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THE TIRE MODEL IN THE SIMULATION OF THE TRACTOR MOTIONS

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ABSTRACT

The influence of tire characteristics is investigated by the simulation of an agricultural tractor.

First the simulation of the tire is discussed. Different models are proposed and evaluated on their validity and their applicability. Also the practical measurement of some parameters is discussed.

In a second paragraph the tractor model used is presented.

In the third part some results of the simulation are communicated. Beside the normal motions along and around the lateral axis, special attention is attracted on the hop. But one of the conclusions is that the simulation of hop is not possible without non-linear elements.

1. INTRODUCTION

With the increasing mechanisation and automation, the power of the off-road vehicles is also increasing. There is also a trend to higher speeds. For agricultural tractors e.g. that are used for 30% for transport, speeds of 40 - 50 km/h are no more unusual. This means that one becomes vibration technical problems concerning the steerability of the vehicle and the ergonomy of the driver. These trends lead to changes in the concept of the vehicle. Of course this needs a lot of prototype research which is very time consuming and expensive. Simulation therefore is an acceptable solution on condition that the model is well chosen.

In this contribution we will only study the pitch and vertical vibration of the body. It is clear that the choice of the tire model is of highest importance in

These results are obtained on a test rig in which the tire is included as the second spring in a mass-spring system and is rolling at different speeds over a drum. The springed mass is excited by a hydraulic actuator with a harmonic motion with varying frequency. The resonance frequency of the system is tuned to approximately the resonance frequency of the vehicle on this wheel. The values for k and c are calculated from the force needed to sustain the motion with constant amplitude at resonance frequency. Of course, the drum radius influences the results in comparison with a flat road. A flat-belt tire test rig is more suitable for these measurements. There are also problems due to the compressibility of the soil. Rough measurements in the field confirm the results on the described testrig and show the influence of soil. On a humid soil (loamy sand 10% RH), a decrease of about 25% can be expected for the stiffness rate. The damping rate however can be doubled or even be three times the rate measured on an asphalt paved road.

Tire Model II

From the moment that the tire is exerting traction on the soil we also have to take the longitudinal and even the lateral stiffness and damping into consideration.

A sophisticated model is described by EL-Razaz and Crolla (3) who use a three-dimensional multi-spoke model, such as a chimney sweeper. Analogue less complicated models are also available.

These models are important for a better understanding of the tire behaviour in off-road manoeuvring and steering conditions, but are not suited for our purposes.

Tire Model III

A frequently used model consists of three Hertz models, one for each direction. For our purposes it is sufficient to use only the vertical and the longitudinal elements. When we also will also take into account the influence of the soil on the damping ratio, we can use the lateral model as compensation for the damping and stiffness in function of the "sinkage" in the soil. For our calculations we only use the "two Hertz model".

Tire Model IV

Because our study aims at examining the vehicle motion during a four wheel drive ride on the terrain, we also have to include the slip of the tire on the order to obtain significant results. Therefore we will discuss this problem very exhaustive.

More specific the hop of the vehicle will be discussed because it is an indicator for the validity of the model.

2. TIRE MODELS

The vibrational and tractional characteristics of a tire are mainly determined by its visco-elastic properties and the interaction between tire and road. In literature, different models for simulation characteristics have been published. They vary from the very simple spring-damper systems to more sofisticated models as e.g. the multi-spoke model. One of the problems is of course the choise of the complexity of the model. At the one hand it must be complex enough in order to obtain the intended results in an accurate way, at the other hand it should not be too complicated in order to not surcharge the total simulation but to reduce the calculation time.

Tire Model I

The most simple model for the vibrational characteristics of the tire is the Hertz model. Fig.1. It contains a spring that is parallel with a damper. In this case we can speak of a static model in this sense, that it can be used to study the motions of a vehicle when it is in standstill or at least when no traction is exerted. At first sight, it is easy to determine the values of the spring stiffness k and the damping coefficient c. This can be done by a simple test in which a harmonic displacement with different frequencies and amplitudes is given on the hub of a tire which is standing on a flat floor. The damping and the tire stiffness can be calculated from the time and amplitude relation between the force and the displacement.

Typical results of such a measurement are given in fig.2. (v = 0) in function of the displacement. Remark that the results are largely dependent on the amplitude. When the tire is rolling, other results are obtained, as you can see. For a speed higher than 5km/h the stiffness is practically independent of the hub. From the figure it can be concluded that for a test with v = 0 we need high amplitudes in order to obtain any validity for the stiffness.

The same can be concluded for the damping but the influence of the speed is perceptable up to about 25 km/h.

soil, in order to take into account the different speeds of the front and the rear wheels. This can be obtained with the use of a Burger model. The difference from the previous model is the addition of a viscous damper in series with the Hertz model. Due to the fact that the vehicle is running on the ground, the speed v_x is to be introduced as the real vehicle speed, and the added damper has to simulate the slip.

One of the problems is the estimation of the different parameters. They can be calculated from the transient responses of non-rolling tires for all the values except c'. For the need of the lateral model we can refer to the previous model. The value of c' is not only a tire property but it also depends on the friction and shearing properties of the surface. A lot of work can be done in this direction.

Tire Model V

In '89 Crolla (1) discribed a new model where he uses a Maxwell model for both horizontal directions. We can be sure that this is an excellent model for traction and steering simulation.

3. THE TRACTOR MODEL

The tractor body is assumed rigid with two translational and one rotational degree of freedom, Fig. 3. The front axle is not suspended and can not pivot in roll. There are also no separate freedoms for the rear axle, so we become a twodimensional (bycicle) model.

For the tires, different models can be chosen. When the vehicle is running in four wheel drive without differential we also need a (torsional) spring between the two axles. This gives a rotational moment on the body. This moment depends on the pitch angle of the body and the relative position between the front and the rear wheels.

4. THE SIMULATION

The differential equations for the model are all linear in this stage of the investigation, so they can be solved by simple numerical methods. Because it is our intention to work further with non linear functions, we preferred to use an Applied Dynamics System 10 computer (AD10). It is a peripheral multiprocessor system linked with a hostcomputer (μVAX). The architecture gives the possibility to solve in real time models existing of some hundreds differential equations. In order to obtain a less sophisticated use of the AD10 and to be able to have an optimal use, a higher level simulation language "MSP10" is developped.

The numerical integration methods which can be established are:
- predictor (Adams-Bashford);
- predictor-corrector (Adams-Moulton);
- Runge Kutta.

The configuration also contains different ADC and DAC and gives the possibility to connect the simulated model with the real model so that it is possible to make a parameter estimation.

5. THE INPUT

Different inputs for the simulation can be used. A first one we have is the free motion or free oscillation after a step input of one of the variables. A second one can be a harmonic excitation for both axles with the same or different amplitude. Both excitations have the same frequency of course, but they have a time lag which depends on the real vehicle speed.

Another input may be a real road input or a pink or even weighted noise.

6. SOME RESULTS

As long as the vehicle is having a differential and is not exerting traction, tire model I can be used in order to obtain some results about the movement. E.g. the amplitude of vertical displacement of the centre of gravity and the pitch motion are shown in fig.4. The calculation is done for a vehicle without coupling mass cn a harmonic road. Of course the effective situation depends on the relation between the resonance frequencies, the wheelbase, the wavelength and the vehicle speed.

For the same excitation and traction mode, the use of tire model III gives no big difference.

Other results are obtained from rides on a real (random) road. The surface under the PSD is a measure for the RMS value of a calculated variable. So in the table we can notice the influence of the variation of the horizontal tire stiffness on the RMS values of the forces between tire and road. Remark that the centre of gravity lies on about 2/3 of the wheelbase.

When the vehicle is running with four wheel drive on a flat road, with tire model III we become an irrealistic situation due to the fact, that there is no slip between road and tire which results in a "wind up" of the tractor. When tire model IV is used we become a stable motion.

The envelope of e.g. the displacement of the centre of gravity in function of time becomes zero after a short transient period. This means that it is impossible to simulate the Hop motion with this tire model.

Several runs with different parameters make clear, that it will be impossible to describe the hop with a linear model. The origin of this motion has to be explained as a kind of slip stick between road and tire. Only a non linear relation between the friction coefficient and the slip will be able to start the hop motion without external excitation.

CONCLUSION

From the results of this study it can be concluded that the choice of the tire model depends on the goal of simulation and that it is impossible to simulate hop without non-linearities.

Bibliography

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3 El-Razaz, A.S.A. and Crolla, D.A.. A multi-spoke model for off-road tyres. ISTVS- 4th European Conference. Wageningen 21-23 march 89.

Table Influence of horizontal tire stiffnesses on the tire forces

[kN]	kvx khx	kvx/10 khx	kvx khx/10
Fvx	9160	50800	583
Fhx	1630	1	343
Fvz	4160	15	458
Fhz	2910	458	4

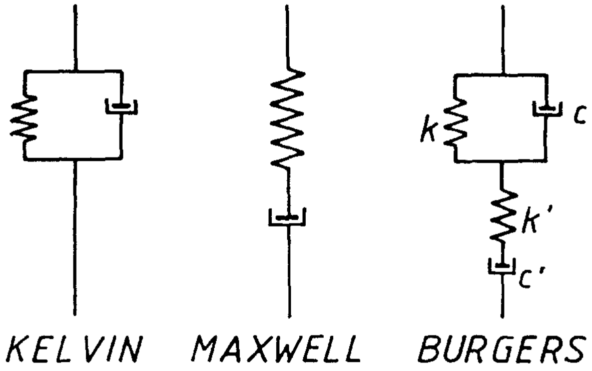

Fig.1 Different rheological models.

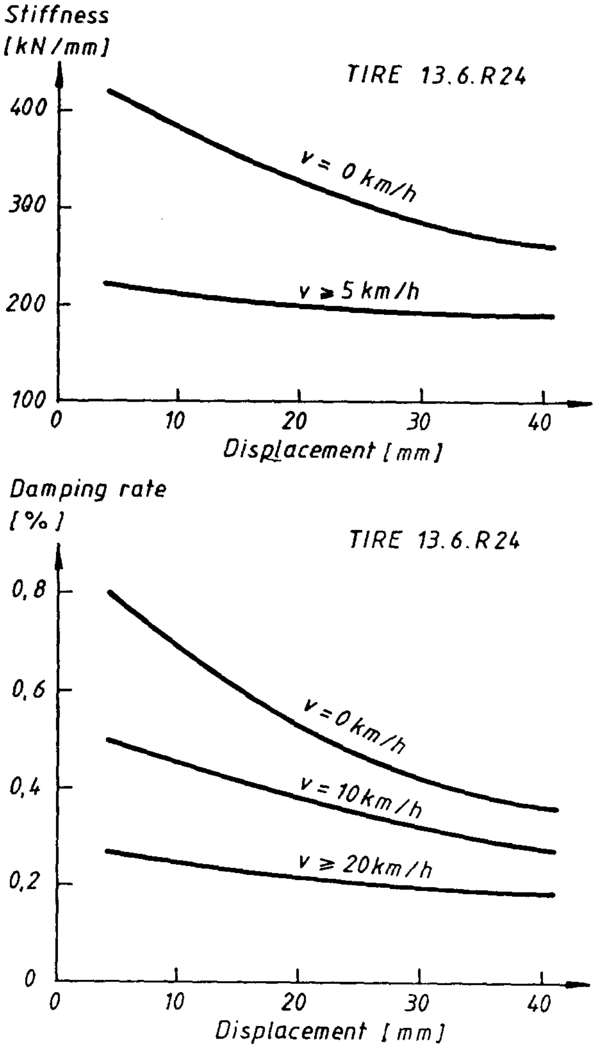

Fig. 2 Influence of speed and displacement on tire stiffness and damping.

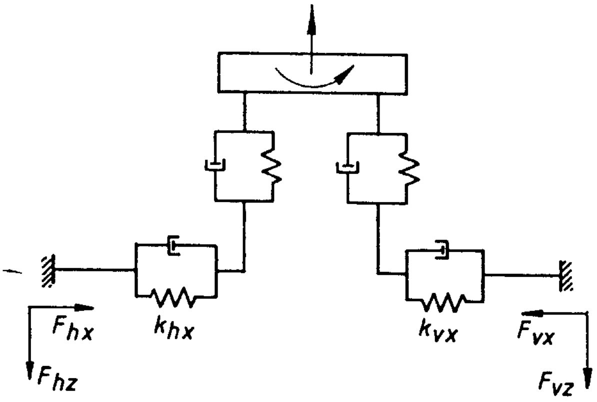

Fig. 3 Tractor model.

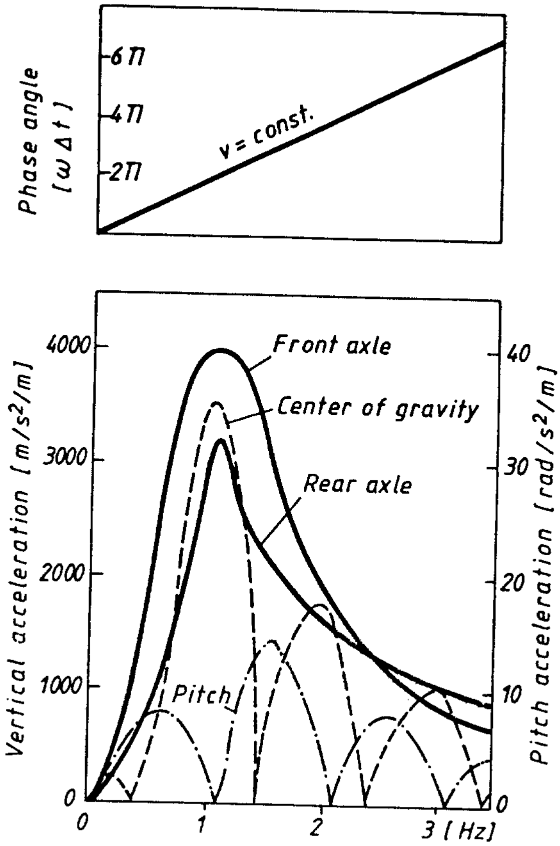

Fig. 4 Vertical and pitch acceleration for a two axle vehicle.