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Dynamics of Buses - Part II

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Abstract: Dynamics, or dynamic processes, is the part of mechanics dealing with the study of processes trying to describe as real as possible the movement of a body, element, mechanism, car, etc., also taking into account the action of the forces on the respective system with their influence on the actual movement of system. The present paper aims to present the study of the dynamics of the vehicles, with particularization on the buses. Here are the main elements of the bus dynamics, taking into account all the elements that influence the dynamic operation of a bus, in general and in particular situations, with emphasis on the main systems and elements that act on the actual, dynamic, on a normal path or on an inclined with an alpha angle path.

Keywords: Mechanisms, Machines, Buses, Dynamics, Kinematics

Introduction

Transport is the movement of persons as well as goods, signals or information from one place to another. The term comes from Latin, from "transport", trans (over) and porting (meaning wearing or carrying).

Transport is an activity that arose with the existence of man. The physical limits of the human body in terms of walking distances and the quantity of goods that could be transported led, over time, to the discovery of a variety of ways and means of transport.

Transport facilitates access to natural resources and stimulates trade.

The transport sector has different aspects. Simplifying and generalizing can be discussed by three major branches: Infrastructure, vehicles, management:

Transport infrastructure, including the entire transport network (streets, motorways, railways, waterways, flight color, pipelines, etc.) and terminals (airports, railway stations, bus stations, etc.).

Vehicles of all types: Motor vehicles, trains, ships, airplanes, etc., together with all aspects related to vehicle design, construction, diagnosis and exploitation, road traffic, management.

Transport management is the responsibility of transport engineering and engineering for the design of transport networks and systems, aiming at optimizing transport systems, increasing transport safety, protecting the environment, etc.

Land transport is the most widespread form of transport. People can move by their own forces or using means of transport that use human power, such as a bicycle, or they can use animal traction to pull wagons or other types of carriages. The most widespread and efficient form of land transport uses vehicles equipped with liquid-fueled engines (Frăţilă *et al*., 2011; Pelecudi, 1967; Antonescu, 2000; Comănescu *et al*., 2010; Aversa *et al*., 2016a; 2016b; 2016c; 2016d; 2017a; 2017b; 2017c; 2017d; 2017e; Berto *et al*., 2016a; 2016b; 2016c; 2016d; Mirsayar *et al*., 2017; Cao *et al*., 2013; Dong *et al*., 2013; De Melo *et al*., 2012; Garcia *et al*., 2007; Garcia-Murillo *et al*., 2013; He *et al*., 2013; Lee, 2013; Lin *et al*., 2013; Liu *et al*., 2013; Padula and Perdereau, 2013; Perumaal and Jawahar, 2013; Petrescu and Petrescu, 1995a; 1995b; 1997a; 1997b; 1997c; 2000a; 2000b; 2002a; 2002b; 2003; 2005a; 2005b; 2005c; 2005d; 2005e, 2016a; 2016b; 2016c; 2016d; 2016e; 2013; 2012a; 2012b; 2011; Petrescu *et al*., 2009; 2016a; 2016b; 2016c; 2016d; 2016e; 2017a; 2017b; 2017c; 2017d; 2017e; 2017f; 2017g; 2017h; 2017i; 2017j; 2017k; 2017l; 2017m; 2017n; 2017o; 2017p; 2017q; 2017r; 2017s; 2017t; 2017u; 2017v; 2017w; 2017x; 2017y; 2017z; 2017aa; 2017ab; 2017ac; 2017ad; 2017ae; Petrescu and Calautit, 2016a; 2016b; Reddy *et al*., 2012; Tabaković *et al*., 2013;

Tang *et al.*, 2013; Tong *et al.*, 2013; Wang *et al.*, 2013; Wen *et al.*, 2012; Antonescu and Petrescu, 1985; 1989; Antonescu *et al.*, 1985a; 1985b; 1986; 1987; 1988; 1994; 1997; 2000a; 2000b; 2001).

Materials and Methods

Airflow Resistance

Air resistance is the force that opposes the forwarding of the bus while moving into the air.

The causes of air resistance when driving a bus are as follows:

1. Pressure exerted by the air particles encountered on the front of the bus
2. Friction of the outer surface of the bodywork by air particles
3. In particular, whirlwinds are produced in front of the bus and a depression zone (Fig. 1) is created behind the bus, which consumes much energy (generating high resistances on the bus)

For the calculation of air resistance, the motion of the bodies is used in fluid media at speeds below 300 m/s. In this case, the air resistance is given by the relation (1), in which: c is a coefficient of resistance to advance which depends on the shape of the body; ρ air density in kg/m^3; A is the transverse (frontal) area of the bus in m^2; v is the bus speed in m/s.

$$R_a = c \cdot \rho \cdot A \cdot v^2 \tag{1}$$

If we take into account that the air density ρ has very small (insignificant) variations at the height from the ground at which the vehicles circulate, then the product $c.\ \rho = K$ = constant and the relation (1) takes the form (2) bears the name of the aerodynamic coefficient:

$$R_a = K \cdot A \cdot v^2 \tag{2}$$

Taking into account that for buses their travel speed v is usually expressed in km/h, the relation (2) can be written in the form (3), where V is the speed of the bus in km/h:

$$R_a = K \cdot A \cdot \left(\frac{V}{3,6}\right)^2 = \frac{1}{13} K \cdot A \cdot V^2 \tag{3}$$

The power consumed by the bus [W] to overcome the air resistance will be given by the relationship (4), where as previously mentioned the bus speed V is introduced in km/h, the cross-sectional area of the bus A is given in m^2 and the power consumed Pa results in W:

$$\begin{aligned} P_a &= R_a \cdot v = \frac{1}{13} K \cdot A \cdot V^2 \cdot \frac{V}{3,6} \\ &= \frac{1}{13} K \cdot A \cdot V^2 \cdot 0,27 \cdot V = 0,021 K \cdot A \cdot V^3 \end{aligned} \tag{4}$$

For a driver to be able to operate economically on the bus, he should go as low as possible, given that the treadmill is the main factor that increases the air resistance when the bus goes and even the third; in other words, the air resistance increases directly in proportion to the cube of the bus speed. Obviously a bus on a national or international road can not travel at very low speed and then the only way to reduce the air resistance when driving a bus is to reduce constructively the aerodynamic coefficient K from the body design.

For rapid, approximate, good results, the surface A can easily be determined by the relationship (5), where B is the bus path (front gauge, distance between the front axle wheels) and H the maximum bus height, both measured in m.

Instead of gauge or track, the width of the bus (trolley, or truck, as the case may be) may be more accurate (Fig. 2):

$$A = B \cdot H \tag{5}$$

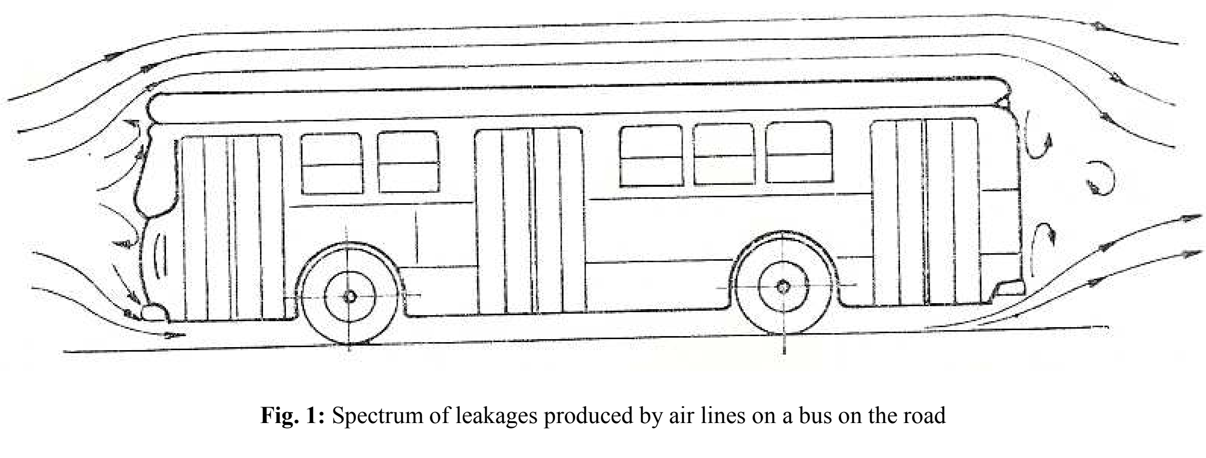

Fig. 1: Spectrum of leakages produced by air lines on a bus on the road

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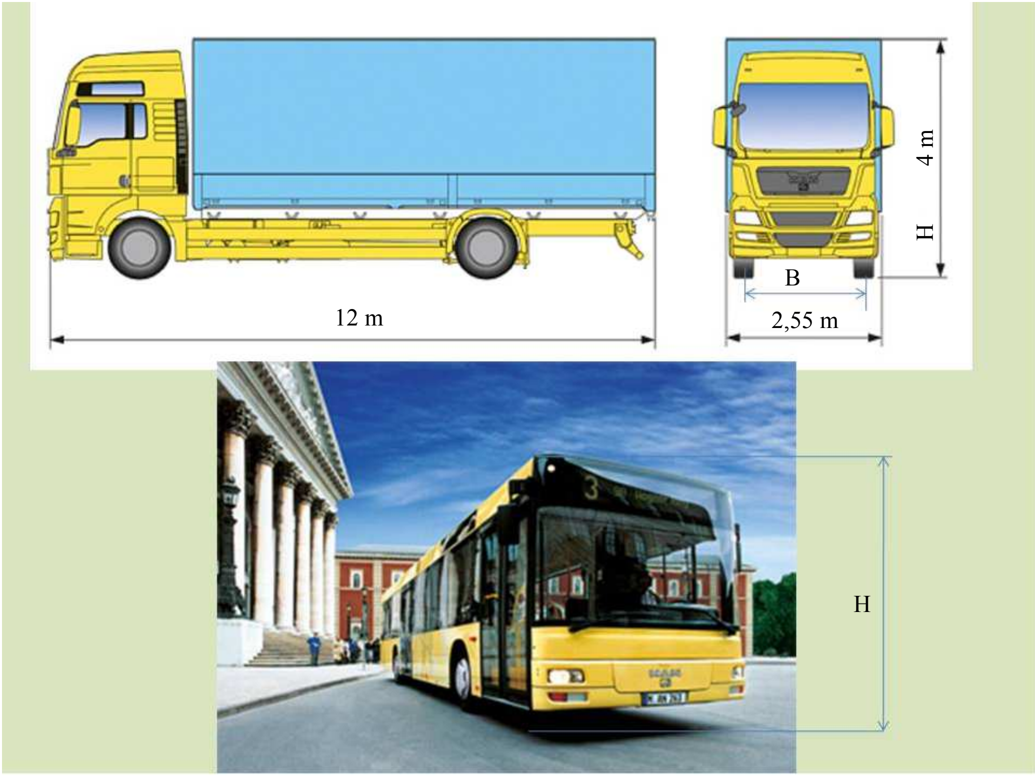

Fig. 2: Schema for approximate front surface calculation

Fig. 3: New building designs for buses to reduce aerodynamic coefficients

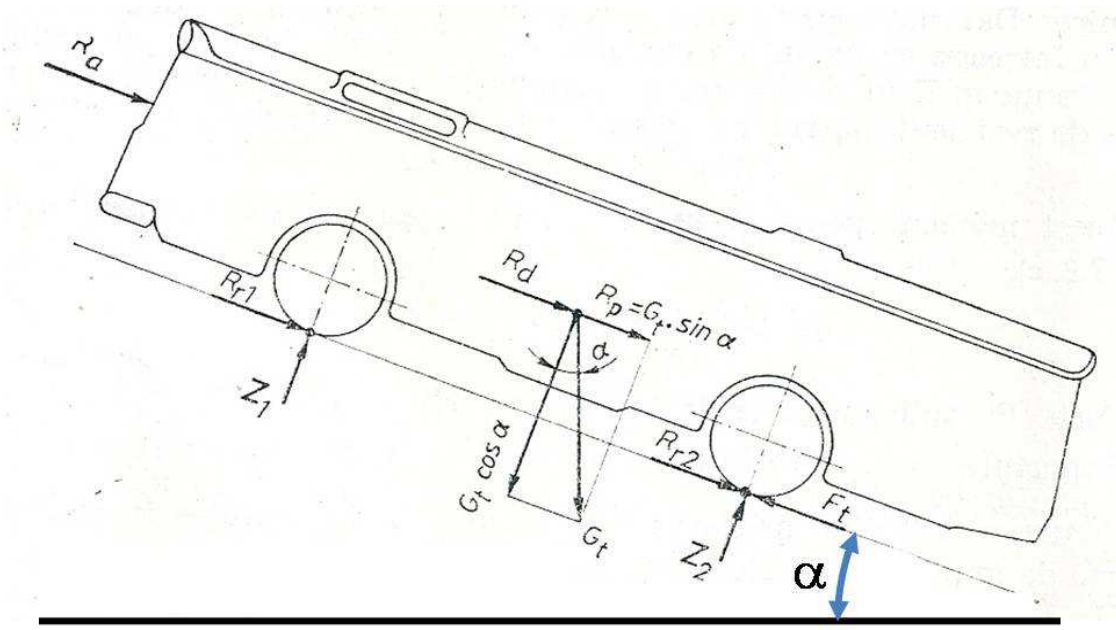

Fig. 4: Resistance to climbing a slop of a bus

For urban buses (including trolleybuses) the aerodynamic coefficient K = 0,030 ... 0,044, while the frontal area of a bus varies within A = 4,5 ... 12,5 m^2 for the usual cases.

As shown, it is necessary to reduce the aerodynamic coefficient from the design, which is why modern buses have new constructive shapes (Fig. 3).

Resistance to Climbing a Slope

The slope resistance of a bus (Fig. 4) is a component parallel to the sloping path (of the slope) of the total weight of the bus G_t, i.e., the component $R_p = G_t.\sin\alpha$, given by the relation (6):

$$R_p = G_t \cdot \sin\alpha \tag{6}$$

where, G_t is the total weight of the bus given in daN, the angle α represents the slope angle of the slope versus the horizontal in degrees deg.

In the case of small slopes (α<10°) we can approximate: $\sin\alpha = tg\alpha = \alpha$ [rad] = p. Thus the resistance to the ascension of a slope will be given by the relation (7):

$$R_p = G_t \cdot p \tag{7}$$

When descending a slope, the weight component of the bus becomes an active force, tending to increase its speed.

The power consumed by an extra bus for ascending an angle slope α, precisely for overcoming the slope resistance, is given by the relation (8):

$$\begin{cases} P_p[W] = R_p[N] \cdot v[m/s] \\ = R_p[N] \cdot 0{,}27 \cdot V[km/h] \\ = 10 \cdot R_p[daN] \cdot 0{,}27 \cdot V[km/h] \\ = R_p[daN] \cdot 2{,}7 \cdot V[km/h] \\ = G_t[daN] \cdot \sin\alpha \cdot 2{,}7 \cdot V[km/h] \\ = G_t[daN] \cdot p \cdot 2{,}7 \cdot V[km/h] \end{cases} \tag{8}$$

Resistance to Acceleration

Acceleration resistance is a force that opposes the bus movement, which occurs at the speed of the bus and the start of it, being an inertial force. Force acceleration force is the force of inertia that opposes speed variations and is given by the relation (9), where g is the gravitational acceleration in m/s^2, considered constant (for a given location of the planet and a certain height on average with the calculation value of 9.81 ms^{-2}), a is the acceleration of the bus which creates the inertia force, given also in m/s^2 and G_t is the total weight of the bus, which in the international system of measurement is taken in N, technically given in daN, the force Rd having the same unit of measure as the weight of the G_t bus. If G_t is considered in daN obviously and Rd will result all in daN:

$$R_d = m \cdot a = \frac{G_t}{g} \cdot a \tag{9}$$

In relation (9), the additional movements of certain assemblies belonging to the bus, such as the engine's flywheel, transmission organs, which also perform rotational movements with some influence on the final translation movement of the bus, the lost power and on its stability.

For rotation of the organs during the acceleration period, additional power is spent so that the acceleration resistance will actually be composed of the inertia force corresponding to the accelerated translation of the entire bus and the inertia force corresponding to the angular acceleration of the movement of the organs in rotation. This second force of inertia can be taken into account in calculations by means of a coefficient δ, called coefficient for increasing the speeds of the masses in rotation. The total resistance to bus acceleration will now be given more precisely by the relationship (10):

$$R_d = \delta \cdot m \cdot a = \delta \cdot \frac{G_t}{g} \cdot a \tag{10}$$

The value of the coefficient δ is determined by calculation. It can be determined by an empirical relationship (11), where icv is the transmission ratio of the gearbox in that gear and σ is a coefficient, which for buses takes values in the beach: σ = 0,05 ... 0.07:

$$\delta = 1 + \sigma \cdot i_{cv}^2 \tag{11}$$

The power required to overcome the bus acceleration resistance can be calculated using the relationship (12):

$$\begin{cases} P_d[W] = R_d[N] \cdot v[m/s] \\ = \delta \cdot \dfrac{G_t[N]}{g} \cdot a \cdot v[m/s] \\ = \delta \cdot \dfrac{10 \cdot G_t[daN]}{g} \cdot a \cdot 0{,}27 \cdot V[km/h] \\ = \delta \cdot \dfrac{G_t[daN]}{g} \cdot a \cdot 2{,}7 \cdot V[km/h] \end{cases} \tag{12}$$

Results and Discussion

Normal Pathway Reactions at Bus Decks

Determination of normal reactions on decks is considered to be a bus that ascends a slope α with an accelerated motion. The forces and moments acting on the bus are shown in Fig. 5.

Writing the equation of moments to the center of gravity of the bus, the relation (13) is obtained, in which: Z_1 and Z_2 are the normal dynamic reactions at the front and rear axles; G_t is the total weight of the bus that decomposes on the inclined slope of the slope in the two components $G_t.\sin\alpha$ parallel to the path and $G_t.\cos\alpha$ perpendicular to the track; R_a is the air resistance on the bus; R_d is the acceleration resistance of the bus; M_{rul1} and M_{rul2} are the moments corresponding to rolling resistance for the front axle and rear axle respectively; F_t is the traction force at the engine wheels; h_g is the height of the center of gravity of the bus and h_a is the height of the center of pressure where air resistance is assumed to act; r_r is the radius of the wheels:

$$\begin{aligned} & Z_1 \cdot a - Z_2 \cdot b + M_{rul1} + M_{rul2} \\ & + F_t \cdot h_g + R_a \cdot (h_a - h_g) = 0 \end{aligned} \tag{13}$$

For the determination of the two reactions, the equation of projection of the forces on a plane perpendicular to the plane of the tread (14) is also written:

$$Z_1 + Z_2 = G_t \cdot \cos\alpha \tag{14}$$

Taking into account the relation (15), the relation (13) takes the form (16):

$$\begin{aligned} & M_{rul1} + M_{rul2} = f \cdot r_r \cdot Z_1 + f \cdot r_r \cdot Z_2 \\ & = f \cdot r_r \cdot (Z_1 + Z_2) = f \cdot r_r \cdot G_t \cdot \cos\alpha \end{aligned} \tag{15}$$

$$\begin{aligned} & Z_1 \cdot a - Z_2 \cdot b + f \cdot r_r \cdot G_t \cdot \cos\alpha \\ & + F_t \cdot h_g + R_a \cdot (h_a - h_g) = 0 \end{aligned} \tag{16}$$

Since in most buses the ha-hg difference is very small, the product $R_a(h_a\text{-}h_g)$ can be neglected, so that the relation (16) obtains the approximate, simplified form, (17):

$$Z_1 \cdot a - Z_2 \cdot b + f \cdot r_r \cdot G_t \cdot \cos\alpha + F_t \cdot h_g = 0 \tag{17}$$

Thus, a two-equation system (18) with two unknowns, Z_1, Z_2, is obtained, from which two dynamic normal reactions at the bus bridges, Z_1 and Z_2 (system 19), where $L = a + b$:

$$\begin{cases} Z_1 \cdot a - Z_2 \cdot b + f \cdot r_r \cdot G_t \cdot \cos\alpha + F_t \cdot h_g = 0 \\ Z_1 + Z_2 = G_t \cdot \cos\alpha \end{cases} \tag{18}$$

$$\begin{cases} Z_1 = \dfrac{G_t \cdot (b - f \cdot r_r) \cdot \cos\alpha - F_t \cdot h_g}{L} \\ Z_2 = \dfrac{G_t \cdot (a + f \cdot r_r) \cdot \cos\alpha + F_t \cdot h_g}{L} \end{cases} \tag{19}$$

Taking into account that the product $f.r_r$ has a small value in relation to the distances (lengths) a, b, the system (19) gets the simplified form (20):

$$\begin{cases} Z_1 = \dfrac{G_t \cdot b \cdot \cos\alpha - F_t \cdot h_g}{L} \\ Z_2 = \dfrac{G_t \cdot a \cdot \cos\alpha + F_t \cdot h_g}{L} \end{cases} \tag{20}$$

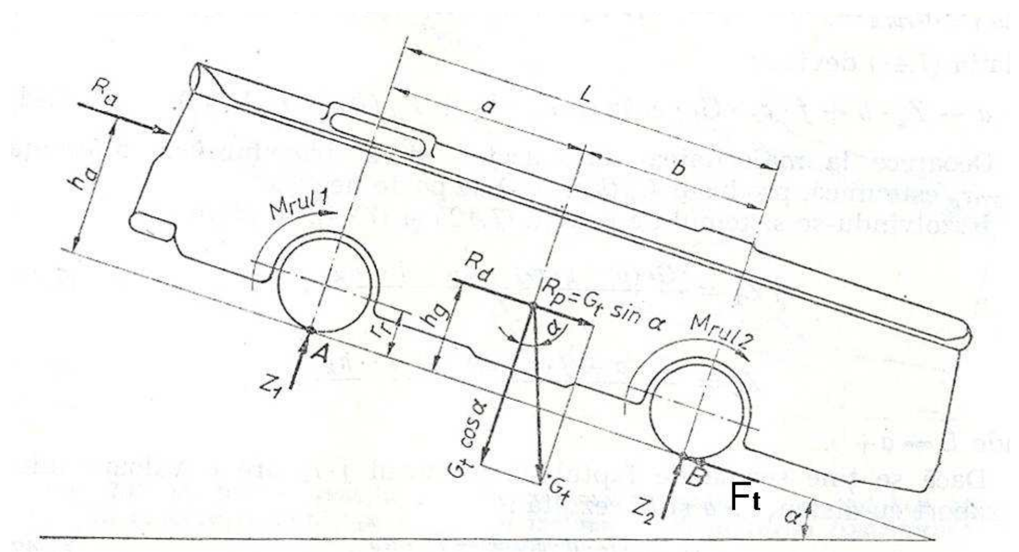

Fig. 5: The forces, moments and reactions that act on a bus when climbing a slope with an accelerated motion

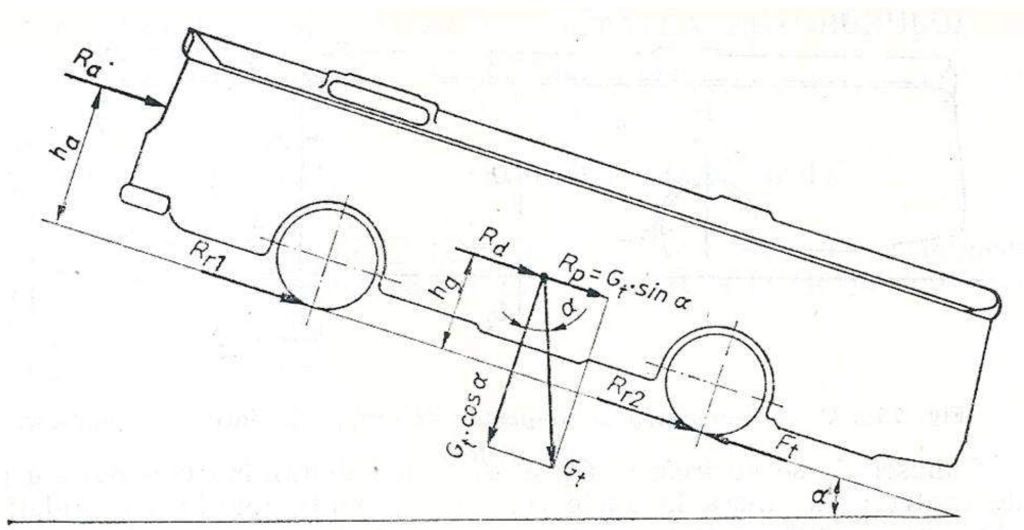

Fig. 6: Forces and reactions acting on a bus that is in a straight line on a α inclination and transient (acceleration)

From the system (20) we find that dynamic loads on the bridges Z_1 and Z_2 depend on the total weight of the bus G_t, the position of the center of gravity (*a*, *b*, *hg*), the slope angle α and the force traction F_t and the tractive force loads the rear axle and simultaneously unloads the front axle, the more it is.

Air resistance and acceleration resistance do not really influence the dynamic loads on the two front axles.

Equation of Bus Movement

In order to establish the general equation of bus movement, it is considered a straight-ahead bus on a α inclination path, in dynamic mode (variable speed, acceleration period).

Figure 6 shows the forces and responses acting on the bus in the mentioned case, these being: The weight of the G_t bus (with the two components), the rolling resistance R_{r1} and R_{r2} at the two decks, the normal reactions of the path Z_1 and Z_2, the resistance due the slope R_p, the air resistance Ra, the acceleration resistance R_d and the tangential reaction F_t of the path to the drive wheels (equal to the traction force).

The projection equation, on a path parallel to the path, of the forces acting on the bus has the form (21) or (22), wherein $R_r = R_{r1} + R_{r2}$:

$$F_t - \left(R_{r1} + R_{r2} + R_p + R_a\right) - R_d = 0 \tag{21}$$

$$R_d = F_t - \left(R_r + R_p + R_a\right) \tag{22}$$

If the acceleration resistance (22) is replaced in relation (22), the expression (23) is obtained, where $\Sigma R' = R_r + R_p + R_a$:

$$a \cdot \delta \cdot \frac{G_t}{g} = F_t - \sum R' \tag{23}$$

From the relation (23) directly follows the expression (24), which represents the differential equation of the rectilin motion of the bus; it expresses the value of the acceleration that the bus can obtain for a certain value of the traction force Ft and a certain value of the cumulative resistances $\Sigma R'$:

$$a = \frac{g}{\delta \cdot G_t} \cdot \left(F_t - \sum R'\right) \tag{24}$$

Conclusion

The present paper aims to present the study of the dynamics of the vehicles, with particularization on the buses. Here are the main elements of the bus dynamics, taking into account all the elements that influence the dynamic operation of a bus, in general and in particular situations, with emphasis on the main systems and elements that act on the actual, dynamic, on a normal path or on an inclined with an alpha angle path. The paper presents the second part of the bus dynamics.

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Author's Contributions

All the authors contributed equally to prepare, develop and carry out this manuscript.

Ethics

This article is original and contains unpublished material. Authors declare that are not ethical issues and no conflict of interest that may arise after the publication of this manuscript.

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