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Simulation of the suspension kinematics of a front-end-mounted mower

The suspension kinematics of front-end-mounted mowers make a crucial contribution to the ability of the mower to cope with obstacles on uneven ground. The structures of the multi-body models required for simulating the movement behaviour of the tractor and mower are shown here. They provide the basis for simulation studies used to examine the influence of the geometric parameters as well as the rotating masses on the mobility of the cutter.

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Keywords

Multi-body simulation, front-end-mounted mower, modelling

Literature

Books are signified with •

[1] • *Rauen de Souza, W.*: Ein Beitrag zur kinematischen und dynamischen Analyse von Frontmähwerksaufhängungen. Fortschritt-Berichte VDI Reihe 14, Nr. 72, VDI-Verlag, Düsseldorf, 1995

To design and improve front-mounted mowers used in agriculture, it is necessary to know about their movement behaviour in connection with the tractor and the ground surface. The aim is to ensure that the cutter follows ground contours optimally under the widest possible range of conditions.

Modelling

The models for the tractor and mower are in principle spatial transmissions or mechanisms.

During the studies the movement behaviour of front-mounted disc mowers was observed, because they are more widely used throughout the world than drum mowers. For the Institute's own system tractor, the component parts were only modelled in rough detail. What is crucial for the model are the points of contact between the tyres and the soil and the position of the connecting points between the tractor and the mower.

In the case of front-mounted mowers without their own guide kinematics for the cutter, the lower and upper links form the movable parts for a spatial four-joint transmission unit. These components as well as the mower components were measured precisely. Two series-produced front-mounted mowers from Krone were available for this purpose and for field tests. One mower has its own guide kinematics, while the other is directly mounted in the balls of the front three-point hitch.

Idealised, friction-free joint types were used to define links or joints. *Figure 1* shows the general structure of a system consisting of tractor and front-end-mounted mower – in this case with a mower suspended rigidly on the front hydraulics. The tractor consists essentially of the front and rear parts and the coupling points for the front power lift. Two virtual transmission members direct the tractor forward motion through a universal coupling to the rear part or alternatively the front part of the tractor. This makes it possible for the rear or front part of the tractor to turn around the longitudinal vehicle axis and around the centre of the wheels while driving over obstacles. The system tractor is equipped with a central swivel joint between the front and rear parts so that it has a front-axle-driven lower link pair. Another swivel joint connects the lower link pair to the front part of the tractor. The connection between the mower and the three-point hitch is designed with three ball joints. To create a statically determined drive here, one of the two lower ball joints is capable of not just the three rotary movements, but also a translatory movement in the z direction.

Other models were developed for mowers with their own, integrated spatial four-joint kinematics. Arrangements were built with three as well as four connecting rods between the mounting bracket and the cutter. In both cases the tension rods were partly connected to the cutter with swivel joints, as found in the series-produced machine. The axial bearing play in the joints that occurs in reality here is provided for by a corresponding mobility. Stop forces ensure that this mobility is restricted within the limits of the bearing play. This ensures that in the model too, the cutter used can incline about the glo-

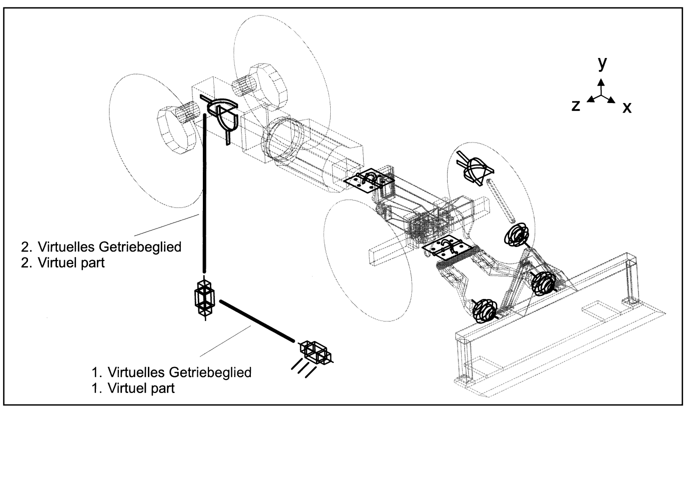

Fig. 1: Design of system with gear parts and joints

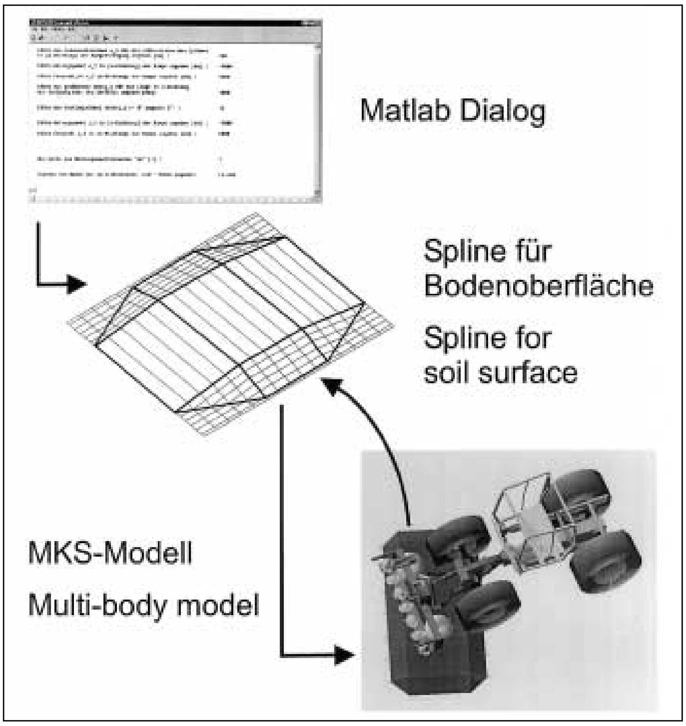

Fig. 2: Implementation of the soil surface geometry

bal vertical axis (y axis) and about the system longitudinal axis (x axis) running in the direction of travel, which corresponds to what happens in practice.

Interfaces

Three-dimensional mathematical nets were used to define a ground surface for the zero level and for regularly shaped obstacles. These so-called splines define the peaks of the points in the ground profile and are formed from a large number of reference points. An interpolation is made between the reference points to determine the heights of the ground surface there. The spline data are entered with computer support through automatically generated command structures in ASCII text files. An interactive computer dialogue created using the Matlab software is used to generate these (*fig. 2*).

Using this method, simple trapezoidal or symmetrical trapezoidal obstacles can be defined in the ground profile. The user determines the obstacle geometry parameters by entering local co-ordinates and the desired ramp pitch angle.

No links were used for the dynamic behaviour between tractor and ground and between mower and ground. The mower must have the option of partially lifting off the ground. A network of several hundred contact forces was installed on the underside of the mower to guide the mower body over the ground surface. Each individual contact force is characterised by a certain spring-and-damper characteristic and is activated only when a pre-defined distance to the spline of the ground surface is undercut. The large number of contact forces in the area of the wear runners makes it possible to simulate a realistic motion behaviour. Here again, the forces are entered with computer support. The automatic procedures necessary to generate the contact forces in the multi-body model are created by means of corresponding Matlab programming.

Variations of simulation patterns

Different approach positions and angles in relation to the obstacles can be evaluated by placing and positioning the tractor and mower appropriately. The spring-and-damper characteristic between the ground and the machines is selected in such a way as to prevent plunging below the soil surface, even when contact is made with obstacles during the simulation. The deformability, the shearing-off behaviour and the extent of yield on soft bases are not examined in the simulation. Possible modelling approaches for this would involve reproducing the soil on the basis of finite elements. Corresponding models would require many times the amount of hardware resources used here and it would require a great deal of work to enter the parameters. This is why the ground was assumed to be rigid.

Depending on the respective position of the lower link and upper link to each other and the position of the tension rods between the mounting bracket and the cutter, various mower types result. Observing the suspension kinematics from the side it is possible to divide the types of mowers into pushed, pulled or lifted mowers depending on the instant centre position of the cutter[1]. For spatial transmissions, the instant screw axis represents the equivalent of the instant centre of a level transmission. Its position in turn depends on the arrangement of the transmission parts, i.e. the connecting rods or the upper and lower links. That is why during the simulation the joint positions of the mower parts are systematically varied.

A further variation characteristic of mowers relates to the rotation masses. Here, the simulation models can be used for qualitative statements about their influence on the mobility of the cutter. For this purpose the mowing beam is specifically twisted around an axis with its rotating gear wheels, mower disks and swath drums. The influence of the coriolis forces on the torque necessary for rotation is made clear by the simulation. The density of the rotating components is varied for equal peripheral conditions.

Initial findings and future prospects

Many common mower designs rely on the cutter being guided over the ground by means of drawn kinematics. This results in a good evasion behaviour on central contact with obstacles, because the cutter can evade upwards. If it hits an obstacle from the side, the mower beam moves to a position, seen from above, inclined a few degrees in relation to the direction of travel. The reduction in cutting width this causes is insignificant. What is more noticeable are the different distances between the blades and the ground along the cutting width. This behaviour occurs when the mower beam only touches the ground at two points along its entire length. So far an influence of the rotating masses on the mobility of the mower beam could only be detected to an insignificant extent.

The multi-body simulation tools are powerful aids for evaluating the movement behaviour of front-end-mounted mowers. The mutual influences of the tractor, mower and ground contours can be impressively represented virtually on the computer in the form of curves and motion animations. The models described here are being used with further functions for automated simulation studies in ongoing experiments.