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Analysis of energy dissipation of shock-absorber during random excitation

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1. Introduction

Contemporary vehicle is one of the greatest scientific and technical achievements in the field of realization. Depending of the purpose of the vehicle, one can make totally different requirements for it. It is necessary to ensure a special comfort and prestige level in the high-class limousines. At this time low-powered town type vehicles must really have low maintenance costs, low fuel consumption and even alternative kinds of fuel. In that way so--called hybrid vehicles appeared. We can see them already in Lithuania.

A hybrid vehicle is such kind of car, in which useful power is received from several different sources. Mostly from an internal combustion engine and an electric motor. Internal combustion engine uses liquid or gas fuel, and an electric motor is powered by the battery, which is charged from the network when the vehicle is not operating. Usually this mean of transport uses an electric motor. If the battery discharges or the vehicle needs more power, both kinds of motors are used together, but other variants of the both sources arrangement are possible. Such solution is advertised as especially friendly for nature and human due to low emission, but in reality this is only pollution transference from street to electric power station, witch is usually out of town. It is necessary to agree, that only the result of reducing the concentration of exhausts gases in towns is partially achieved only.

Storage batteries charging from the network and the resource are the main problems of electrical transmission usage in cars. Another problem of hybrid vehicle is big weight of his motors and batteries. There is a long charging time and a short distance, what is difficult to get over. The latter problem stimulates the interest of looking for new possibilities to charge the battery during driving. Already since long time ago the possibility to recuperate a part of energy is known, e.g. as transport mean is being slowed down, what in reality is made in trolleybuses and some concept cars. It is known also the determination to use sun energy by applying special elements, which are covering roof of the car. These elements charge the storage battery at bright time when the car is standing or moving. Rather perspective is the application of fuel-cells. Fuel-cell is an element which produces electric energy by contacting hydrogen with oxygen of atmosphere. But in this case the hydrogen is indispensable again, to get it electrical energy is necessary for water hydrolysis or special reactors. Those get hydrogen from methanol or petrol in the vehicle. Itself however the latter solution is still very expensive and does not solve the problem of petrol resources saving.

It is known as well that vehicle's shock-absorbers get hot in operation. Mechanical energy in shock-absorber is converted into thermal and is dissipated into environment.

The same shock-absorber damps down return movement. Technically (directly of by rotary movement) it is possible to convert this energy into electrical energy. But first of all it is necessary to evaluate, how much of the energy is turned into the useless heat and dissipated. Analyzing small city type vehicle, in this work one seeks to determinate the amount of dissipated energy in shock-absorbers by estimating the following parameters:

- road profile;
- vehicle driving speed;
- nonlinear suspension characteristics.

2. Random excitation

147 m interval of Karaliaus Mindaugo avenue Fig. 1 in Kaunas town will be used for the analysis of dissipated energy. Car quarter model is shown in [1, 2] Fig. 2. In the first approach linear suspension characteristics used. The linear characteristics [3, 4] are shown in the Table 1.

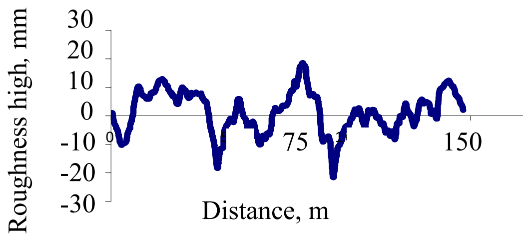

Fig. 1 Road profile

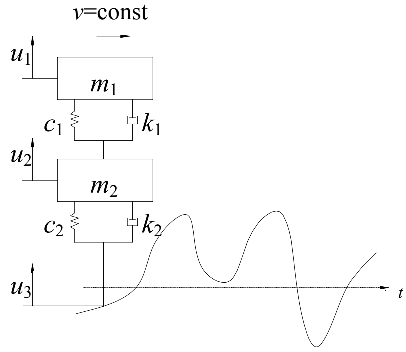

Fig. 2 Car quarter model

Table 1

Linear suspension's characteristics

Mass, kg		Stiffness, N/m		Damping, Ns/m	
m_1	m_2	k_1	k_2	c_1	c_2
117.8	20	6000	160000	6000	405

The system of (Fig. 1) differential equations of the model given is bellow [5, 6]

$$\begin{bmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{bmatrix}\begin{Bmatrix} \ddot{u}_1 \\ \ddot{u}_2 \\ \ddot{u}_3 \end{Bmatrix} + \begin{bmatrix} c_1 & -c_1 & 0 \\ -c_1 & c_1 + c_1 & -c_2 \\ 0 & -c_2 & c_2 \end{bmatrix}\begin{Bmatrix} \dot{u}_1 \\ \dot{u}_2 \\ \dot{u}_3 \end{Bmatrix} + \begin{bmatrix} k_1 & -k_1 & 0 \\ -k_1 & k_1 + k_1 & -k_2 \\ 0 & -k_2 & k_2 \end{bmatrix}\begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix} = 0 \quad (1)$$

here m^3 is a conditional denotation of moving base (road), $u_1=f(t)$ is the speed of unsprung mass in vertical axis, $u_2=f(t)$ is the speed of sprung mass in vertical axis.

After mathematical operations with first and second lines of equations system (1) the following equation was obtained

$$[M]\{\ddot{U}\} + [C]\{\dot{U}\} + [K]\{U\} = \begin{bmatrix} 0 \\ c_2 \end{bmatrix}\dot{u}_3 + \begin{bmatrix} 0 \\ k_2 \end{bmatrix}u_3 \quad (2)$$

here $u_3=f(t)$ is the road profile excitation when moving speed is constant.

Eq. (2) will be expressed in the following form

$$[M]\{\ddot{U}\} + [C]\{\dot{U}\} + [K]\{U\} = \{F(t)\} \quad (3)$$

Eq. (3) can be solved using the broad-brush Newmark method [7]. For this reason it is practical to make a program in MATLAB.

Nonlinear damping and stiffness characteristics have been taken to reach more realistic results and to precise the model.

Linear zones of nonlinear characteristics (shown in the Fig. 3 and 4) are given in the Table 2.

Stiffness and damping of the tyre were considered as linear characteristics: k_2 =160000 N/m, c_1 =405 Ns/m.

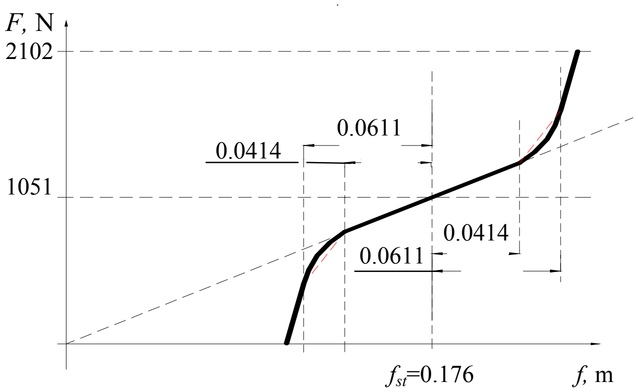

Fig. 3 Nonlinear stiffness characteristics

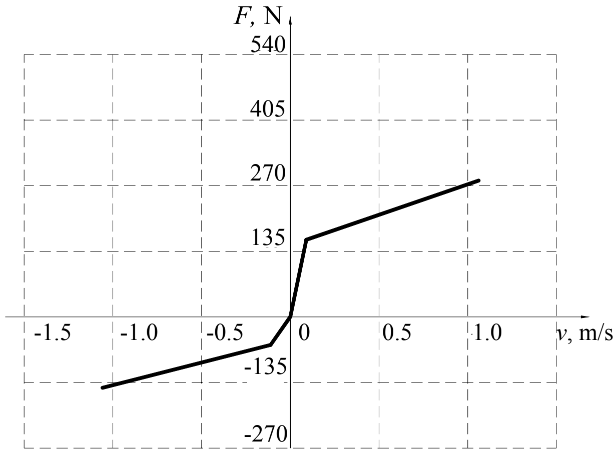

Fig. 4 Nonlinear damping characteristics

Table 2

Nonlinear suspension's characteristics

Spring		Shock-absorber	
Spring's deformation *f*, m	Stiffness k_1, N/m	Speed *u*, m/s	Damping c_1, Ns/m
		<-0.11	188
0-0.041	6000	-0.11-0	519
0.041-0.061	10000	0-0.077	2061
0.061-0.15	16000	0.077>	458

3. Calculation of the shock-absorber dissipated power and energy

Shock-absorbers diffused power is directly proportional to the product of its viscosity factor *F* and of vertical speed of the suspension relatively to the body

$$P = F(\dot{u}_1 - \dot{u}_2) = c_1(\dot{u}_1 - \dot{u}_2)^2 \quad (4)$$

As vertical speed of the suspension changes, absorption of the amortization is taken as constant (simplified). And if we square each constant part of the speed difference of sprung and unsprung masses and multiply by time interval Δt (which is constant) we get diffused energy

$$N = c_1(\dot{u}_1 - \dot{u}_2)^2 \Delta t \quad (5)$$

Below the movement of a small city car quarter model at a constant speed on a random road surface profile is presented. This numerical analysis was performed according the above presented formulas in MATLAB.

The obtained results show, that it is possible to select the suspension for a concrete car, which mass (of a quarter) is known, considering not only the requirement of comfort and stability, but also the amount of suspension's diffused energy at a specific excitation law. Using data from the Table 2 the difference between the results using totally linear and nonlinear characteristics are shown in Fig. 5.

In Fig. 6 we can see energy dissipation in time. The analyzed road interval passed in t_{test}=5.88 s (driving speed 90 km/h). So we can declare that within one hour on an analogical road the amount of dissipated energy will be $3600/t_{test}$ (~612) times more.

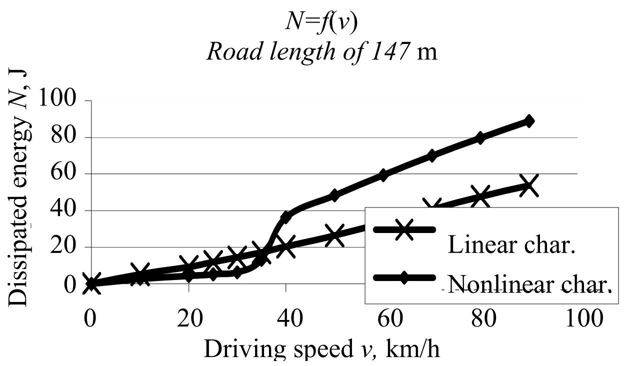

Fig. 5 Function $N=f(v)$ of suspension with linear and nonlinear characteristics

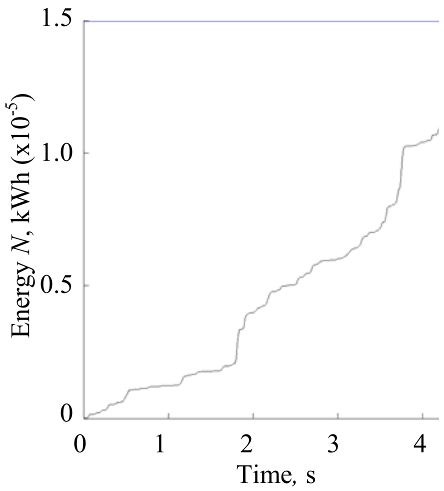

Fig. 6 Function $N=f(t)$ of suspension with linear characteristics

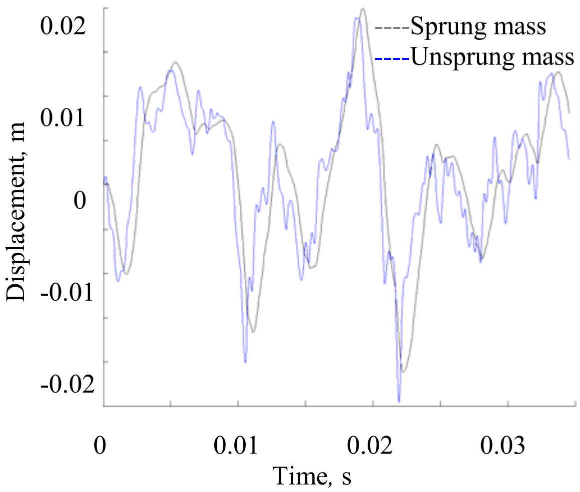

Fig. 7 Displacements of sprung (car body) and unsprung (suspension) masses using linear characteristics. Driving speed 90 km/h

Modelling results, presented in Figs. 7-10 permit us to evaluate the influence of characteristic linearisation on masses displacements and shock-absorbers resistance power.

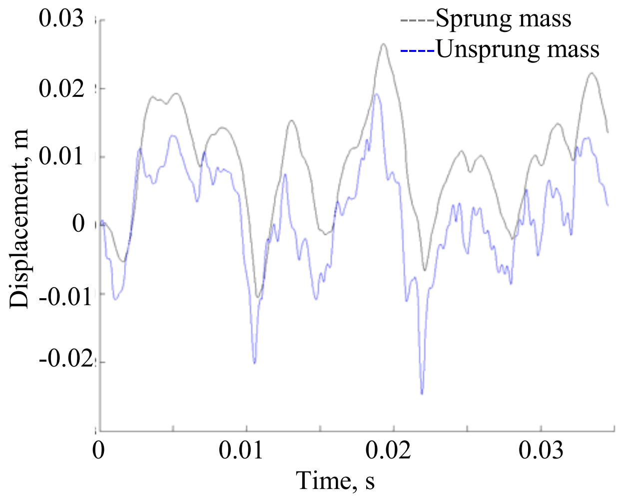

Fig. 8 Displacements of sprung (car body) and unsprung (suspension) masses using nonlinear characteristics. Driving speed 90 km/h

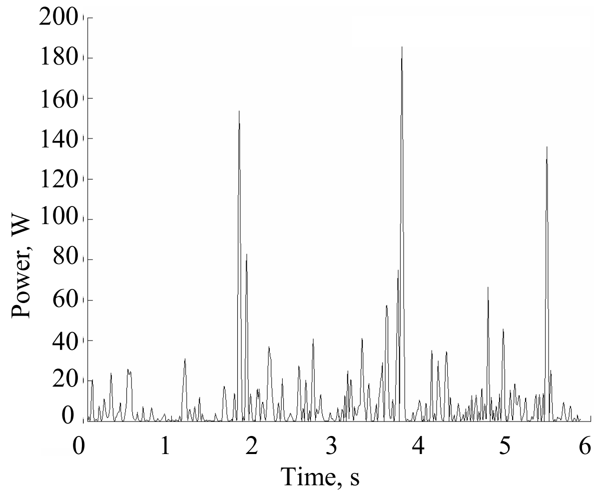

Fig. 9 Dependence of shock-absorber's dissipated power on a random excitation using linear characteristics. Driving speed 90 km/h

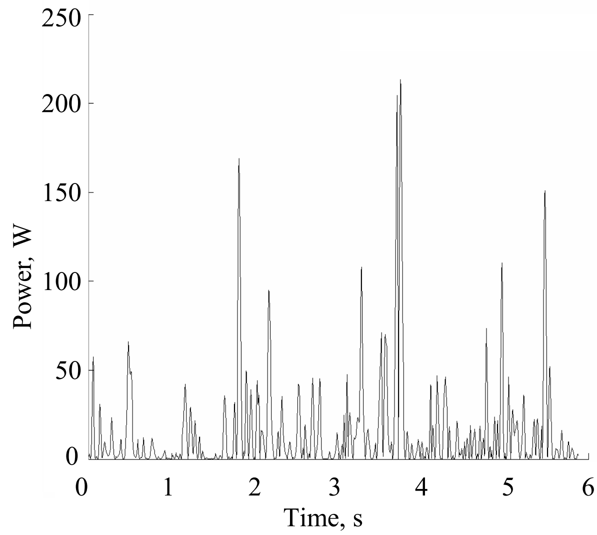

Fig. 10 Dependence of shock-absorber power dependence on a random excitation using nonlinear characteristics. Driving speed 90 km/h

4. Conclusions

In the paper the movement of a small city car has been simulated at different driving speeds, using linear and nonlinear suspension's characteristics on 147 m interval of av. Karaliaus Mindaugo in Kaunas. The results obtained show us, that whole car (4 quarters) can dissipate quite important part of the total engine's power of the vehicle.

1. Small car's suspension can dissipate 0.06-0.1 kWh of energy per hour and this means that up to 1% off the total energy created in the engine can be lost in shock-absorbers.

2. Using linear suspension characteristics quantity of dissipated energy directly depends from the driving speed.

3. Using nonlinear suspension characteristics the amount of dissipated energy is linear in the linear intervals of the characteristics.

4. Comparing simulation results using linear and nonlinear suspension characteristics it was observed that a car body displacements are smoother when characteristics are nonlinear. When driving speed is over 40 km/h, shock-absorber's resistance power is about 60 % higher by using nonlinear characteristics.

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ENERGIJOS NUOSTOLIŲ ATSITIKTINĖS APKROVOS VEIKIAMAME AMORTIZATORIUJE ANALIZĖ

R e z i u m ė

Darbe analizuojami automobilio pakabos energijos nuostoliai. Sukurtas modelis pritaikytas panaudojant tiesines ir netiesines pakabos savybes. Abiejų skaičiavimų rezultatų palyginimo rezultatai rodo, kad, automobiliui judant iki 30 km/h greičiu, skirtumas nedidelis. Greičiui viršijus 30 km/h, skirtumas didėja, todėl pasirenkamas netiesinis modelis.

Per valandą išsklaidytos energijos kiekis apytiksliai lygus 0.06-0.1 kWh. Tai gana daug, turint omenyje, kad bendra mažo hibridinio miesto tipo automobilio galia siekia apie 10 kW (1.5 kW elektros ir 8.5 kW vidaus degimo variklio). Jeigu tokio pat sukimo momento automobilis turėtų tik elektros variklį, tai jo galia būtų ~3 kW, o tai reiškia, kad būtų išsklaidoma beveik 3 % visos sukuriamos galios.

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ANALYSIS OF ENERGY DISSIPATION OF SHOCK-ABSORBER DURING RANDOM EXCITATION

S u m m a r y

This paper presents the investigation of energy dissipation in a car suspension. To start some research of damping energy's recuperation is important to calculate the quantity of looses. Developed model has been applied using linear and nonlinear suspension characteristics. Results of both calculations has been compared and gotten results show that till driving speed 30 km/h the difference is very little. When speed is over 30 km/h – nonlinear characteristics has to be applied.

The quantity of dissipated energy is around 0.06…0.1 kWh. This quantity is quite important regarding full power of a small city's type hybrid which is around 10 kW (1.5 kW electric motor and 8.5 kW internal combustion engine). When car has only electric motor, the same torque can be produced by ~ 3 kW electric motor and it means that dissipated energy can be around 3% of total produced power.

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АНАЛИЗ ЗАТРАТ ЭНЕРГИИ В АМОРТИЗАТОРЕ ПРИ СЛУЧАЙНОМ ВОЗДЕЙСТИИ

Р е з ю м е

В настоящей работе проведено исследование затрат энергии в автомобильной подвеске. Разработанная модель была применена используя линейные и нелинейные характеристики подвески. Результаты сравнения обоих вычислений показывают, что до скорости движения 30 км/ч различие неначительное. Когда скорость превышает 30 км/ч, нелинейные характеристики должны быть применены.

Количество рассредоточенной энергии – приблизительно 0.06…0.1 7кВтч. Это количество весьма важно относительно полной мощности маленького гибридного автомобиля городского типа, составляющая около 10 кВт (1.5 кВт электрический двигатель и 8.5 кВт двигатель внутреннего сгорания). Когда автомобиль имеет только электрический двигатель, тот же самый вращающий момент может быть произведен электрическим двигателем ~3 кВт, и это означает, что рассеянная энергия может составить приблизительно 3% полной произведенной мощности.

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