Effect of structural parameters on roll motions of the wheeled timber harvesting vehicle

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Abstract. The smooth ride of the wheeled timber harvesting vehicle is much dependent on its roll motions [1, 2, 3] which makes it interesting to investigate the effect posed by the main structural parameters on them. The values of the linear lateral accelerations inside the timber harvesting vehicle’s cabin at the driver’s head are taken as an estimate figure of the ride smoothness [4]. The research has been made in relation to the structural parameters of a timber harvesting vehicle type JohnDeere by a method of numerical quadrature of differential equations against full evaluation diagram and by a method of statistical dynamics for a simple mathematical model.

1. Introduction
A tire stiffness in radial and lateral directions, a moment of a section inertia relative to the horizontal joint axis, a height of a section center of mass relative to the same axis, a type of a timber harvesting vehicle undercarriage (with a universal joint or equalizing front axle), tire damping properties as well as efficiency of installation of additional damper between sections have been considered as the main structural parameters influencing the motions of a timber harvesting vehicle in a cross plane [5, 6, 7, 8, 9].

The roll motions are much influenced by a degree of coupling between linear cross and cross-angle motions. It follows from the general regularities specific for dual-frequency coupled motions that with the weakening coupling the natural frequencies tend to their partial values, with that dampening rises at a low natural frequency and reduces at a high frequency, and with the reinforcing coupling the values of the natural frequencies separate, dampening reduces at a low natural frequency and increases at a high frequency.

2. Analyzing relationship between roll motions and radial and tire roll stiffness
Relationship between tire radial stiffness (at fixed value of roll stiffness) and the values of lateral accelerations inside a timber harvesting vehicle cabin is shown in Fig. 1. It follows that with the reduced tire radial stiffness the values of natural frequencies shift toward low values with simultaneous significant reduction in the value of spectral density function at a high frequency.
Figure 1. Relationship between tire radial stiffness $C_z$ (black line), and roll stiffness $C_y$ (red line) and values of spectral density function of linear lateral accelerations inside a timber harvesting vehicle cabin during movement along a primary skid road:

- $C_z = 382 \text{ kN/m}$;
- $C_z = 500 \text{ kN/m}$;
- $C_z = 608 \text{ kN/m}$;
- $C_y = 196 \text{ kN/m}$;
- $C_y = 294 \text{ kN/m}$;
- $C_y = 490 \text{ kN/m}$.

The reason for this is that with the reduced tire radial stiffness the aperiodicity coefficient rises and coupling between motions strengthens that leads to increased dampening at a high frequency. The accompanying increase in acceleration dispersion at a low natural frequency is insignificant as its share in the total dispersion is small.

Likewise, with the reduced tire radial stiffness leads to reduced level of maximum lateral accelerations during crossing of isolated cosinusoidal irregularity. Thus, when front tire internal air pressure drops from 1.86 bar (stiffness of 608 kN/m) to 0.78 bar (stiffness of 382 kN/m), the acceleration values reduce by 29%.

The tire roll stiffness depends on the profile width and configuration of the protector cord threads. It can significantly vary when replacing tires with diagonal configuration of the cord threads for tires type P.

Fig. 1 (red lines) shows diagrams of the spectral density function of the lateral accelerations for variable values of tire roll stiffness whereof it follows that with the increased tire roll stiffness and conservative value of a radial stiffness the values of natural frequencies of the roll motions increase.
and the values of the spectral density functions slightly reduce at a high frequency, which is due to increased dampening at a high frequency because of increased degree of coupling between linear cross and cross-angle motions.

As a result, variation in the tire roll stiffness within fairly narrow limits has little effect on the values of RMS accelerations during the vehicle’s movement along a skid road with random microprofile and mainly effects the motion frequencies.

Thus, it follows from the analysis of relationship between roll motions and tire radial and roll stiffness that the value of lateral accelerations is mainly influenced by tire radial stiffness which reduction is an important factor for reducing both vertical and lateral accelerations.

3. Analyzing effect of structural parameters on motions of the wheeled timber harvesting vehicle

Investigating effect of the moment of inertia of the vehicle section relative to longitudinal axis going through the joint axis on the roll motions is of interest as those parameters are different for the vehicles with different types of undercarriage as well as for the loaded and empty vehicle. Calculations demonstrate that with the increased moment of inertia in the cross plane the values of the natural frequencies of the roll motions reduce, with that the high frequency mainly reduces. Thus, with the vehicle section moment of inertia increase from 2,600 to 4,600 kg·m² the value of the high natural frequency reduces from 38 to 23 rad/s, i.e. approx. by 21%. The increase in the moment of inertia is also accompanied by reduction in RMS and maximum values of the lateral accelerations.

Thus, the theoretical analysis demonstrates that the increase in the moment of inertia in the cross plane has a positive effect on the ride smoothness. It follows that the vehicles with balanced front axle will have smoother ride during roll motions at timber bunch transportation due to increased moment of inertia of the system. In case of a timber harvesting vehicle with a universal joint, due to weak coupling between roll motions the timber bunches mostly impact linear roll motions of the front section.

The researches of the influence of the height of section’s center of mass relative to the horizontal joint axis and height of the joint axis relative to the road surface on the roll motions demonstrate the increase of the above parameters leads to increase of the value of the high natural frequency and has a negative effect. At the same time, high frequency gets dampened that has a positive effect. For the sake of the tractor’s roll stability the above parameters shall be taken as little as possible.

The roll motions of the springless wheeled timber harvesting vehicle shall be dampened at radial and roll deformations of the tires which dampening properties are insufficient. To compensate this deficiency of the springless vehicles a research has been carried out to possibly reduce lateral accelerations by introducing additional dampening of the roll motions at relative at relative turns of the vehicle’s sections around the horizontal joint axis. Additional dampening of the roll motions can be achieved by installing, example, a special or series shock-absorber which operates at cross-angle motions of the vehicle’s sections relative to each other. The positive effect of dampening introduction is based on the reason that additional damper shall couple the sections and seem to engage the second section thus increasing the total moment of inertia of the system and reducing the level of maximum accelerations.

The efficiency of introduction of additional dampening for the vehicle with a universal joint during ride over isolated irregularity is shown in Fig. 2 which demonstrates that additional dampening reduces the level of maximum lateral accelerations. At optimum dampening the level of the lateral accelerations can be reduced by 35-40%.
Figure 2. Effect of additional dampening between the sections of the timber harvesting vehicle $\mu_a$ on the values of linear-lateral acceleration inside the cabin at crossing an isolated cosinusoidal irregularity (speed of 2 m/s):

- $\mu_a = 0$;
- $\mu_a = 3 \cdot 10^5$;
- $\mu_a = 6 \cdot 10^5$.

Similar estimates made for a vehicle with balanced axles have shown that introduction of additional dampening has little effect on the value of lateral accelerations. This can be explained by that a moment of inertia of the balanced front axle is not too large as compared to a moment of inertial of the vehicle’s body and its coupling with use of additional damper gives no meaningful effect.

Thus, the analysis of effect of the structural parameters on the timber harvesting vehicle’s roll motions makes it possible to evaluate ride smoothness of the vehicles different in design and outline structural changes to improve it.

4. Conclusion

The smooth ride of the timber harvesting vehicle during roll motions is mostly influenced by tire radial stiffness which when decreased significantly reduces lateral accelerations thus making the motions’ frequency content more comfortable for the operator. Tire roll stiffness has little effect on the smooth ride.

The lateral accelerations of the timber harvesting vehicles with a universal joint can be reduced by introducing additional dampening of the relative cross-angle motions between the sections.
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