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Reducing friction by ultrasonic vibration exemplified by tillage

Friction forces account for a significant share of the total power required in several agricultural processes, such as tillage. Therefore a reasonable possibility to lower the power requirement is to reduce these friction forces. The application of ultrasonic technology offers a very promising opportunity to achieve this friction reduction. In cooperation with the Institute of Dynamics and Vibration Research of Leibniz Universitaet Hannover the Institute of Agricultural Machinery and Fluid Power of the Technische Universitaet Braunschweig carries out a project to research the possibilities of reducing friction in agricultural machinery by applying ultrasonic vibration to a cultivator tine.

Keywords
Ultrasonic, tillage, friction reduction

Abstract
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In the field of tillage the required drawbar work in combination with increasing working widths is responsible for the biggest part of the total power requirement [1]. Therefore the trend of increasing working widths causes more and more problems at the tractor's wheels to convert power into drawbar work in combination with low tyre surface slip. Depending on the intensity of tillage this production step generates a great fuel consumption that accounts for a great part of the total production costs.

The biggest part of the required drawbar work from tillage-implements is caused by friction between soil and implement. Therefore the reduction of friction forces is a reasonable possibility to lower the power requirements in tillage.

Different approaches of reducing friction forces in tillage can be found in scientific publications. In the 1950s amongst others Eggenmueller has run experiments with mechanical vibrations at a frequency of 50 Hz. He was able to demonstrate a reduction of drawbar forces up to 80 %. One disadvantage of this system was the limited maximum working speed of 2 m/s. According to Eggenmueller an enhancement of the oscillation frequency could permit a higher working speed [2]. For this reason the idea of the current project is to activate the tool by ultrasonic oscillation hereby reducing the macroscopic coefficient of friction.

Theoretical foundation

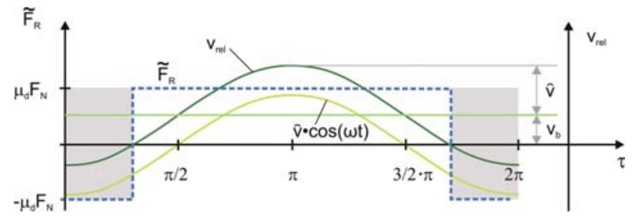
The theoretical model requires the simplification that soil particles move with a constant velocity v_b along a cultivator tine which is pulled through the soil. The soil particles are pressed against the cultivator tine's surface by a force F_N, which is oriented orthogonal to the direction of motion. The friction coefficient μ between soil particles and cultivator tine results in a friction force $|F_R| = \mu \bullet F_N$. This friction force works against the direction of the velocity v_b.

The cultivator tine is activated by the velocity $\tilde{v}(t) = \hat{v}\cos(\omega t)$ to reduce the friction. Thereby the oscillation amplitude varies along the cultivator tine. The direction of oscillation is parallel to the moving direction of the soil particles.

From superposing the ultrasonic vibration with the soil particle motion follows a periodically changing relative velocity $v_{rel}(t) = v_b + \hat{v}\cos(\omega t)$. v_{rel} changes its algebraic sign periodically if the velocity amplitude $\hat{v}$ is bigger than v_b . Therefore the relative velocity between cultivator tine and soil particles operates periodically propulsive. This decreases the temporal mean value of the friction force with ultrasonic vibration compared to the friction force without ultrasonic vibration.

Figure 1 clarifies the correlation between the periodically changing velocity v_{rel}, which results from the soil particle's velocity v_b and the superposed oscillation $\hat{v}\cos(\omega t)$, and the friction force $\tilde{F}_R$ (blue graph). Time is given in normalized form τ = ωt. Areas of propulsive operating friction force are highlighted in grey.

Fig. 1



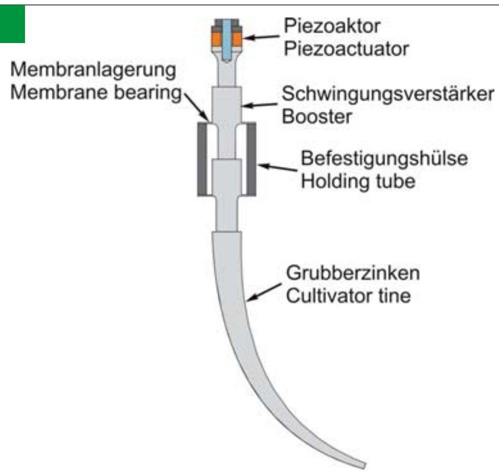
Current friction force (left scale) and relative velocity (right scale) over one oscillation period [3]

Experimental setup

The required force to oscillate the cultivator tine is provided by an actuator. In this case electrical energy is converted to mechanical oscillation energy by a piezoactuator. By stacking several ring-shaped piezoceramics it is possible to realize the required force and stroke. The piezoactuator is mounted on top of the cultivator tine as seen in **figure 2**. Thereby a low-loss induction of the oscillation into the cultivator tine is possible. Suitable dimensioning of the booster's profile allows enlarging the velocity amplitude of the ultrasonic oscillation but also reduces the available forces. The ultrasonic actuator and booster are constructed in such a way, that the cultivator tine's natural oscillation has the required frequency of 20 kHz. Because of several challenges analysing a loaded oscillator is only the free running oscillator analysed during the dimensioning process.

To detain ultrasonic vibration from the framework the cultivator tine is fixed to the holding tube by two membranes. These two membranes are each positioned in a node, in which the oscillation amplitude is nil. The booster unit is connected to the cultivator tine which is moved through the soil. The electric energy for the piezoactuator is provided by a sine-wave voltage generator.

Fig. 2

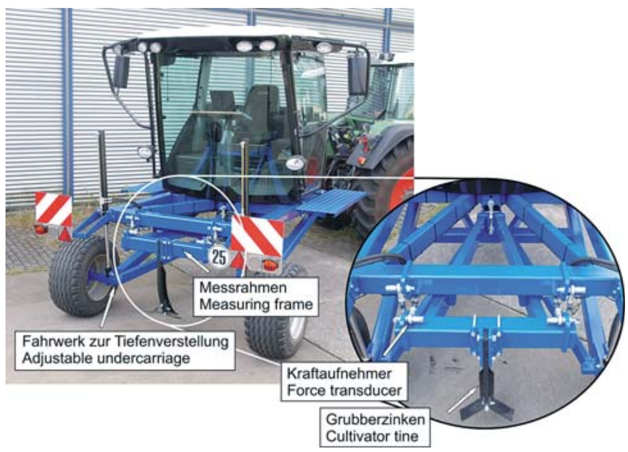


Sketch of the cultivator tine with ultrasonic vibration

For an experimental validation of the theoretical model of friction reduction a special test rig has been designed (**figure 3**). Due to a six-component-measuring frame, which is integrated in the mobile test rig, it is possible to measure forces acting on the cultivator tine in x-, y- and z-direction with and without ultrasonic oscillation.

For experiments the test rig is coupled to a tractor, enabling an infinite adjustment of the working speed and the electric power supply of the measuring technique. The mobile test rig itself is equipped with a hydraulically adjustable undercarriage to lift it up in case of transportation or to drop it down to the required working depth. Different clip-on spacers for the plunger allow a precise adjustment of the working depth. Six traction force transducers with a nominal load of +/- 20 kN and a measuring accuracy of +/- 40 N are used to measure the forces at the measuring frame. A tracking system mounted in the cabin records the measured data and displays the results on a laptop screen. The cabin is positioned on the test so that the operator can easily supervise the experiment.

Fig. 3

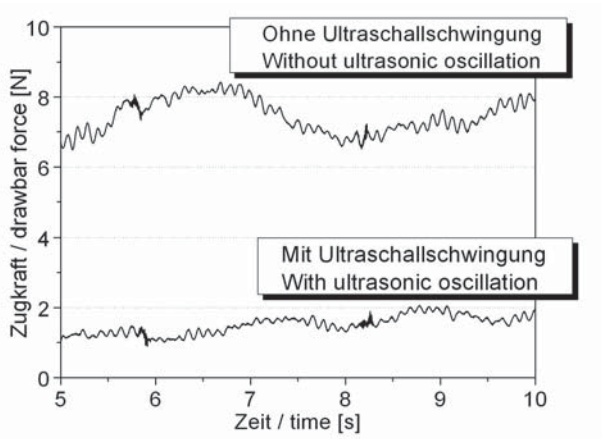


Mobile test rig coupled to a tractor

First tests results

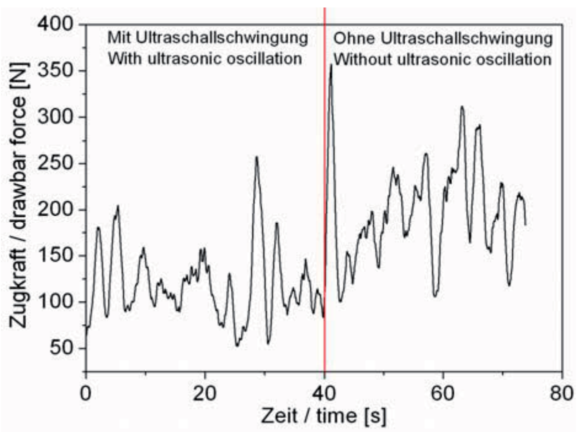
At the beginning of the research project the potential to reduce friction in tillage operations was evaluated by different pilot tests. These tests were realized with an ultrasonic knife, which was moved on a linear axis through a soil-filled box. The knife was inserted 50 mm into the soil with a working speed of up to 50 mm/s. Results shown in **figure 4** demonstrate that the drawbar forces with ultrasonic oscillation are significantly lower than the forces without ultrasonic oscillation. After building up the ultrasonic cultivator tine and the mobile test rig it was possible to run first experiments under practical conditions. In **figure 5** the results of a practical experiment with a working speed of 100 mm/s and a working depth of 50 mm are presented. They indicate that the drawbar forces with ultrasonic oscillation are lower than the forces without ultrasonic oscillation. These results have to be confirmed in further test series. Furthermore it must be pointed out that during the described experiment the energy consumption of the piezoactuator was significant higher than the reduction of drawbar work.

Fig. 4



Results of drawbar force with and without ultrasonic vibration from pilot tests

Fig. 5



Results of drawbar force with and without ultrasonic vibration from first test with the ultrasonic cultivator tine

Conclusions

The results from first practical tests point out that one of the next important steps is to improve the ultrasonic cultivator tine regarding its energy requirement. Furthermore various test series under different working conditions have to be done to evaluate the potential of the ultrasonic technology in agricultural processes.

Literature

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