Experimental analysis of the dissipated energy through tire-obstacle collision dynamics

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ABSTRACT

Wheeled vehicles are responsible for a substantial portion of dissipated energy while the share of tire-ground interface is among the most role playing elements in this regard. The vibrations and kinetics of a traversing wheel over an obstacle is a paradigm that can serve as a functional example for energy dissipation of wheeled vehicles. This paper communicates the analysis of the dissipated energy for a traveling wheel at collision time with obstacles while a controlled laboratory condition of the soil bin facility equipped with a single wheel-tester rig was utilized to carry out the experiments. The tests were conducted as affected by wheel load, obstacle height, obstacle geometry, slippage and speed. It was inferred that the increment of collision speed, obstacle height and tire slippage lead to the increase of the dissipated energy; however, the complexity lies in the contradictory effect of wheel load. This can be attributed to the nonlinear wheel dynamics and the vibration attenuation process. It has to be emphasized that the outcome of this study would serve as a functional catalyst for the extensive researches concerned with the machine design industry and the heavy vehicle trafficking management.

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1. Introduction

The ever expanding requisite to the efficient energy systems and proficient energy management is getting more and more importance. The termination of crude oil supplies in addition to the social-political turmoil of crude oil producers, which has caused significant price fluctuations, divulges that both the developed and developing industries have to take drastic measures to achieve correct energy management policies. A great source of energy dissipation corresponds to the wheeled vehicles (both traveling on pavement and on off-road terrain) particularly at wheel-road interface. The majority of the power transmitted to the wheels is dissipated at the soil-tire interface [1]. As an example, a gallant and extensive study reported that about 20–55% of the energy developed to the drive tractor wheels is wasted in the tire-soil interaction [2]. This is a very considerable portion of energy loss which has to be minimized in order to achieve a sustainable development. The

sources for this massive energy dissipation could be attributed to the rolling resistance that occurs in the forms of heat loss, friction in the bearings, tire deformation, etc. This can be aggravated in the case of tire-obstacle contact problems where a sudden load creates serious fluctuations and vibrations. Road irregularities, particularly those of off-road terrains, exert continuous vibrations to the wheel depending on the shape and geometry of the irregularities, vehicle characteristics and the natural frequency of the wheel. The main difficulty resides in the determination of the tire-obstacle interaction nonlinearity due to the complex wheel dynamics and also the influence of a large range of obstacles and test courses. The progress of ride comfort, safety and structural integrity of large wheeled vehicles traversing over rough terrain with irregularities has gained ever increasing importance in the scope of vehicle trafficking and therefore; the tire-road interaction presents one of the biggest challenges in creating an accurate vehicle model [3].

A multibody model of a 4-axle vehicle was parametrically studied regarding the ability to overcome discrete obstacles on a steep slope and the suspension control while the attention was given to the wheel load distribution and the vehicle height [4]. Different methods to acquire the required parameterization data for a 16.00R20 Michelin XZL tire based on laboratory and field tests over discrete obstacles and uneven hard surfaces were conducted

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and the existing tire models were utilized to precisely describe the vertical behavior of large off road tires while driving over uneven terrain [3,5]. In another investigation, tire-road contact forces measurement system was proposed based on the measurement of three deformations of the wheel rim through strain gauges as of vehicle dynamic elements assessed by series of experimental and outdoors tests [6]. Moreover, the dynamic load of heavy vehicle at the bridge expansion joint was synthesized using a computational method based on spring-damping element considering the contact length between the tire and the road in addition to the dynamic characteristics of the wheel. A mathematical modeling attempt was undertaken for vehicle traversing over an obstacle considering the obstacle height that the wheel can overcome the instability [7]. Collision of automobile wheels with a vertical obstacle was performed and the required force and the minimal speed of driving for disassembling of the tire from the wheel rim after the collision with an obstacle were determined [8]. It was also reported that the values of this force and speed depends upon the height of the obstacle and the angle of collision with the obstacle [8]. However, the knowledge of energy loss due to wheel dynamics is not deterministic and still needs to be further ascertained. There are some investigations available in the literature regarding the traction dynamics and energy efficiency of heavy vehicles [9–12]. Several studies documented in the literature exist addressing the energy loss of off-road vehicles due to rolling resistance [13–15].

As far as our literature survey is concerned, this study spearheads the investigation of the dissipated energy of wheeled vehicles at collision with obstacles from the vehicle dynamics perspective. It is supposed that gaining an insight into the energy dissipation at tire-obstacle collision process would further contribute to the knowledge on the mechanical efficiency of the driveline system of vehicles for the traveling on road irregularities. In this regard, the experimental step included some of the most influential parameters such as wheel load, speed, slippage, obstacle geometry, and obstacle height. Furthermore, provision of a controlled experimental setup is an essential step to discover reliable and precise results. To this end, a soil bin testing facility accommodating a single wheel-tester was utilized.

2. Materials and method

Energy assessment was conducted on account of direct measurement of the vertical and longitudinal induced forces and quantifying the waste power:

$$P = \frac{F \times dx}{dt} = F \times V \tag{1}$$

where P is power (W), F is force (N) with vertical and longitudinal components, and V is forward speed (m/s). The power dissipation is presented to compute the energy dissipation:

$$E = \int P dt \tag{2}$$

By substituting Eq. (1) and Eq. (2);

$$E = \int F V dt \tag{3}$$

However, velocity should be presented as a vector in both vertical and longitudinal directions:

$$\vec{V} = \dot{x}i + \dot{y}j \tag{4}$$

The path of wheel is affected by the obstacle geometry as following:

$$y = sin\frac{2\pi}{l}x \quad 0 < x < 2\pi \tag{5}$$

For the triangular shaped obstacle, the following equation is described:

$$y = \begin{cases} ax & x < \dfrac{l}{2} \\ -ax & x > \dfrac{l}{2} \end{cases} \tag{6}$$

where l is the obstacle length and a is 0.4, 0.6, and 0.8 for the obstacles with the heights of 1, 2, and 3 cm, respectively.

As aforementioned, the provision of controlled testing environment is crucially significant for the reliability of the results s. Hence, a SWT (single wheel-tester) inside a soil bin facility was used to conduct the required experiments. The soil bin channel with 24 m length, 2 m width and 1 m depth was filled with the soil texture of the test region. The holistic system is consisted of a soil bin channel, SWT and the carriage. The SWT was connected to the carriage to be able to traverse through the soil bin channel. The carriage was powered with a 22 kW electromotor which was connected to the inverter for the start/stop and velocity control procedures. The power transmission was carried out through the electromotor to the chain system that was linked to the carriage. The carriage was traversing in the channel by means of four ball bearings positioned on the sidewalls of the soil bin. The SWT was connected to the carriage through an L-shaped part and also four horizontal arms each accommodating one S-shaped Bongshin load cell with 500 kg capacity. It is worth to note that the horizontal load cells were used to measure the horizontal forces applied to the wheel. One U-shaped frame was used to hold the tire and a three-phase electromotor of 5 kW was used to power the driving wheel. An appropriate inverter was also used to control the rotational velocity delivered to the wheel shaft and therefore; the linear velocity was adjustable. It is worth mentioning that the linear speed difference between the carriage and the SWT yielded different levels of adjustable slippage. Furthermore, the SWT was connected to the L-shaped frame by a power bolt rod (to adjust the applied wheel load) which was connected to a vertically situated S-shaped load cell responsible to measure the load variations while traversing over the obstacle and irregularities. The load cells were connected to Bongshin digital indicators which were in connection with a data logger with RS232 output signals. The data were subsequently sent to the laptop computer to be stored and processed with the frequency of 30 Hz. The general soil bin facility along with the single-wheel tester is shown in Fig. 1.

For all the experiments the tire inflation pressure was maintained at 131 kPa. Two shapes of triangular and curved obstacles were used in the study each at three heights of 1, 2 and 3 cm while two wheel load levels of 1 and 2 kN were considered. Furthermore, two levels of slippage were induced at 10 and 20%. Three forward velocities for the carriage were planned at three levels of 1.08, 1.8 and 2.52 m/s. In order to remove the soil effect on the experiment outputs due to the soil nonhomogeneous properties, a wooden board with 2 m width and 3 m length was used. The obstacles situated in the traversing direction of the wheel are depicted in Fig. 2.

3. Results and discussion

It is with no doubt that vehicle dynamics are significantly affected by the forces and torques exerted to the wheel as the unique bridge between the vehicle and ground. In addition to