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Reducing friction in tillage using ultrasonic vibration

Within a research project at the Institute of Agricultural Machinery and Fluid Power at the Technische Universität Braunschweig in cooperation with the Institute of Dynamics and Vibration Research at the Leibniz Universität in Hannover the possibilities are researched to reduce friction in tillage operations by applying ultrasonic vibration. In this paper the design of a cultivator tine with ultrasonic vibration is described in consideration of its vibrational behaviour. The results of different experiments demonstrate the possibility to reduce required tractive forces significantly at a cultivator tine by applying ultrasonic oscillation. But furthermore it must be pointed out that there is still further research needed to reduce the energy consumption of the piezoactuator and to increase the possible working speed.

Keywords
Ultrasonic, tillage, friction reduction

Abstract
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4 references

The biggest part of the required drawbar work from tillage-implements is caused by friction between soil and implement. Therefore reducing friction forces is a reasonable possibility to lower power requirements in tillage. For this reason in the first step to research the possibility of reducing friction by applying ultrasonic vibration a cultivator tine is used.

According to the theoretical foundation [1] a high-frequent oscillation of the cultivator tine effects a reduction of the average coefficient of friction between cultivator tine and soil. The velocity of soil particles is superposed by the oscillation of the cultivator tine which changes periodically the direction of the friction force. Thus the time-averaged value of the friction force between cultivator tine and soil is reduced.

Design and operation of the ultrasonic cultivator tine

During the research project a special cultivator tine was developed in order to achieve an oscillable tine (figure 1). The most important device to generate the oscillation is the piezoactuator, which is powered by a sine-wave voltage generator in combination with an amplifier [2].

Based on conventional design methods in ultrasonic technology and common cultivator tine shapes the ultrasonic cultivator tine was designed as a longitudinal oscillator. To achieve a maximized velocity amplitude at the tine's tip, two boosters were positioned between the piezoactuator and the tine. The boosters were also used to bear the ultrasonic cultivator tine.

During several dynamic analyses at the Institute of Dynamics and Vibration Research in Hannover the ultrasonic cultivator tine was adjusted to the required resonance frequency of 20 kHz. In accordance with the principle of half-wave synthesis the single parts were designed separately before analysing them as a complete system. During these analyses the strong influence of internal damping on the cultivator tine's vibration characteristics became apparent. For this reason materials with a high oscillation performance such as titanium and high-strength aluminium were used to build up the ultrasonic cultivator tine. After evaluating the results of first experiments the ultrasonic cultivator tine's oscillation characteristics were improved by adjustments at the tine's and boosters' geometries. The oscillation mode of the tine is marked red in **figure 1**.

Besides the ultrasonic cultivator tine's design another key factor to operate the tine at high efficiency is the electrical control of the piezoactuator. As the soil contact at the ultrasonic cultivator tine during the experiments effects a significant shift of its resonance frequency, an adjustment of the excitation frequency is essential. Different concepts for readjustment were tested during the project. The phase-locked loop turned out to be the most robust concept. Therefore it was used for all experiments presented below.

In the phase-looked loop the aim is to achieve a phase balance between electricity and voltage. For this purpose the frequency of the excitation signal is adjusted. The length of time to detect the phase should be chosen sufficiently long, in order to achieve the greatest possible robustness against load variations at the tine.

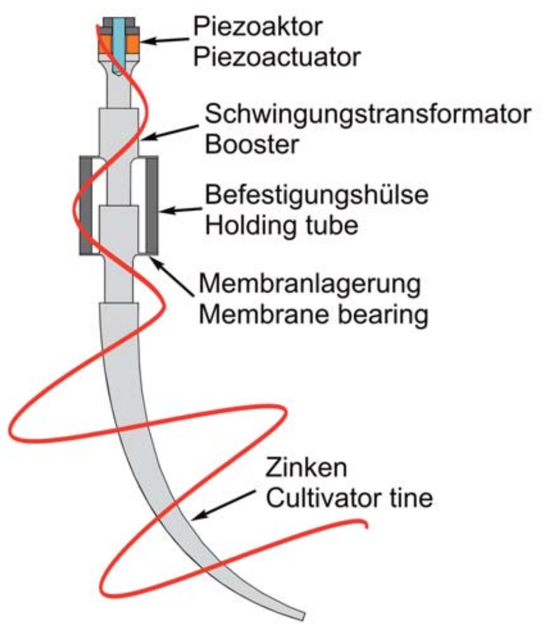
Experimental setup

A mobile test rig was built up at the Institute of Agricultural Machinery and Fluid Power to measure the forces acting on the ultrasonic cultivator tine. The test rig allows experiments on a field as well as in a soil bin (**figure 2**). Due to an integrated measuring frame it is possible to measure the forces separately in the three spatial directions. The mounted cabin offers enough space to store the necessary measuring equipment and to supervise the experiments [3].

The experiments were run on a loamy field as well as in the soil bin. It was possible to fill the soil bin either with masonry sand, with screened topsoil or with compost.

Due to the homogeneous soil conditions and the good possibility of changing them most of the experiments were run in the soil bin with masonry sand at speeds of 0.01 m/s, 0.14 m/s and 0.28 m/s. The working depth in the experiments added up to either 55 mm or to 110 mm.

Fig. 1



Sketch of the ultrasonic cultivator tine with its oscillation mode

Fig. 2

Mobil test rig with ultrasonic cultivator tine and soil bin

Fig. 3

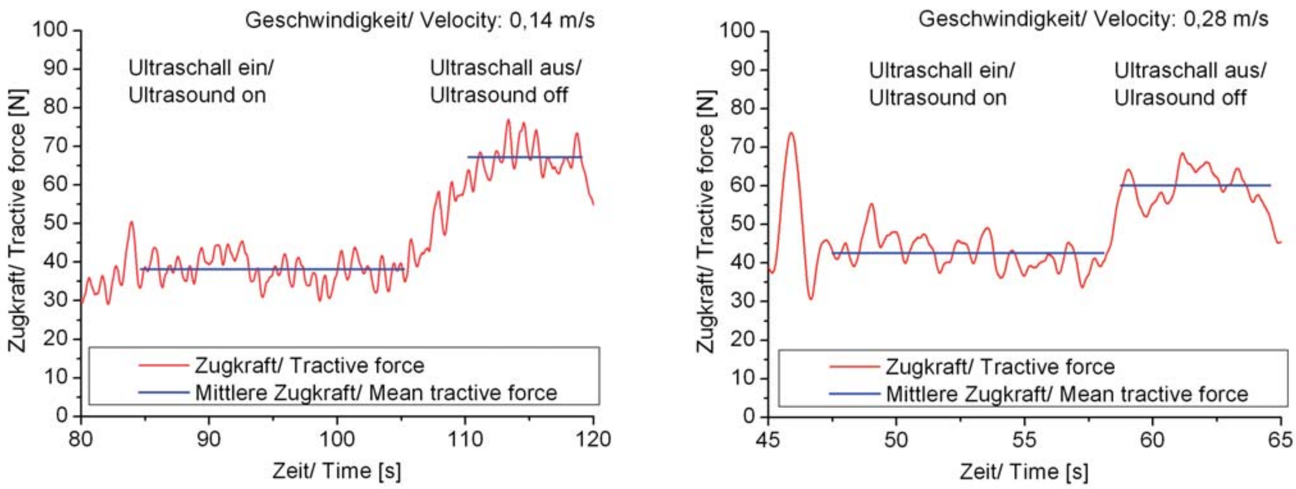


Chart of measurement results of tractive force in sandy soil at different velocities

Test results

As a selection from the test program **figure 3** shows recorded measurements in which the speed was varied. In both experiments the working depth was 110 mm and the soil water content 6 %. On the basis of the force peaks the transient response of the excitation frequency's control could be seen at the beginning of both charts. Under steady state conditions both measurements show a significant reduction of draught forces by applying ultrasonic vibration.

In the experiments the effective electric power being supplied to the piezoactuator was between 150 and 200 W. According to this the electric power consumption is several times higher than the reduction of tractive power. This is mainly caused by the unfavourable design of the ultrasonic cultivator tine related to its load.

In a next step the previously shown results are analysed together with further measurements. This analysis, which is displayed in **figure 4**, indicates a decrease of the percentage draught force reduction.

The plotted measuring points show in double repetition the averaged draught forces with and without ultrasonic vibration. Out of this the percentage draught force reduction was calculated. The plotted trend lines are solely for illustrative purpose.

Due to a lack of supporting points it is impossible to give a clear statement about the exact course of the graphs. But following the formula of forces at a plough from Gorjatschkin [4] an exponential increase of the draught force can be expected at higher speeds. By means of the in [1] described theory of reducing friction by applying high frequent vibration the decrease in percentage reduction of draught force with increasing speeds can be explained. This results from the deteriorating relationship between the cultivator tine's vibration velocity amplitude and the soil particles' velocity along the surface of the cultivator tine.

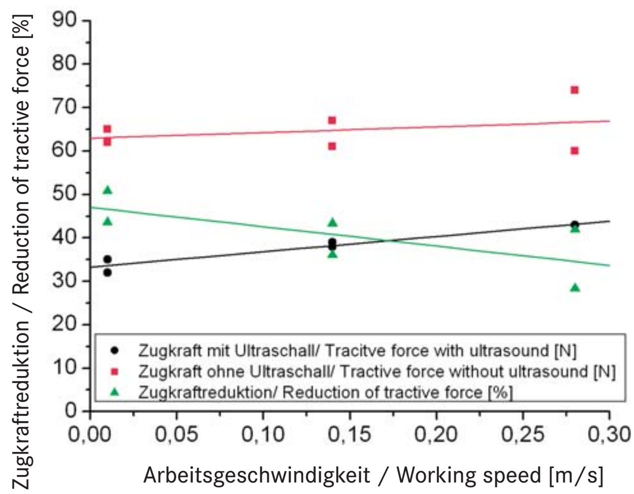
With a view on the quality of work the analysis of video records demonstrates that with ultrasonic vibration soil particles slide more easily from the tine's surface than without. This fact of enhanced sliding of soil from the tine's surface was observed in all experiments.

Conclusions

The present test results demonstrate that a significant draught force reduction at a cultivator tine is possible by applying ultrasonic vibration. Currently the energy consumption of the piezoactuator and the low working speed is challenging.

Out of these two challenges the reduction of the piezoactuator's energy consumption and the enhancement of the possible working speed are of particular importance for

Fig. 4



Percentage reduction of tractive force depending on the working speed further work. For this purpose a more detailed analysis of the load and damping of the soil acting on the cultivator tine is a promising approach. This analysis offers the opportunity for an improved design and control of the ultrasonic cultivator tine.

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