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Vibrational resistance to vehicle motion due to road unevenness

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ABSTRACT

The subject of this study is the effect of road unevenness on the dynamics of the averaged longitudinal motion of a vehicle. These phenomena are considered in this work with the help of a minimal model which enables us to understand the mechanism of interaction between the longitudinal motion and the vertical vibrations excited by road unevenness. The analysis of this model is fulfilled in a frame of the concept of vibrational mechanics. This makes it possible to present the final result for averaged motion as a standard equation of the longitudinal vehicle with additional "vibrational", i.e. vibration-generated, slow force. This representation makes an investigation of the vehicle behavior on the road with unevenness especially transparent. Some features of this behavior are considered. Particularly, the possibility of a Sommerfeld effect sticking at a critical velocity during increasing power) is analyzed.

1. Introduction

Resistance to vehicle motion affects the environmental impact as well as operating expenses, and thus is an important aspect of vehicle theory and engineering [1–4].

Besides rolling and aerodynamic drag [1,2], a significant factor in the energy lost is vibrational dissipation due to the unevenness of the road [3–7]. Experimental studies [5,6] show that unevenness can increase vehicle fuel consumption by up to 10%. This effect is especially significant for some resonance velocities [4]. It affects both cars and railway vehicles due to some specific features of these vehicles; a significant factor for cars is tire characteristics, whereas the railway vehicles demonstrate additional effects connected with excitation of the ground and track vibrations [3].

The common behavioural traits for all types of vehicle on an uneven road are connected with the vertical vibration of vehicle parts, i.e. with excitation of internal degrees of freedom. Appropriate mathematical models are essential for studying these effects.

Rather sophisticated models for numerical simulation of vehicle dynamics on an uneven road are known [7–11]. The main goal of these models is the calculation of vertical vibrations in the context of comfort issues, damping technique and additional loading on the vehicle parts. The success of a dynamical model depends, first of all, on the quality of its validation which can be a rather difficult problem in the case of many degrees of freedom and unknown parameters. The application of the very detailed models is, therefore, not optimal if the aim of the investigation is the averaged longitudinal motion of the

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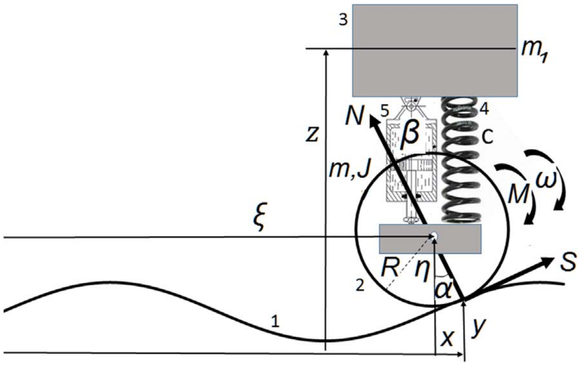

Fig. 1. Minimal model of vehicle (1- road with unevenness, 2- wheelset with undercarriage, engine and driving train, 3 – vertical vibrating part of vehicle, 4 – elasticity of connection, 5- damping of connection).

vehicle, and not the high-frequency vertical vibrations themselves. In this case, a minimal model is preferable, which allows us to describe the interaction between the longitudinal motion of the vehicle and the vertical vibrations of its parts due to road unevenness.

Such a model could be particularly effective in combination with the approach of vibrational mechanics [12–16]. The concept of vibrational mechanics makes it possible to present the final result for averaged motion as a standard equation of the longitudinal vehicle with additional ‘vibrational’, or vibration-generated, slow force. This makes the further interpretation of the problem and its solution especially clear.

The goal of the present paper is to examine a vehicle on an uneven road with the aid of a minimal model and with the perspective of vibrational mechanics. It allows us not only to estimate analytically the resistance to vehicle motion depending on its velocity and road unevenness, but also to describe some qualitative peculiarities of the vehicle behaviour. These phenomena are similar to the Sommerfeld effect in the dynamics of unbalanced motors and rotating shafts at a critical speed [14,17–21].

2. Minimal model of vehicle and its equations

The minimal model of a vehicle on the road with unevenness is depicted in Fig. 1.

The considered system has two degrees of freedom. The rolling body 2 has mass m and moment of inertia J and represents a wheelset of radius R with the undercarriage, engine and driving train. The body 3 of mass m_1 represents vertical vibrating parts of the vehicle or its load. Its connection with the body 2 has elasticity c and damping β and allows only vertical relative motion between the bodies. The road 1 is described by equation

$$y = f(x), \tag{1}$$

where f is a known periodical function and (x, y) are coordinates of the contact point between the road and the wheel. Normal force N and sticking friction force S act on the wheelset at the contact point between the wheel and the road. The kinematics of the wheel is described by the following relationship between its angular velocity ω and the coordinates ξ and η of its centre

$$\omega R = \sqrt{\dot{\xi}^2 + \dot{\eta}^2} \tag{2}$$

The dot denominates the derivative with respect to time t. The position of the body 3 is characterized by its absolute vertical coordinate z. The dynamics of the system can be described as follows:

$$J\dot{\omega} = M - SR - \mu N \tag{3}$$

$$(m + m_1)\ddot{\xi} = S\cos\alpha - N\sin\alpha \tag{4}$$

$$m\ddot{\eta} = S\sin\alpha + N\cos\alpha + c(z - \eta) + \beta\left(\dot{z} - \dot{\eta}\right) - mg \tag{5}$$

$$m_1\ddot{z} = -c(z - \eta) - \beta\left(\dot{z} - \dot{\eta}\right) - m_1 g \tag{6}$$

Eqs. (3)–(6) correspond to the rotation of the wheelset, to longitudinal and vertical vehicle motion and to vertical motion of the body 3. M is here the engine torque acting on the wheel. The parameter μ denotes the rolling resistance coefficient or