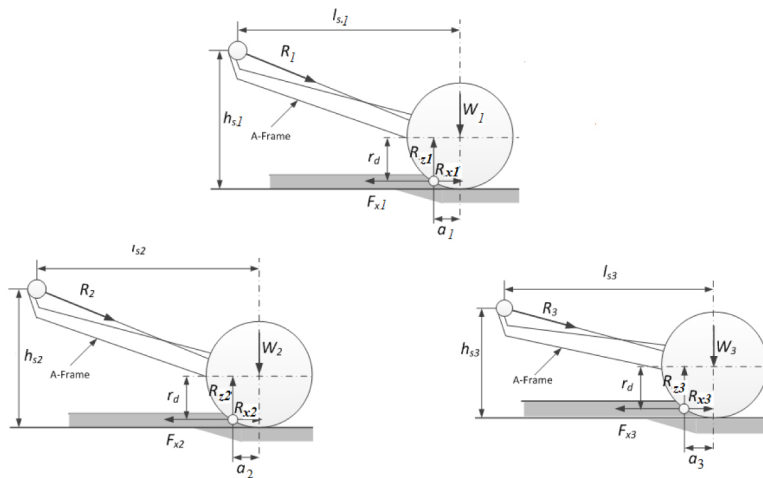


Figure 3. Free-body diagrams of the front, second and third axles with A-frame suspension.

equation of equilibrium about point O_1 at the front axle presents the relationship of the normal reactions of the tandem's axles:

$$R_{z2}l_2 + R_{z3}l_3 - W_a l_a - D_a h_w - F_a h_a - F_d h_d = 0 \quad (1)$$

or

$$R_{z2}l_2 + R_{z3}l_3 = A \quad (2)$$

here, $A = W_a l_a + D_a h_w + F_a h_a + F_d h_d$.

The tandem design provides equal normal loads of the second and third axles (see Fig. 2): $W_2 = W_3 = W = 0.5W_{\text{tandem}}$.

Taking this condition in the consideration and forces in Fig. 3 (in this study, the A-frames are oriented as shown in Fig. 3), the following equations of equilibrium can be written for the second and third axles:

$$R_{z2}l_{s2} - Wl_{s2} - F_{x2}h_{s2} + R_{x2}h_{s2} = 0 \quad (3)$$

$$R_{z3}l_{s3} - Wl_{s3} - F_{x3}h_{s3} + R_{x3}h_{s3} = 0$$

By subtracting [equation \(4\)](#) from (3), another relationship between the normal reactions R_{z2} and R_{z3} can be obtained as follows:

$$R_{z2}l_{s2} - R_{z3}l_{s3} - B = 0 \quad (5)$$

here, $B = W(l_{s2} - l_{s3}) + F_{x2}h_{s2} - F_{x3}h_{s3} + R_{x3}h_{s3} - R_{x2}h_{s2}$.

The normal reactions at the tandem's axles are determined from [equations \(2\)](#) and (5):

$$R_{z2} = (Al_{s3} + Bl_3)/(l_2l_{s3} + l_3l_{s2}) \quad (6)$$

$$R_{z3} = (Al_{s2} - Bl_2)/(l_2l_{s3} + l_3l_{s2}) \quad (7)$$

As seen from [equations \(6\)](#) and (7) and the above-given expression for the parameter B , the normal reactions of the two axles are not equal to each other if $l_{s2} \neq l_{s3}$ and $B \neq 0$ (even the normal load on the axles are the same as this is seen in [Fig. 2](#)). The difference in the normal reactions is caused by the following factors: (i) the suspension geometry represented by the non-equal dimensions, l_{s2} and l_{s3} , h_{s2} and h_{s3} ; (ii) driveline system characteristics which determine the values of the circumferential forces F_{x2} and F_{x3} (those values are not typically equal to the rolling resistance forces R_{x2} and R_{x3}); (iii) different rolling resistance of the tires at the second and third axles.

To further analyze the difference in the reactions R_{z2} and R_{z3} , consider a stationary truck, when $A = W_a l_a$ and $B = W(l_{s2} - l_{s3})$:

$$R_{z2} = [W_a l_a l_{s3} + W(l_{s2} - l_{s3})]/(l_2 l_{s3} + l_3 l_{s2}) \quad (8)$$

$$R_{z3} = [W_a l_a l_{s2} - W(l_{s2} - l_{s3})]/(l_2 l_{s3} + l_3 l_{s2}) \quad (9)$$

One can see from [equations \(8\)](#) and (9) that the A-frame type suspension geometry impacts the normal reactions of the stationary truck; the reactions are identical if only $l_{s2} = l_{s3} = l_s$. In this case $B = W(l_s - l_s) = 0$ and [\(8\)](#) and [\(9\)](#) become

$$R_{z2} = W_a l_a / (l_2 + l_3) \quad (10)$$

$$R_{z3} = W_a l_a / (l_2 + l_3) \quad (11)$$

The impact of the suspension geometry on the difference of the normal reactions, R_{z2} and R_{z3} , is introduced here by the ratio

$$K = \frac{l_{s2}}{l_{s3}} \quad (12)$$

Hence the ratio of the normal reactions is derived from [equations \(8\)](#) and (9) as follows

$$R_{z2}/R_{z3} = [W_a l_a + W(K - 1)]/[W_a l_a K - W(K - 1)] \quad (13)$$

[Fig. 4](#) illustrates the ratio R_{z2}/R_{z3} computed for a truck of weight of 685 kN and the normal load of the tandem equal to 484 kN; the longitudinal coordinate of the center of mass is 3.88m.

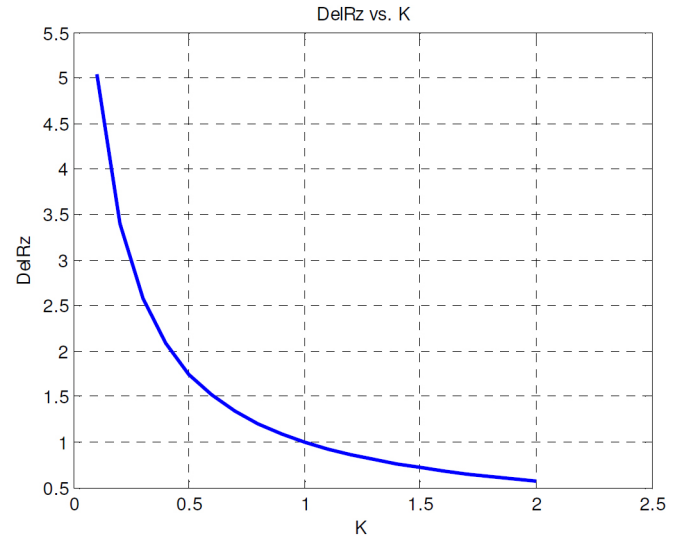


Figure 4. The ratio of the normal reactions of the tandem axles R_{z2}/R_{z3} as a function of K .

The data in [Fig. 4](#) shows that the normal reactions are the same if $K = l_{s2} / l_{s3} = 1$. If $l_{s2} > l_{s3}$ ($K > 1$), the normal reaction of the second axle of the stationary truck is smaller than the normal reaction at the third axle. If $l_{s2} < l_{s3}$ ($K < 1$), $R_{z2} > R_{z3}$. The difference between the normal reactions when ($K < 1$) is more sensitive to changes of the suspension geometric parameters l_{s2} and l_{s3} . For the truck researched in this study, ($K = 1.14$ and $R_{z2}/R_{z3} = 0.8984$). The normal reaction at the first axle is determined from the equilibrium of the forces in the vertical axis:

$$R_{z1} + R_{z2} + R_{z3} - W_a = 0 \quad (14)$$

By substituting reactions from [\(8\)](#) and [\(9\)](#) in [equation \(14\)](#), the front axle reaction comes as follows:

$$R_{z1} = W_a - [A(l_{s2} + l_{s3}) + B(l_3 - l_2)]/(l_2 l_{s3} + l_3 l_{s2}) \quad (15)$$

and for the stationary truck:

$$R_{z1} = W_a - 2W_a l_a / (l_2 + l_3) \quad (16)$$

The front reaction can be also determined from the balance of forces acting on the front axle (see [Fig. 3](#)):