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DYNAMIC LOAD ANALYSIS OF AGRICULTURAL PRODUCT TRANSPORT MOTORCYCLES UNDER DIFFERENT OPERATING SPEEDS IN LOCAL MARKETS

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ABSTRACT

In Vietnam's local markets, motorcycles are widely used for transporting agricultural products. During transportation, it is desirable to determine the load of the products without unloading them from the vehicle in order to avoid product deterioration and improve handling efficiency. However, vehicle motion induces dynamic loads that may affect weighing accuracy. This study investigated the effect of vehicle speed on the dynamic load of a motorcycle used for agricultural product transportation. A four-degree-of-freedom oscillation model of the motorcycle was developed and analyzed in MATLAB/Simulink. Simulations were carried out for operating speeds ranging from 3 to 25 km/h under road conditions representative of local markets in Vietnam. The results show that dynamic load increases with vehicle speed and is strongly influenced by road surface irregularities. The findings provide a basis for improving the accuracy of on-vehicle weighing systems for agricultural products and support the development of locally manufactured weighing equipment for agricultural logistics applications.

Keywords: Motorcycle oscillation model, dynamic load, suspension model, agricultural product transportation; weighing accuracy.

Phân tích ảnh hưởng của sự thay đổi tốc độ vận hành của phương tiện vận chuyển nông sản gây ra tải trọng động tại các chợ dân sinh

TÓM TẮT

Tại các chợ dân sinh ở Việt Nam, vận chuyển sản phẩm nông sản bằng xe máy hiện đang chiếm tỷ trọng lớn. Yêu cầu đặt ra trong quá trình vận chuyển là cần cung cấp thông tin về khối lượng chuyên chở của các sản phẩm nông sản nhưng hạn chế việc bốc dỡ sản phẩm để ngăn ngừa sự suy giảm về chất lượng của các sản phẩm này. Nhằm nâng cao độ chính xác của quá trình theo dõi khối lượng vận chuyển sản phẩm nông sản cần thiết phải khảo sát và đánh giá được ảnh hưởng của tốc độ di chuyển của phương tiện gây ra tải trọng động trong quá trình đo. Bài báo sử dụng mô hình dao động của phương tiện hai bánh gồm bốn bậc tự do. Mô hình được khảo sát và tính toán trong phần mềm Matlab trong vùng tốc độ thay đổi từ 3 đến 25km/h theo điều kiện mặt đường tại Việt Nam. Kết quả khảo sát có thể được sử dụng để hiệu chỉnh làm tăng độ chính xác trong quá trình theo dõi khối lượng nông sản vận chuyển. Sản phẩm theo dõi khối lượng này có thể sản xuất được ở Việt Nam, hỗ trợ rất tốt cho quá trình kinh doanh và vận chuyển sản phẩm nông sản tại các chợ dân sinh.

Từ khóa: Mô hình dao động, tải trọng động, mô hình hệ thống treo, quá trình vận chuyển sản phẩm nông sản.

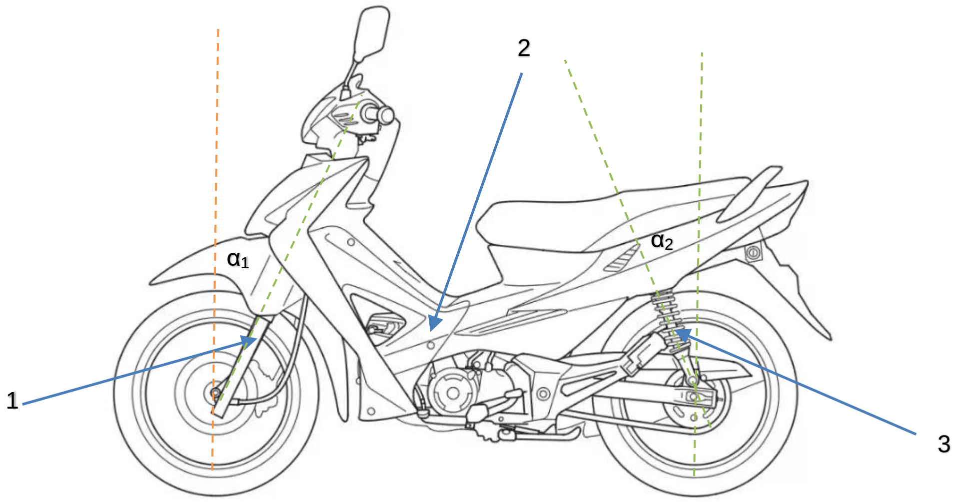
INTRODUCTION

Local markets play an important role in the daily lives of Vietnamese people. They serve as key places for the exchange of essential goods for daily consumption. The supply chain of agricultural products for local markets relies on transport from wholesale markets and business households, whom have the ability to grow agricultural products in small quantities to supply to local markets. In this context, motorcycles are commonly used to transport these goods to local markets (Figure 1).

During the transportation process, efforts are made to maintain the quality of agricultural products without affecting the transportation process and increase transportation efficiency by limiting the number of times agricultural products are transported. It is vital for managers to monitor and control the volume of products being transported, which helps maintain the quality of the agricultural products provided to users and improves the business performance of the seller. This creates a practical need for a weighing device that can monitor the quantity of agricultural products during transportation from distributors to retailers without unloading the goods from the motorcycle.

Motorcycles used in transporting agricultural products in local markets are often manufactured by Honda, Yamaha, SYM, and Suzuki, among others, with low and medium prices, and can transport passengers and commodities. These types of motorcycles have front and rear suspensions (Figure 2). The front wheel suspension system connects the front wheel and the frame. The rear wheel suspension system connects the rear wheel and the body of the vehicle. The suspension systems on both the front and rear wheels have spring elastic elements to soften oscillations and shock absorbers to absorb oscillations during movement linked between the frame and the wheels.

Figure 1. Transporting agricultural products by motorcycle



Note: 1: Front suspension, 2: Frame, 3: Rear suspension.

Figure 2. Suspension arrangement on motorcycles used in agricultural product transportation

During vehicle motion, road surface irregularities excite the suspension system and induce vehicle oscillation. These oscillations generate dynamic forces acting on the road surface or on the weighing platform during the weighing process. They cause undesirable consequences on the road and affect the outcome of weighing processes. For accurate weighing, the influence of these dynamic forces should be quantified and, as far as possible, minimized.

To investigate and evaluate the above dynamic forces, we needed to build a model of the motorcycle's oscillations. The oscillation model of a motorcycle can be built based on the following methods: the finite element method (Wong *et al.*, 2021; Islam *et al.*, 2024), multi-body method (Bonisoli *et al.*, 2022), and concentrated mass modeling method (Segla & Roy, 2020; Francis *et al.*, 2021).

The results of oscillation assessment surveys can be used in the process of assessing the impact of oscillations on the health and comfort of the driver and passengers (Liguori *et al.*, 2013; Francis *et al.*, 2021), or assessing the impact of oscillations on the stability of vehicles (Debowski, 2021). From these research results, it is possible to optimize the elements inside the vehicle's suspension system (elastic elements and shock absorbers) (Man *et al.*, 2020) to improve the comfort of the passenger and increase vehicle safety when the vehicle operates on the road (Cossalter *et al.*, 2011; Islam *et al.*, 2024). Some papers on the safety of motorcycles have shown the impact of collisions on the level of injury to users (Piantini *et al.*, 2016).

In a study of human comfort, a model describing the impact of oscillations on humans was constructed using a mass concentration represented by the mass of human body parts sensitive to oscillations. The model was used to evaluate the impact of oscillations on different parts of the human body (Shivakumara & Sridhar, 2010; Ueki *et al.*, 2025).

To investigate the effect of oscillation-induced loads acting on the road surface or a weighing platform, this study employed a lumped-parameter model of a motorcycle. The model was used to evaluate the variation in dynamic loads under different operating speeds for two road surface conditions: a step profile and a random profile.

MATERIALS AND METHODS

Oscillation model

The oscillation model was built based on dividing the motorcycle into sprung and un-sprung masses.

The sprung mass included the frame, engine, rider, and payload, and was represented by a lumped mass (M) and a mass moment of inertia (I_y) about its center of gravity (O_1). The sprung mass had two degrees of freedom: vertical translation and pitch rotation about the transverse axis.

The front un-sprung mass, denoted by (m_1), included the front wheel, tire, and associated components, and had one degree of freedom, (q_1). Similarly, the rear un-sprung mass, denoted by (m_2), included the rear wheel assembly and associated components, and had one degree of freedom, (q_2).

The front suspension was characterized by stiffness and damping coefficients (k_f) and (c_f), respectively, while the rear suspension was characterized by (k_r) and (c_r). Because the front and rear suspension axes are inclined at angles (α_1) and (α_2) (Figure 2), the equivalent stiffness and damping coefficients used in the model are given by ($k_1 = k_f \cos^2\alpha_1$), ($c_1 = c_f \cos^2\alpha_1$), ($k_2 = k_r \cos^2\alpha_2$), and ($c_2 = c_r \cos^2\alpha_2$) (Segla & Roy, 2020).

The tires were modeled as linear elastic elements with stiffness coefficients (k_{tf}) and (k_{tr}) (Figure 3) for the front and rear wheels, respectively. Tire damping was neglected because the associated energy dissipation was assumed to be small compared with that of the suspension system.

The input signals affecting the model were the road surface profiles at the wheel contact position represented by (q_f) and (q_r) (Figure 3).

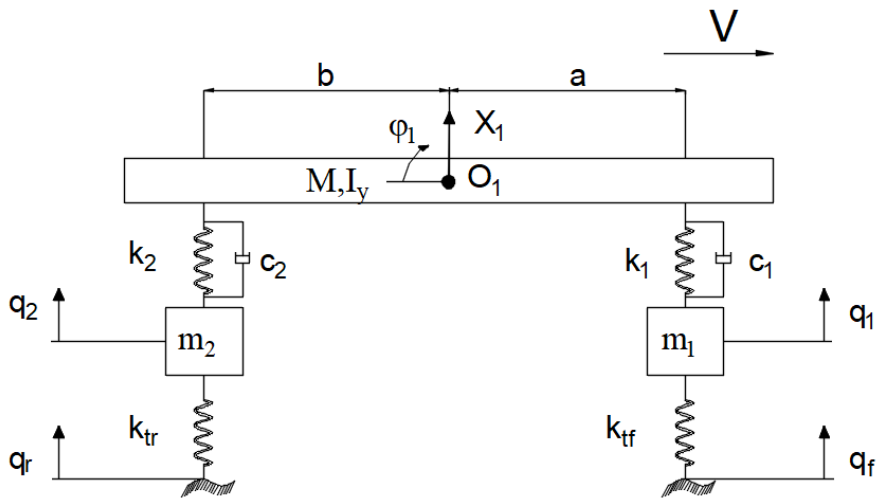


Figure 3. Oscillation model of an agricultural product transport vehicle

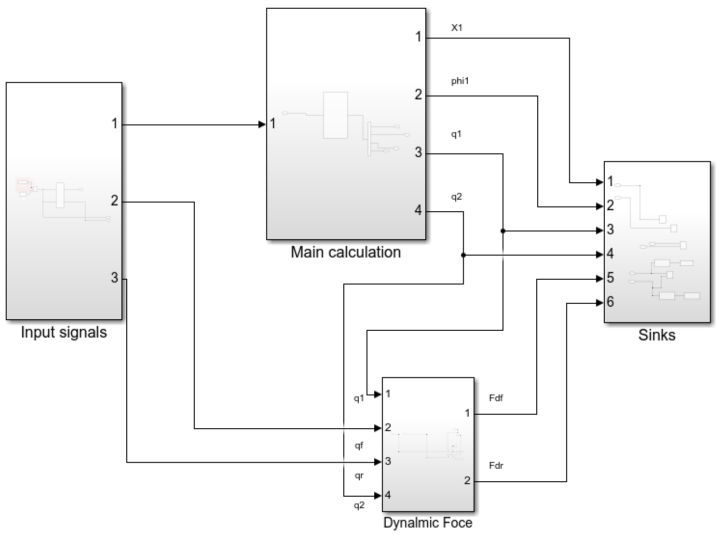


Figure 4. Oscillation model of an agricultural product transport vehicle in Simulink

The Lagrange equation was applied as follows:

$$\frac{d}{dt}\left(\frac{\partial E_k}{\partial \dot{q}_i}\right)-\frac{\partial E_k}{\partial q_i}+\frac{\partial E_n}{\partial q_i}+\frac{\partial E_p}{\partial \dot{q}_i}=0 \qquad (2.1)$$

where q_i is the degrees of freedom (DOF) with I = 1:4 corresponding to X_1, φ_1, q_1, and q_2.

The system of differential equations describing the oscillations of the agricultural product transport vehicle included four differential equations corresponding to the four degrees of freedom X_1, φ_1, q_1, and q_2. These equations described the oscillation process of the mechanical system including the sprung mass M and un-sprung masses m_1 and m_2. The system of differential equations was rewritten in matrix form:

$$M\ddot{X}+C\dot{X}+KX=F(x) \qquad (2.2)$$

where:

$$M=\begin{pmatrix} M & 0 & 0 & 0 \\ 0 & I_y & 0 & 0 \\ 0 & 0 & m_1 & 0 \\ 0 & 0 & 0 & m_2 \end{pmatrix}$$

$$C=\begin{pmatrix} c_1+c_2 & -c_1a+c_2b & -c_1 & -c_2 \\ -ac_1+bc_2 & a^2c_1+b^2c_2 & ac_1 & -bc_2 \\ -c_1 & c_1a & -c_1 & 0 \\ -c_2 & -c_2b & 0 & c_2 \end{pmatrix}$$

$$K=\begin{pmatrix} k_1+k_2 & -k_1a+k_2b & -k_1 & -k_2 \\ -ak_1+bk_2 & a^2k_1+b^2k_2 & ak_1 & -bk_2 \\ -k_1 & k_1a & -k_1+k_{tf} & 0 \\ -k_2 & -k_2b & 0 & k_2+k_{tr} \end{pmatrix}$$

$$F(x)=\begin{pmatrix} 0 \\ 0 \\ k_{tf}q_f \\ k_{tr}q_r \end{pmatrix}$$

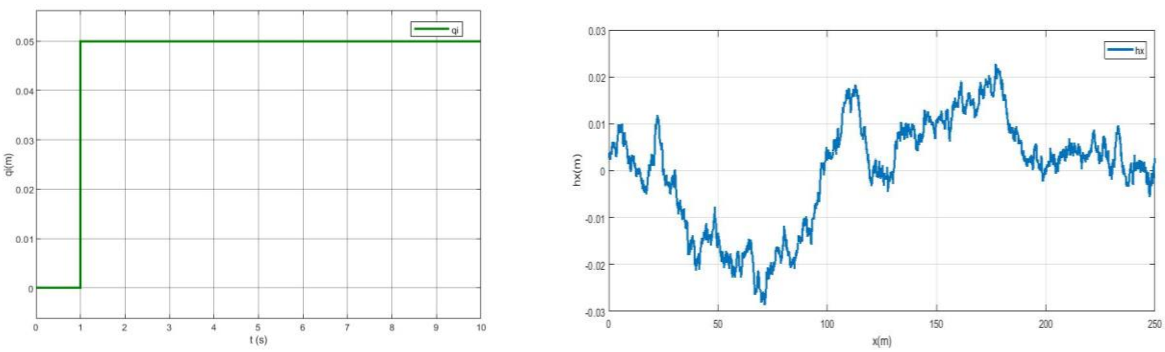
The oscillation model was implemented in MATLAB/Simulink to analyze two operating conditions: (i) motion over a step profile and (ii) motion over a random road profile. The simulation framework consisted of four main blocks: the main calculation block, the input signal block, the dynamic force evaluation block, and the result display block (Figure 4).

Parameters of the model

The total weight of an agricultural product transport motorcycle is 300 kg, including an average tare weight (100 kg), weight of the driver (70 kg), and weight of the agricultural products (130 kg). Other parameters were determined by direct measurement and reference (Francis *et al.*, 2021) as shown in Table 1. The simulate speed range was 3-25 km/h.

Table 1. Calculation parameters of agricultural product transport motorcycle

Symbol	Parameters	Unit	Value
M	Sprung mass	kg	273
I_y	Sprung body mass moment of inertia	Kg.m2	22
m_1	Front un-sprung mass	kg	12
m_2	Rear un-sprung mass	kg	15
c_1	Front sprung damper	N.s/m	2134
k_1	Front sprung stiffness	N/m	25000
c_2	Rear sprung damper	N.s/m	1165
k_2	Rear sprung stiffness	N/m	58570
k_{tf}	Front tire stiffness	N/m	141000
k_{tr}	Rear tire stiffness	N/m	141000
a	Distance between the center gravity and front axle	m	0.7
b	Distance between the center gravity and rear axle	m	0.6



a b

Figure 5. Road profiles (a: Step profile b: Random profile)

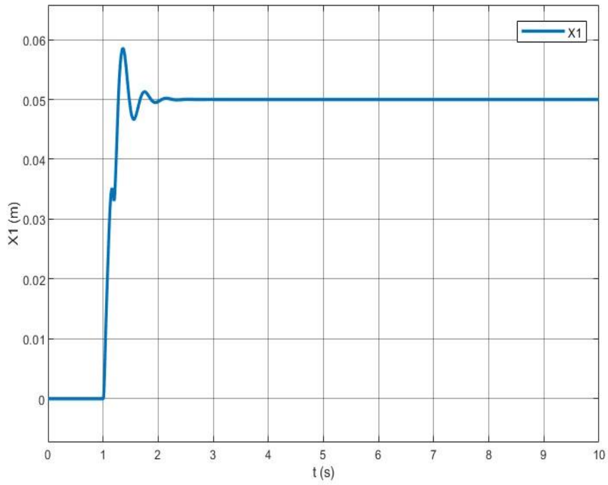
RESULTS AND DISCUSSION

Simulations were performed in MATLAB for two road surface conditions: a step profile with a height of 0.05 m and a random profile. In both simulations, concrete was selected as the local market road surface, which has good road surface standards and is considered an A-B road surface according to ISO 8608 standard (Truong *et al.*, 2019). This profile was built by mfile in MATLAB software (Figure 5).

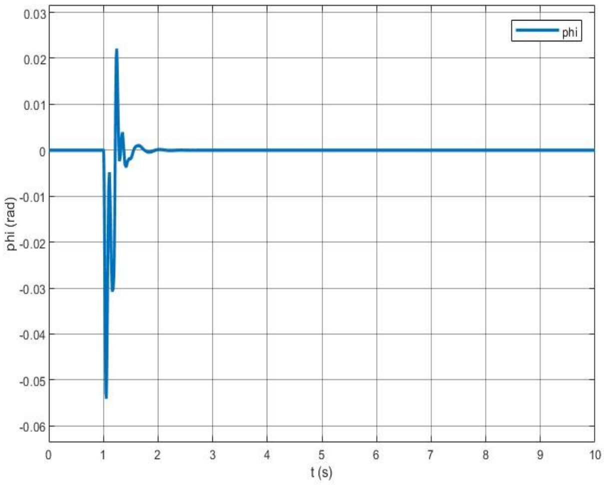
The dynamic forces applied to the road surface were determined by the equations: $F_{Đf} = k_{tf}(q_1\text{-}q_f)$ and $F_{Đr} = k_{tr}(q_2\text{-}q_r)$. To evaluate the impact of vehicle operation at each operating speed, the paper used the force RMS (root mean square) index values of the dynamic force values obtained at the positions of the front and rear tires.

Step shape profile simulation

The simulation results shown in Figure 6 indicate that when the motorcycle passes over a step profile of 0.05 m at a speed of 20 km/h, the vertical displacement of the sprung mass (X_1) and the pitch motion (φ_1) persists for approximately 1 s before returning to equilibrium due to damping, beginning when the front wheel encounters the step and gradually decaying after both wheels have passed the obstacle.



a



b

Figure 6: (a) Displacement of sprung mass, (b) rotation of sprung mass

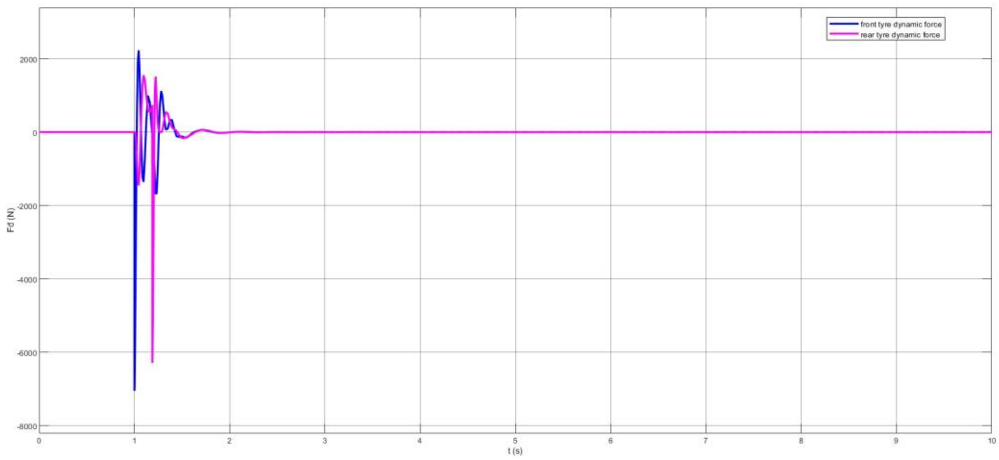
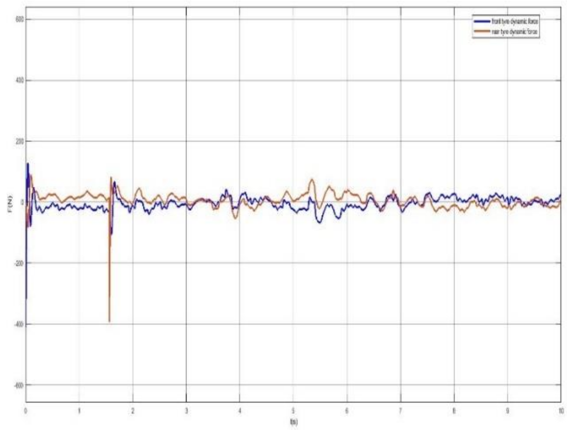
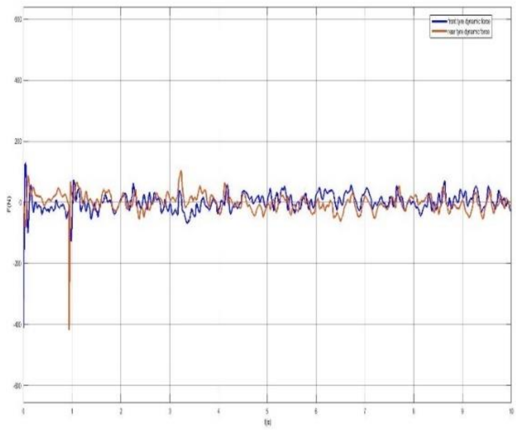


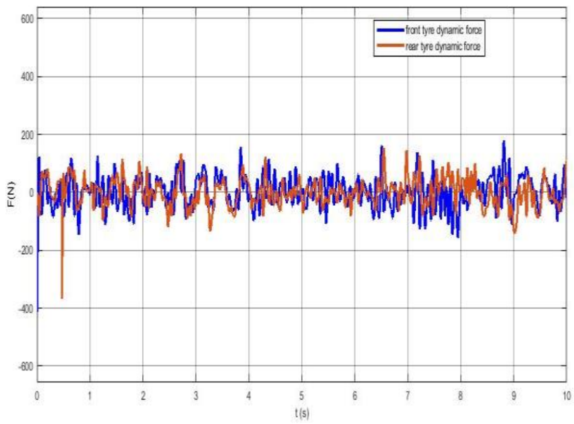
Figure 7. Dynamic force in the case of the step profile



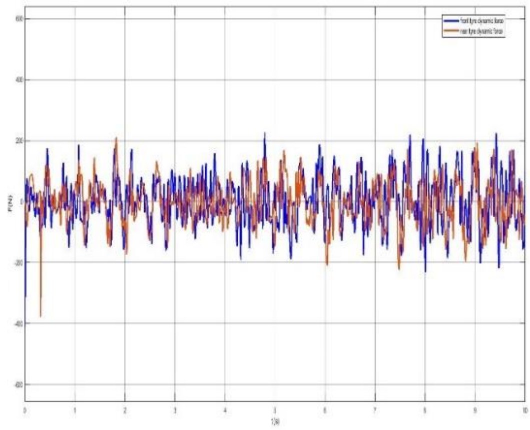
V = 3 km/h



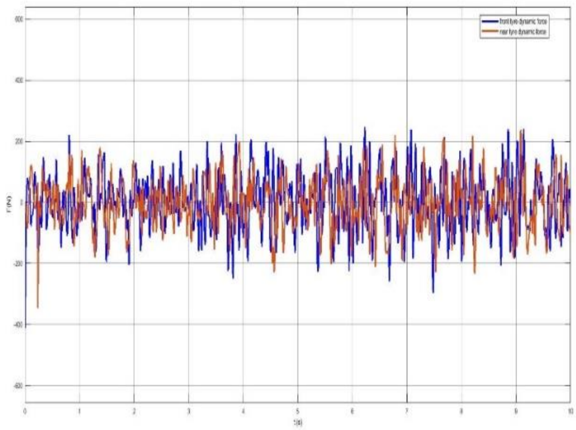
V = 5 km/h



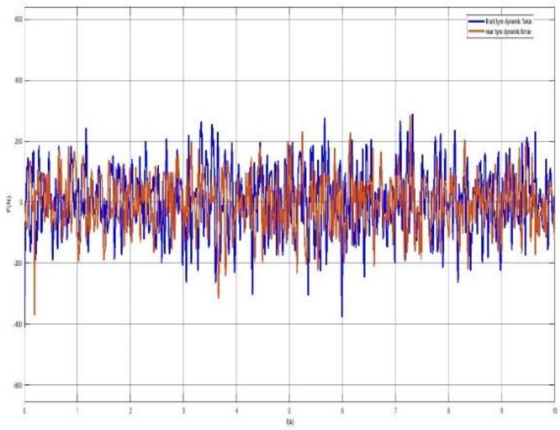
V = 10km/h



V = 15km/h



V = 20km/h



V = 25km/h

Figure 8. The dynamic load at the front and rear wheels in the case of the A-B random profile

Figure 7 shows that large dynamic force peaks occur at the front and rear wheel contact points when the motorcycle encounters the step profile. These force peaks decay within approximately 1 s and exhibit a phase difference corresponding to the time interval between the front and rear wheels contacting the step.

These results indicate that sudden changes in road elevation can significantly increase dynamic loading. Therefore, the weighing platform should be installed on a surface with a high degree of flatness to minimize measurement errors.

Random profile simulation

The results of the dynamic force survey at the front and rear wheels of the agricultural product transport vehicle at speeds of V = 3 km/h, V = 5 km/h, V = 10 km/h, V = 15 km/h, V = 20 km/h, and V = 25 km/h are shown in the Figure 8.

Figure 8 indicates that the amplitude of the dynamic load fluctuations generally increased with vehicle speed. At 10 km/h, the fluctuation amplitude was approximately twice that of 3 km/h, and it continued to increase at higher speeds. The corresponding RMS values are presented in Table 2.

The RMS survey results show that the total dynamic force value exerted by the vehicle on the road surface was the smallest when operating the vehicle at low speed. The total deviation value compared to the total weight of the motorcycle at speed V < 5 km/h was less than 1.4%.

The research res2ults will be used as a reference for further studies to evaluate the effects of dynamic loads running through the weighing equipment.

CONCLUSIONS

The motion of a motorcycle over an uneven road surface generates dynamic loads that act on the road surface or on a weighing platform. These loads depend on both the vehicle speed and suspension characteristics.

Within the investigated speed range of 3-25 km/h, higher operating speeds generally resulted in larger dynamic loads. Therefore, the speed of the motorcycle should be limited when passing over agricultural product weighing equipment in order to reduce weighing error.

The results also showed that road surface unevenness can significantly affect weighing accuracy. Accordingly, the weighing platform should be installed on a surface with a high degree of flatness.

Further experimental studies are required to validate the simulation results and to quantify the actual influence of dynamic loading on weighing accuracy.

Table 2. RMS values of dynamic load at the tires

Speed	Items	RMS Value	Unit	Total deviation (%)
V = 3 km/h	Dynamic load value at the front wheel	28.34	N	1.1
	Dynamic load value at the rear wheel	7.096	N	
V = 5 km/h	Dynamic load value at the front wheel	31.040	N	1.3
	Dynamic load value at the rear wheel	9.539	N	
V = 10 km/h	Dynamic load value at the front wheel	18.000	N	4.2
	Dynamic load value at the rear wheel	108.000	N	
V = 15 km/h	Dynamic load value at the front wheel	97.990	N	4.18
	Dynamic load value at the rear wheel	41.570	N	
V = 20 km/h	Dynamic load value at the front wheel	10.000	N	4.16
	Dynamic load value at the rear wheel	115.000	N	
V = 25 km/h	Dynamic load value at the front wheel	0.695	N	4.06
	Dynamic load value at the rear wheel	121.200	N	

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