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# THE DYNAMIC ACTION OF THE VEHICLE WHEEL ON THE RIPPLED ROAD

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**Keywords:** Earthmoving vehicles, road-tyre contact, contact force, dynamic.

**Abstract.** The vehicle wheel has a very important role in earthmoving machine dynamic analysis. The wheel is the first part of the vehicle in contact with the road und its ripples. The wheel properties such as mass, elasticity and oscillations attenuation capacity affects largely the dynamic of the entire vehicle. A vehicle can have more wheels with independent or common suspension and generalizes the dynamic of the entire ensemble based firstly on the action of the wheel-tyre. The present paper describes the dynamic action of a single wheel under consideration of his properties only.

## 1. INTRODUCTION

For a heavy laded vehicle on rippled road the ensemble wheel-tyre plays an important role in generation and development of the dynamic forces. This kind of vehicle can be a construction equipment, respectively a frontal loader. This machine circulates mostly on rippled road with different speeds and loads. The rippled road needs great and heavy wheels and tyres with great mass and elasticity. Therefore we have chosen the frontal loader wheel as disquisition model.

## 2. THE MODEL OF THE CONTACT BETWEEN TYRE AND ROAD

We consider a 2D model of the wheel-tyre-road ensemble. The force $F_e$ acts only vertical and contains the weight of the wheel and a certain part of the vehicle and load weight, see fig. 1. The force $F_e$ generates the elastic deformation $y$ of the tyre. The elasticity and attenuation factor are denoted in fig. 1 with $k$ and $c$. The elasticity is produced by the balloon tyre inflated with pressed air, the attenuation is produced from the interior friction forces and a plastic amount of the deformation. The road is considered inelastic.

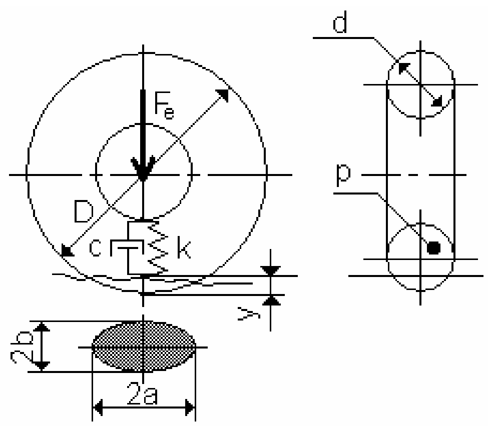


***Fig. 1. The model of the wheel-tyre ensemble***

The wheel-tyre has an annular form with exterior diameter $D$, interior diameter $d$ and pressure $p$. The elliptical contact area is $2a \times 2b$. On the geometrical way is easy to calculate:

$$a = \sqrt{y(D - y)}; \quad b = \sqrt{y(d - y)} \tag{1}$$

and the force $F_e$ becomes

$$F_e = p\pi\, ab = p\pi\, y\sqrt{(D-y)(d-y)} \tag{2}$$

therefore has a nonlinear dependence from the deformation *y*. The elastic factor *k* of the tyre is alike nonlinear.

$$k = \frac{F_e}{y} = p\pi\sqrt{(D-y)(d-y)} \tag{3}$$

## 3. DYNAMIC MODEL

The wheel circulates on a sine profiled road, see fig. 2. The value $y_1$ denotes the sine profile, $y_2$ the position of the centre of the wheel and *v* the speed. The distance between reference axis for $y_1$ and $y_2$, respectively between the incipient contact point and wheel centre is $D/2$. *M* is the mass of the wheel and a certain part of the vehicle and load mass.

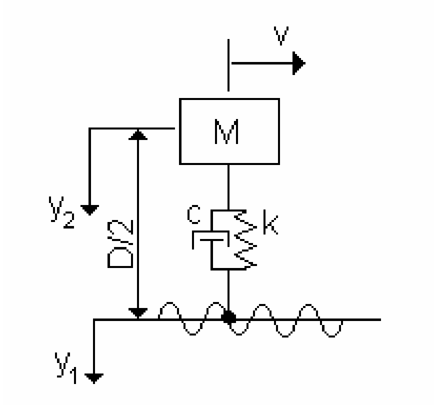


***Fig. 2. The dynamic model of the wheel-tyre-road ensemble***

The differential equation of the wheel movement is

$$M\,\ddot{y}_2 + F_e + F_c = Mg \tag{4}$$

where g=*9,81* $m/s^2$, $F_e$=elastic force

$$F_e = \begin{cases} p\pi(y_2-y_1)\sqrt{[D-(y_2-y_1)][d-(y_2-y_1)]}, & y_2-y_1 > 0 \\ 0, & y_2-y_1 \le 0 \end{cases} \tag{5}$$

$F_c$=attenuation force

$$F_c = \begin{cases} c(\dot{y}_2-\dot{y}_1), & y_2-y_1 > 0 \\ 0, & y_2-y_1 \le 0 \end{cases} \tag{6}$$

The sine profiled road has the expression

$$y_1 = -A\sin\left(\frac{2\pi vt}{l}\right) \tag{7}$$

where *A* is the amplitude of the ripple, $l$ - the spatial period of the ripple, *t* - time.

The results of the equation (4) under the conditions (5)---(7) determines the trajectory of the wheel centre $y_2$, the speed $\dot{y}_2$, the acceleration $\ddot{y}_2$ and the force $F_e$ calculated with eq. (5). The differential equation is nonlinear and can be solved using only numerical methods.

## 4. PRACTICAL RESULTS

As experimental model was chosen the frontal loader MMT 45 type LHD made by the company Promex S.A. of Braila, with following characteristics:

Table 1. Frontal loader MMT 45 type LHD

| Elements | Symbol | Value |
|---|---|---|
| A quarter of the mass of entire machine | M | 1500 kg |
| Wheel (Tyre 12,5x20x12PR) | D | 1,00 m |
| | d | 0,250 m |
| | p | 3 bar |

The attenuation factor *c* was evaluated in laboratory on *c=15000 Ns/m* by the evaluation of the attenuation of the free oscillations. The frontal loader moves with the speeds between 20 Km/h in situ up to maximal 50 Km/h. The numerical solving was made on Pentium IV PC with the Runge-Kutta [5], [6] fourth order method and Borland Pascal language. For the spectral analysis we used the pure Fourier's transformation because other methods same as fast Fourier's transformation (FFT) or ready software like as LabVIEW offers dubitable results [6].

The next figures present the trajectories $y_2$ with $D/2$ translated adown in order to have a direct comparison between the both curves, $y_2$ and road profile.

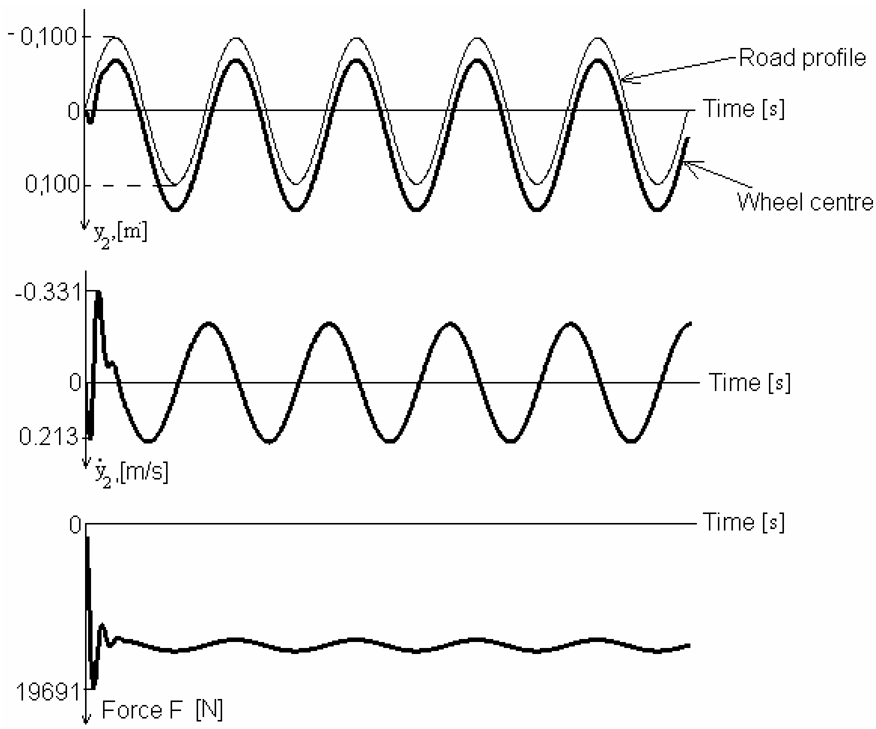


***Fig. 3. The results with A=0,1m, v=1m/s, l=3m***

Fig. 3 shows the dynamic at little speed on long ripple. The elastic forces are quasi constant, the wheel push down continuous on the road and the trajectory reproduces very well the ripple with an exception: its quasi constant deformation.

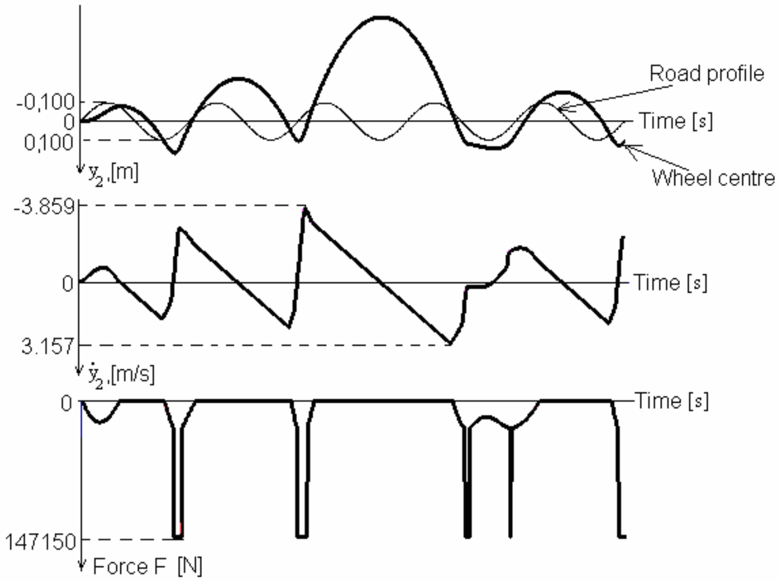


***Fig. 4. The results with A=0,1m, v=1m/s, l=0,5m***

In fig. 4 we observe the same movement but on the shorter ripple. The wheel bounces, the forces are greater and there are periods of time when the tyre goes out of the road.

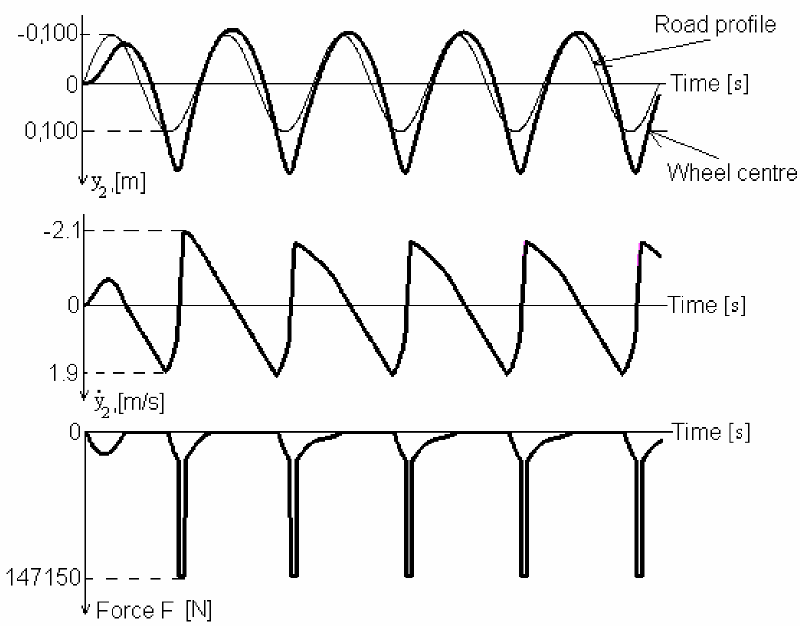


***Fig. 5. The results with A=0,1m, v=5,5 m/s, l=3m***

If the ripple is longer but the speed increases, the fig. 5 shows a very heavy dynamic behaviour and in the same time with the resonance phenomenon. The contact times between tyre and road are shorter and the wheel bounces higher.

The spectral analysis was made on five ripples of the road. The fig. 6---8 show that the dynamical behaviour of the wheel acts on the image of the spectrum and hereby on the excitation possibilities of different part of the machine.

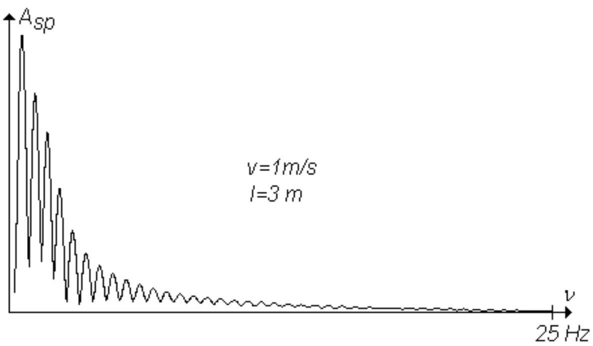


*Fig. 6. Spectrum of the forces from fig. 3 case*

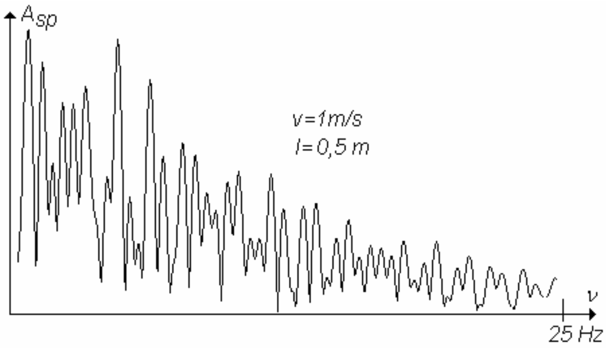


*Fig. 7. Spectrum of the forces from fig. 4 case*

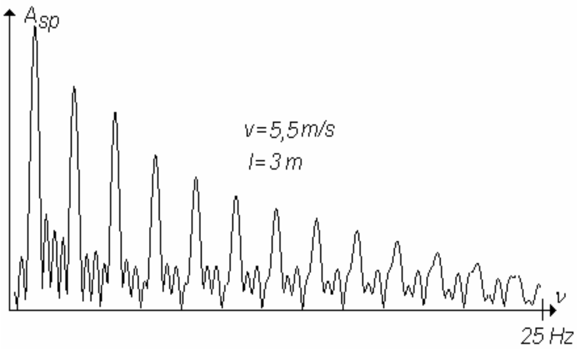


*Fig. 8. Spectrum of the forces from fig. 5 case*

## 5. CONCLUSIONS

The upper results show clearly that the contact between wheel and road and the dynamical behaviour are depending on the speed and length of the ripple together. If the speed is little but the ripple is short, the wheel can have a long time free movement in gravity field and high maximal values of the contact forces, analogous to determination of eq. [4]. The paper demonstrate that the own elasticity of the tyre is suffice to produce such like behaviour and the attenuation has a negligible influence. The spectral analysis fills out the study and shows that the forces can have many harmonic components, especially at irregularly movement of the wheel. These components can activate oscillations on different parts of the machine.

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