DYNAMIC ANALYSIS OF A ROAD VEHICLE USING NUMERICAL METHODS AND MULTIBODY SIMULATION TECHNIQUES

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Abstract: In this paper, the dynamic behavior of a vehicle is studied using computational techniques. Traction forces, resistive forces opposing motion (slope resistance and dynamic friction), as well as inertia forces resulting from the vehicle mass are taken into account. As a solution method, the SOLIDWORKS® application is used to build a vehicle model (an assembly composed of parts) and a driving path that allows the study of vehicle dynamics during uphill and downhill motion on an inclined plane.

Keywords: Vehicle, assembly, velocity, acceleration, force.

1. BASIC PARAMETERS OF VEHICLES

The basic parameters of vehicles define the performance characteristics that must be ensured from the design stage so that the achieved performance places the vehicle among the best models in the same category.

The main parameters characterizing a vehicle can be grouped into the following categories:

- constructive parameters;
- dynamic parameters;
- technical operating characteristics.

These parameters are used for the objective evaluation of the quality of different types of vehicles and to determine whether they meet the operating conditions required in service. Knowing these parameters allows the selection of vehicles suitable for given operating conditions.

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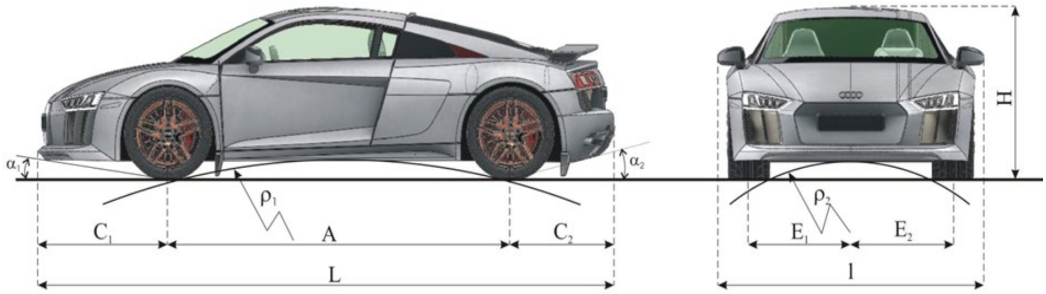

Fig. 1. Main vehicle dimensions

The main constructive parameters of vehicles (Figure 1) are:

- overall dimensions, representing the maximum length *L*, width *l*, and height *H*, including body dimensions;
- wheelbase *A* (distance between axles), defined as the distance between the geometric axes of the vehicle axles. For three-axle vehicles, the wheelbase is considered as the distance between the front axle axis and the midpoint between the two rear axles, with the distance between the rear axles specified additionally;
- track width (front E_1 and rear E_2), representing the distance between the median planes of the wheels on the same axle. For vehicles with dual rear wheels, the track width is defined as the distance between the planes passing through the midpoint between the two wheels on the same axle;
- ground clearance *c*, also called ride height, defined as the distance between the ground and the lowest point at the front axle c_1, the clutch housing *c*, and the rear axle c_2. Generally, $c_1 < c$ to protect the engine and clutch housing, and $c_2 < c_1$ due to the construction of the central reducer and differential.
- front overhang C_1 and rear overhang C_2 – horizontal distances from the symmetry axis of the front and rear axles to the front and rear ends of the vehicle;
- longitudinal breakover radius ρ_1 – the radius of a conventional cylinder tangent to the front wheels, rear wheels, and the minimum ground clearance point of the chassis located between the axles;
- transverse breakover radius ρ_2 – the radius of a conventional cylinder tangent to the wheels on the same axle and the lowest point of the chassis between the wheels;
- approach angle α_1 and departure angle α_2 – angles formed by the ground and tangents drawn through the lowest extreme points at the front and rear wheels;
- vehicle height *H* – the distance from the ground to the outer surface of the vehicle body.

2. VEHICLE SELF-PROPULSION PROCESS

Vehicle propulsion is usually achieved using mechanical energy supplied by internal combustion engines. The transmission system transfers torque and angular velocity to the driving wheels and adapts them to operating conditions. The engine (Figure 2a), together with the transmission (gearbox Figure 2b and differential Figure 2c), forms the powertrain.

a b c

Fig. 2. Powertrain

The torque developed by the internal combustion engine is transmitted through the transmission to the driving wheels. The torque transmitted to the driving wheel is called wheel torque. The torque M_R transmitted to the driving wheels is calculated using:

$$M_R = M \cdot i_{tr} \cdot \eta_{tr} \tag{1}$$

where M is the effective engine torque, i_{tr} is the transmission ratio, and η_{tr} is the transmission efficiency.

3. VEHICLE RESISTANCE TO MOTION

Vehicle motion results from the energy transmitted to the driving wheels, and its nature is determined by the magnitude and direction of the forces acting on it:

- traction force;
- resistive forces to motion;
- inertia force.

At constant speed (uniform motion), the traction force balances the resistive forces, and the inertia force is zero. During acceleration, the traction force balances both the resistive forces and the inertia force, which opposes motion. The excess energy developed by the engine is used to accelerate the vehicle and is stored as kinetic energy. During braking, the traction force is zero, and the inertia force becomes active.

The resistive force diagram is shown in Figure 3. The total wheel force F_R is used to overcome:

- rolling resistance F_r;
- grade resistance F_p;

• aerodynamic resistance F_a;
• acceleration resistance F_d;
• drawbar pull F_{tc}.

The total resistance F_Σ in the most general case (inclined road and variable speed) is given by:

$$F_\Sigma = F_r + F_p + F_a + F_d + F_{tc} \tag{2}$$

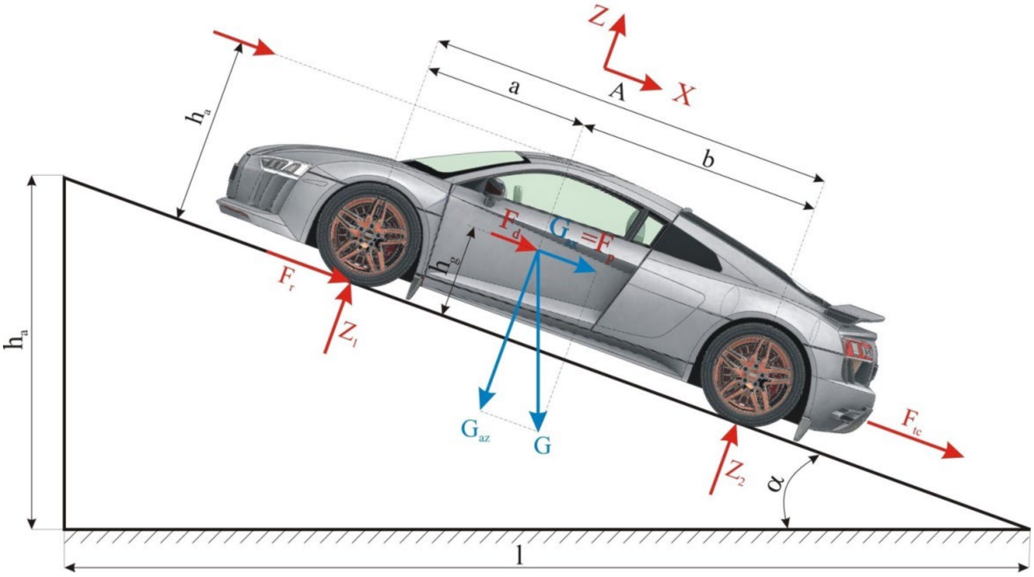

Fig. 3. Diagram of vehicle motion resistances

4. VEHICLE DYNAMIC ANALYSIS USING SOLIDWORKS

Vehicle dynamic behavior was modeled using SOLIDWORKS Motion Study. An assembly consisting of a driving path and a vehicle was created (Figure 4).

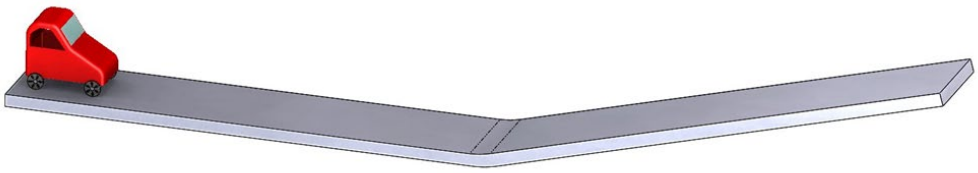

Fig. 4. Assembly for vehicle dynamics study

For the dynamic analysis, a traction force F_a = 1200 N was applied. This value was chosen considering that the main force opposing the uphill motion of the vehicle on the inclined plane is the tangential component of its weight, which has the value: $F_t = G \cdot \sin\alpha = m \cdot g \cdot \sin\alpha = 452 \cdot 9{,}81 \cdot \sin\left(15^0\right) \approx 1148\ N$.

Therefore, it is expected that on the horizontal section of the driving path the motion is accelerated (the velocity increases), while on the inclined section, due to the balance of forces, the motion occurs at constant velocity. The motion analysis allowed the plotting of the vehicle velocity variation (Figure 5). It can be observed that the vehicle velocity becomes approximately constant once it reaches the inclined plane. This is due to the fact that the traction force is approximately equal to the tangential component of the vehicle weight relative to the plane.

For the dynamic analysis of the vehicle starting uphill, a traction force value of $F_a = 1500$ N was imposed. The vehicle is positioned at the initial time as shown in Figure 6. The traction force is greater than the tangential component of the vehicle weight relative to the plane. This implies that the motion on the inclined section of the driving path is uniformly accelerated in the uphill direction. Figure 7 presents the velocity variation graph for uphill starting.

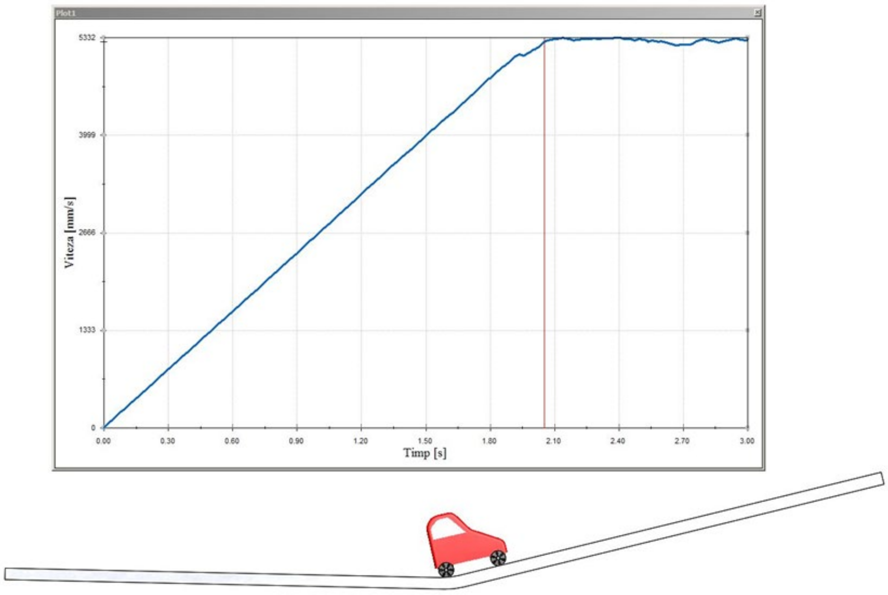

Fig. 5. Vehicle velocity variation graph

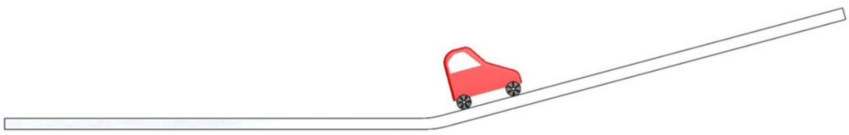

Fig. 6. Position of the vehicle at the initial moment of the dynamic analysis for climbing the inclined section of the driving path

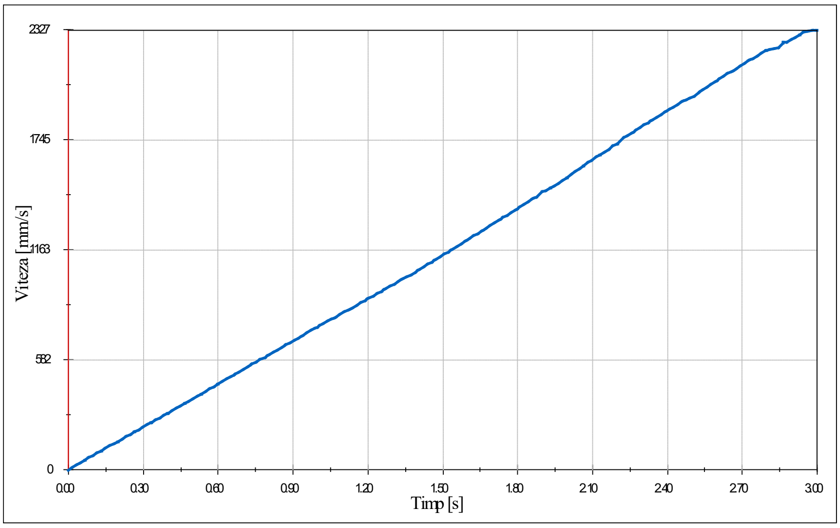

Fig. 7. Vehicle velocity variation graph

The dynamic analysis of the vehicle during downhill motion was performed using a traction force value of 800 N. The initial position of the vehicle is shown in Figure 8.

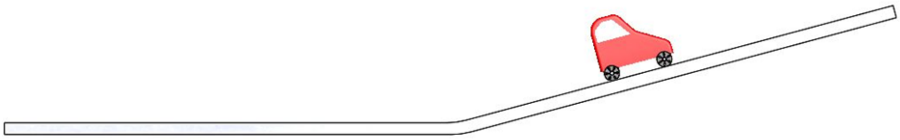

Fig. 8. Position of the vehicle at the initial moment of the dynamic analysis for descending the inclined section of the driving path

In this case, the traction force is smaller than the tangential component of the vehicle weight relative to the inclined plane. This means that initially the motion on the inclined section of the driving path is uniformly accelerated in the downhill direction. The motion is generated by the tangential component of the vehicle weight, while the traction force acts as a braking force as long as its direction is opposite to the direction of vehicle motion. Figure 9 shows the vehicle velocity variation graph during the descent of the inclined section of the driving path.

Next, the velocity diagram shown in Figure 9 is analyzed over time intervals:

0 – a: The vehicle descends along the inclined section of the driving path. The force generating the motion is the tangential component of the vehicle weight relative to the plane, while the traction force acts as a friction (decelerating) force, being opposite in direction to the motion. At point **a**, the horizontal section of the driving path begins, and the tangential component of the vehicle weight becomes zero.

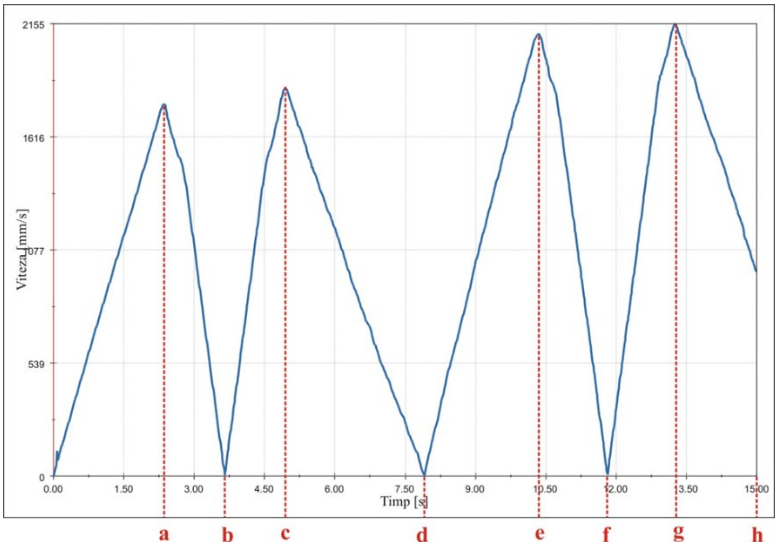

Fig. 9. Vehicle velocity variation graph during the descent of the inclined section of the driving path

a – b: The vehicle moves in a direction opposite to the traction force, with an initial velocity equal to that at point **a**. The motion is decelerated due to the traction force. At point **b**, the vehicle comes to a stop.

b – c: The vehicle changes its direction of motion and begins moving toward the inclined section of the driving path. The motion is accelerated under the action of the traction force, which in this case becomes a driving force. At point **c**, the vehicle enters the inclined section of the driving path.

c – d: The vehicle undergoes uniformly decelerated motion. The decelerating force is the difference between the tangential component of the vehicle weight (which is opposite to the direction of motion) and the traction force. At point **d**, the vehicle velocity becomes zero.

d – e: Time interval during which the events occur in a manner analogous to interval **0 – a**.

e – f: Time interval during which the events occur in a manner analogous to interval **a – b**.

f – g: Time interval during which the events occur in a manner analogous to interval **b – c**.

g – h: Time interval during which the events occur in a manner analogous to interval **c – d**.

CONCLUSIONS

The dynamic behavior of a vehicle model was investigated using the motion analysis capabilities of the SOLIDWORKS® application in the following cases:

- vehicle motion on a horizontal surface under the action of a traction force, followed by entry onto an inclined section of the driving path. The imposed traction force was approximately equal to the tangential component of the vehicle weight. Consequently, motion on the horizontal section is uniformly accelerated, while motion on the inclined section is uniform (constant velocity);
- uphill starting of the vehicle under the action of a traction force greater than the tangential component of the vehicle weight. The motion is uniformly accelerated. The acceleration calculated as the ratio between the resultant force and the vehicle mass is approximately equal to the average acceleration obtained from the velocity–time graph, with a percentage difference of 1.28%;
- descent along the inclined section of the driving path under the action of the tangential component of the vehicle weight, with the traction force acting in the opposite direction. The imposed traction force is smaller than the tangential component of the vehicle weight.

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