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Mathematical modelling of improving the physical and mechanical properties of vehicle movement parameters in mountain conditions.

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Abstract: The article discusses new scientific approaches to the laws of vehicle movement on a mountain road and their analysis in a new interpretation. The results of scientific research related to improving traffic safety in extreme road conditions are presented. Scientific proposals are given.

Keywords: motion, motion parameters, mountain conditions, fluctuation function, adhesion forces, mathematical motion model.

Mountain roads place unique demands on vehicles, including cars. Extreme lean angles, variable weather conditions and uneven surfaces pose many challenges for drivers and vehicle manufacturers. In this regard, improving the physical and mechanical properties of vehicle movement parameters in mountainous conditions becomes an important task to ensure traffic safety and efficiency. This article discusses the main approaches and methods for improving these parameters.

1. Suspension and shock absorption system

One of the key aspects that influences the behaviour of a car in mountain conditions is the suspension and shock absorption system. It is important that the suspension can effectively cope with road irregularities, providing stability and comfort for passengers. Modern cars are equipped with adaptive suspensions that automatically adjust the stiffness of the shock absorbers depending on road conditions. This reduces roll and vibration, providing better traction and increased vehicle stability.

Creating a mathematical model and calculating a car's suspension and depreciation system when driving in the mountains requires considering various factors, including traffic dynamics, the impact of road irregularities, and the characteristics of mountain routes. Let's consider the main aspects of creating such a model.

1.1. Mathematical model of the suspension system

The car suspension system can be thought of as a system with two degrees of freedom, including:

Vehicle mass (m).

Suspension (springs and shock absorbers), is characterized by the spring stiffness coefficient (k) and the shock absorber damping coefficient (c).

Basic equations:

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1.1.1. Equation of motion for spring and shock absorber:

The force acting on the spring is determined by Hooke's law:

$$Fs = -k \cdot x$$

The force acting on the shock absorber is determined by:

$$F_d = -c \cdot \dot{x}$$

where x x is the movement of the spring (deformation),

$\dot{x}$ $\dot{x}$ is the speed of movement of the spring.

1.1.2. Differential equation of motion:

For a system with one degree of freedom (simplified model):

$$F(t) = m \cdot \ddot{x} + c \cdot \dot{x} + k \cdot x$$

where $\ddot{x}$ $\ddot{x}$ is the acceleration of the mass, $F(t)$ F (t) is the external force acting on the system (for example, road irregularities).

1.1.3. Impact of road irregularities

Road irregularities can be modelled as a periodic function:

$$F(t) = A \cdot \sin(\omega t)$$

where A is the amplitude of irregularities,

ω is the frequency of irregularities.

1.1.4. Taking into account mountain conditions

When driving in the mountains, it is necessary to take into account the change in the angle of inclination of the road (θ). The effect of tilt can be taken into account by adding a gravity component to the equation of motion:

$$\mathbf{Fg = m \cdot g \cdot \sin(\theta)}$$

where g is the acceleration of gravity (9.81 m/s^2).

1.1.5. Generalized equation of motion

The generalized equation of motion, taking into account road unevenness and the slope of a mountain road, will look like this:

$$\mathbf{m \cdot \ddot{x} + c \cdot \dot{x} + k \cdot x = A \cdot \sin(\omega t) + m \cdot g \cdot \sin(\theta)}$$

1.1.6. Calculation example

Consider the following parameters:

Vehicle mass $m = 1500$ m =1500 kg

Spring stiffness coefficient $k = 20000$ k =20000 N/m

Damping coefficient of shock absorbers $c = 1500$ c =1500 N s / m

Amplitude of road irregularities $A = 500$ A =500 N

Irregularity frequency $\omega = 2$ ω =2 rad/s

Mountain road inclination angle $\theta = 10^\circ$ θ =10 ∘

1.1.7. Solving the equation

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Numerical methods such as the Runge-Kutta method or methods available in MATLAB or Python software packages can be used to solve this differential equation.

Conclusion to the first part of the article

This simplified model allows you to understand the basic principles of the suspension and damping system of a car when driving in the mountains. For more accurate modelling and taking into account all factors, it is recommended to use specialized software and conduct additional tests.

2 . Mathematical model of car aerodynamics.

Basic parameters and equations:

Vehicle frontal area (A): The area of the front of the vehicle perpendicular to the direction of travel. Usually measured in square meters (m^2).

Drag coefficient (Cd): a dimensionless quantity that characterizes how streamlined a car's shape is.

Air Density (ρ): The density of the air through which the vehicle is moving. A commonly accepted value is 1.225 kg/m^3 under standard conditions (sea level at 15°C).

Vehicle speed (v): The speed at which a vehicle is travelling is measured in meters per second (m/s).

Aerodynamic drag force (Fd): force acting on a car from the air, which is directed opposite to the movement of the car.

The formula for calculating aerodynamic drag force:

$$F_d = 12 \cdot \rho \cdot v^2 \cdot C_d \cdot A \quad F_d = 21 \cdot \rho \cdot v^2 \cdot C_d \cdot A$$

2. Calculation of vehicle weight

The weight of the car (W) is determined by its mass (m) and the acceleration of gravity (g):

$$W = m \cdot g \quad W = m \cdot g$$

where $g = 9.81$ $g = 9.81$ m/s^2 is the acceleration of free fall.

Calculation example

Let's assume we have the following data for a car:
Frontal area (A) = 2.2 m^2
drag coefficient (Cd) = 0.30
Air density (ρ) = 1.225 kg/m^3
Vehicle speed (v) = 27.78 m/s (100 km/h)
Vehicle weight (m) = 1500 kg
Calculation of aerodynamic drag force:

$$F_d = 12 \cdot 1.225 \cdot (27.78)2 \cdot 0.30 \cdot 2.2$$
$$F_d = 21 \cdot 1.225 \cdot (27.78)2 \cdot 0.30 \cdot 2.2$$
$$F_d = 12 \cdot 1.225 \cdot 771.73 \cdot 0.30 \cdot 2.2$$
$$Fd = 21 \cdot 1.225 \cdot 771.73 \cdot 0.30 \cdot 2.2$$

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$$F_d = 12 \cdot 1.225 \cdot 771.73 \cdot 0.66$$
$$F_d = 21 \cdot 1.225 \cdot 771.73 \cdot 0.66$$
$$F_d = 313.47\ N \quad F_d = 313.47\ N$$

Car weight calculation:

$$W = 1500 \cdot 9.81$$
$$W = 14715\ N$$

Conclusion to the second part of the article

The obtained values show that at a speed of 100 km/h, the aerodynamic drag force for this car is approximately 313.47 N, and the weight of the car is 14715 N.

These calculations are a simplified model and do not take into account many other factors such as lift, rolling resistance and other aerodynamic effects that may be important in real conditions. For more accurate modelling, it is necessary to use specialized software and take into account additional parameters.

3. Mathematical model of the suspension system

The car suspension system can be thought of as a system with two degrees of freedom, including:

Vehicle mass (m).

Suspension (springs and shock absorbers), is characterized by the spring stiffness coefficient (k) and the shock absorber damping coefficient (c).

3.1. Basic equations:

1. Equation of motion for a spring and shock absorber:

The force acting on the spring is determined by Hooke's law:

$$F_s = -k \cdot x$$

The force acting on the shock absorber is determined by:

$$F_d = -c \cdot \dot{x}$$

where x is the movement of the spring (deformation),

$\dot{x}$ is the speed of movement of the spring.

3. 2. Differential equation of motion:

For a system with one degree of freedom (simplified model):

$$F(t) = m \cdot \ddot{x} + c \cdot \dot{x} + k \cdot x$$

where $\ddot{x}$ is the mass acceleration,

$F(t)$ is an external force acting on the system (for example, road unevenness).

3.3 . Impact of road irregularities

Road irregularities can be modelled as a periodic function:

$$F(t) = A \cdot \sin(\omega t)$$

where A is the amplitude of irregularities,

ω is the frequency of irregularities.

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3.4 . Taking into account mountain conditions

When driving in the mountains, it is necessary to take into account the change in the angle of inclination of the road (θ θ). The effect of tilt can be taken into account by adding a gravity component to the equation of motion:

$$Fg = m \cdot g \cdot \sin(\theta)$$

where g is the acceleration of gravity (9.81 m/s²).

3.5. Generalized equation of motion

The generalized equation of motion, taking into account road unevenness and the slope of a mountain road, will look like this:

$$m \cdot \ddot{x} + c \cdot \dot{x} + k \cdot x = A \cdot \sin(\omega t) + m \cdot g \cdot \sin(\theta)$$

3.6 . Calculation example

Consider the following parameters:

Vehicle mass m =1500 m=1500 kg

Spring stiffness coefficient k =20000 k=20000 N/m

Damping coefficient of shock absorbers c =1500 c=1500 N s / m

Amplitude of road irregularities A =500 A=500 N

Irregularity frequency ω =2 ω=2 rad/s

Mountain road inclination angle θ =10 ∘ θ=10 ∘

3.7. Solving the equation

Numerical methods such as the Runge-Kutta method or methods available in MATLAB or Python software packages can be used to solve this differential equation.

Conclusion to the third part

This simplified model allows you to understand the basic principles of the suspension and damping system of a car when driving in the mountains. For more accurate modelling and taking into account all factors, it is recommended to use specialized software and conduct additional tests.

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