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Energy harvesting sensitivity analysis and assessment of the potential power and full car dynamics for different road modes

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ABSTRACT

Automobiles are dissipating a considerable amount of vibration energy that is worth of being harvested where it can be exploited in different applications. For a full vehicle suspension assembly, the conflict between the potentially harvested energy and vehicle dynamics represented by ride quality and road safety and handling was comprehensively illustrated for different input modes. The discrepancy between the bounce input mode and the roll input mode was also sufficiently clarified based on an extensive parametric analysis covering the design parameters and the operational parameters as well. Comprehensive simulations were then conducted to estimate the amount of wasted energy in vehicle suspension system for different types of cars (passenger, bus, truck, and off-road vehicle), besides the potential harvested power was quantified for different standard driving cycles (NEDC, WLTP, HWFET, and FTP). Based on that, a 7-DOF full car suspension model was implemented in Matlab/Simulink environment and induced by different levels of road irregularities. The findings of this paper showed that the vibration intensity levels changed clearly in the complex input mode that reflects a realistic view of the real vehicle dynamics on the roads compared to the ideal results from the bounce input mode. Our results also indicate that a potential power up to 420 W can be collected considering standard driving patterns and roll mode input. The analysis indicates that the overloaded vehicles are suitable for the energy harvesting system based on the harvestable energy per unit cost.

1. Introduction

Passive suspensions were considered in automobiles since 1990 for maintaining a sufficient contact performance between wheels and ground. The ride quality is another function of vehicle suspension systems leading to a decrease in the driver's fatigue that is related to accidents. Despite the significant development of recent car suspension systems, passive suspensions are still utilized in a large number of cars what makes the design of the suspension elements are of interest to the researchers and vehicle manufacturers. Essentially, the suspension acts as a vibration isolator to suppress the

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Nomenclature

English symbols

C_{FL}, C_{FR}, C_{RL}, C_{RR} damping coefficient for each suspension corner; N s/m
$DTL_{average}$ average dynamic tire force; N
DTL_{FLW}, DTL_{FRW} front left and right wheels dynamic tire force; N
DTL_{RLW}, DTL_{RRW} rear left and right wheels dynamic tire force; N
F_{KFL}, F_{CFL} spring and damper forces for the front left suspension; N
F_{KFR}, F_{CFR} spring and damper forces for front right suspension; N
F_{KRL}, F_{CRL} spring and damper forces for rear left suspension; N
F_{KRR}, F_{CRR} spring and damper forces for rear right suspension; N
F_{TFL}, F_{TFR}, F_{TRL}, F_{TRR} the corresponding tire forces for each suspension corner; N
I_B body pitch moment of inertia; kg m^2
I_R body roll moment of inertia; kg m^2
K_{FL}, K_{FR}, K_{RL}, K_{RR} spring stiffness for each suspension set; N/m
K_{TFL}, K_{TFR}, K_{TRL}, K_{TRR} tyre stiffness at each corner; N/m
L_1, L_2 longitudinal distance from C.G to the front and rear axles; m
L_L, L_R lateral distances from C.G to left and right wheels; m
M_B vehicle sprung mass; kg
M_{FL}, M_{FR}, M_{RL}, M_{RR} vehicle unsprung masses; kg
RMS_{BACC} bounce body acceleration root mean square; m/s^2
RMS_{PACC} pitch acceleration root mean square; rad/s^2
RMS_{RACC} roll acceleration root mean square; rad/s^2
Z_B vehicle body vertical displacement; m
Z_{BFL}, Z_{BFR}, Z_{BRL}, Z_{BRR} vehicle body vertical displacement at each suspension set; m
Z_{FL}, Z_{FR}, Z_{RL}, Z_{RR} wheel vertical displacement at each corner; m
Z_{RFL}, Z_{RFR}, Z_{RRL}, Z_{RRR} road input vertical displacement for each tire; m

Greek symbols

θ_B vehicle body pitch angle; °
φ_B vehicle body roll angle; °

Subscripts

B_{ACC} body bounce acceleration
FL, FR front left and front right
P_{ACC} body pitch acceleration
R_{ACC} body roll acceleration
RL, RR rear left and rear right

Abbreviations

DTL dynamic tire load
EUDC Extra-Urban driving cycle
FTP Federal Test Procedure
HESA hydraulic energy-regenerative shock absorber
HWFET highway fuel economy test cycle
NEDC New European Driving Cycle
PSD power spectral density
RMS root mean square
WLTP Worldwide harmonized Light Vehicles Test Cycle

disturbance from the road irregularity by dissipating the up and down vibration energy into heat waste [1,2]. In recent century, the energy saving direction witnessed a great development and prosperity as one of energy crisis solutions [3,4]. Obviously, fulfilling a good ride quality and road handling responses and also a good maneuverability with minimum energy consumption is a critical issue for the passive suspension design, that is why the regenerative suspension systems are of interest recently [5–7]. Therefore, the power dissipation can be one of the design considerations besides the ride comfort and road handling dynamics.

The suspension regenerative systems are classified based on the power extraction mechanism; linear, and rotary electromagnetic dampers [8,9]. In the rotary electromagnetic type, the rotary electromagnetic generator is driven by a linear-rotary transmission based on a mechanical transmission [10–12] or a hydraulic transmission [13–15]. Unlike the rotary type, in the