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# INVESTIGATIONS OF OSCILLATING SOIL TILLAGE TOOLS

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A b s t r a c t. A theoretical and experimental basis for developing oscillating soil loosening tools is prepared. Their motion equation is solved on the basis of experimental investigations of tools excited to active oscillation by a crank drive. This method is applied to assess the suitability of oscillating tools affected, e.g., by side tools. The investigations show that the soil interacting with the tool may have an attenuation equalizing effect.

K e y w o r d s: tillage tools, soil loosening tools, oscillating tools

## INTRODUCTION

Tools used for soil tillage are excited to oscillate to a varying degree depending on the parameters of use. Investigations of individual non-oscillating tools, tools excitated by a crank drive to oscillate actively [3] and spring-loaded tools [4] relating to power consumption, loosening and breaking up of soil were carried through to come to optimum solutions in using tools which may be excited to oscillating. As in many other papers [2], energetic and technological advantages of spring-loaded tools as against non-oscillating tools could be demonstrated. The fact that the pull force of tools excited to oscillating actively by a crank drive may increase with the amplitude and frequency of oscillations increasing as against those of non-oscillating tools is generally known [1]. The effects on the advantages which oscillating tools provide as against non-oscillating tools, *inter alia* owing to the parameters and structure of the oscillation system and the arrangement of the tools on the machine and equipment frames, have been investigated only superficially. The following is to make a contribution to it. The following explanations refer to the basis for the development of sine-shaped or superimposed oscillating tools.

## THEORY

In [3,4] the solution of the motion equation of structural components excitable to generate sine-shaped or superimposed oscillations and acting self-exciting, with the aid of tools excited to active oscillation by a crank drive with (Figs 1a and 1b):

$$q_W(t) = A_o \cos \omega t \qquad (1)$$

with amplitude $A_o$ of the way of oscillation, frequency $f=\omega/2\pi$, angle $\varphi$ and other parameters varying, has been given, with the forces $F_x(t)$ and $F_y(t)$ and the moment $M_z(t)$ measured in relation to point I having been harmonically analyzed over a longer period of time $T$. The interaction between tool and soil is represented in a statistical sense (Figs 1c, 1d and 1e) by the damping force amplitude $F_s$ or the damping constant $\rho_\beta$ with:

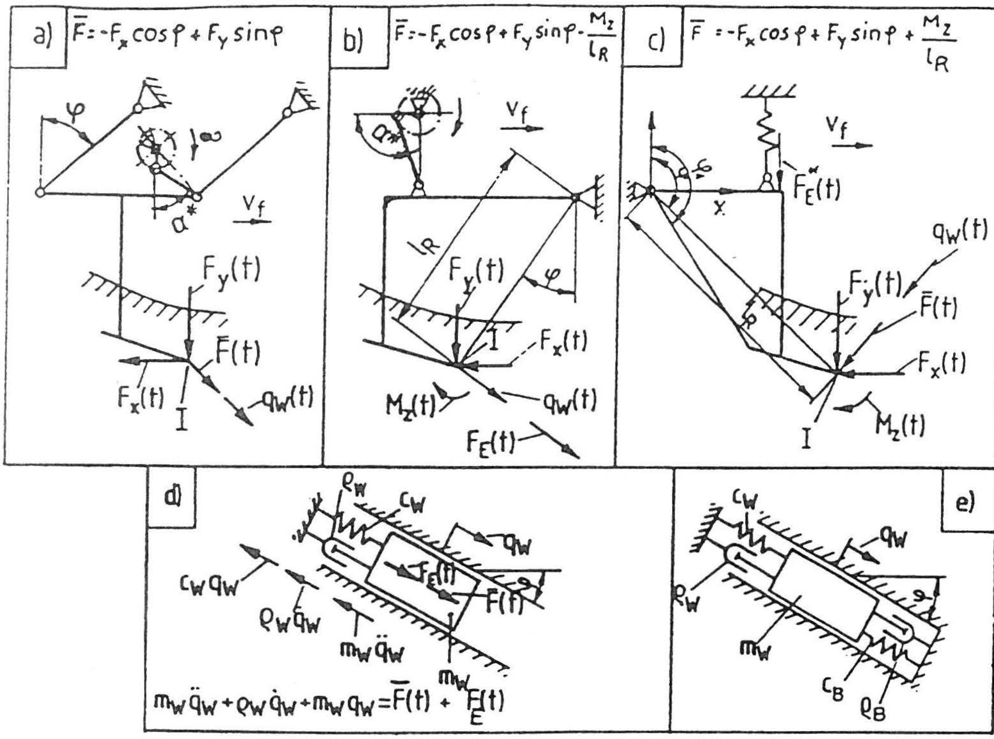


Fig. 1. Fundamentals of model formation of oscillating tools with a plane of oscillation of x-y. a) and b), use as actively oscillating tool, c) use as spring-loaded tool with an insignificant excitation $F_E$*, d) model to simplify the assessment of the oscillation motion in point I by reducing the parameters of the oscillating cranks to this point, e) simplified model, the parameters of the carrier, driving and transmission elements reduced to point I are mass $m_W$, damping constant $\rho_W$, spring constant $c_W$, resistance to oscillation $\bar F(t)$, excitation $F_E$ (t) with the frequency $\omega_E = 2\pi f_E$ by an oscillation drive, spring constant of soil $c_B$, damping constant of soil $\rho_B$, way of oscillation $\dot q_w$, speed of oscillation $\dot q_w$, acceleration of oscillation $\ddot q_w$.

$$F_s = \rho_\beta A_o \omega = \frac{2}{T}\int_0^T F(t)\sin\omega t\,dt \qquad (2)$$

and the spring force amplitude $F_c$ or spring constant with:

$$F_c = c_B A_o = -\frac{2}{T}\int_0^T \bar F(t)\cos\omega t\,dt. \qquad (3)$$

In this connection the proper frequency of the oscillator while being used:

$$f_e = f = \frac{1}{2\pi}\left(\frac{c_W + c_B}{m_W}\right)^{\frac{1}{2}} \qquad (4)$$

differs from the proper frequency:

$$f_{oB} = \frac{1}{2\pi}\left(\frac{c_W}{m_W}\right)^{\frac{1}{2}} \qquad (5)$$

of the freely oscillating tool.

The damping force amplitude:

$$F_{sF} = 8\, m_W D_W A_o f_e^{\,2} \pi^2 \qquad (6)$$

depending on the attenuation measure:

$$D_W + \rho_W / 2 m_W \omega \qquad (7)$$

forms the basis for assessing the damping resistance of the carrier, driving and transmission elements of the tool.

The investigations of tools excited to active oscillation by a crank drive carried through showed that amplitude $F_s$ was negative in some tests. This was a proof of the attenuation-equalizing effect of the soil 'passing' the tool. The attenuation equalization stated at an angle of $\varphi<90°$ is a result of the higher resistance to oscillation of the soil while the tool being moved in the direction of the soil surface or in the range of the circular angle $\alpha^*=\omega t=0...180°$ as compared to the resistance in the subsequent cutting phase. Yet, with the resistance in the direction of the tool movement being higher a residual resistance exciting the tool to attenuation-equalized natural oscillation as a kind of self-excited oscillation will remain after deducting the resistance which in the cutting phase has a damping effect or opposes the tool motion. A prerequisite to it is the condition:

$$\rho_B(A_o) + \rho_W(A_o) = 0. \tag{8}$$

The spring-loaded tool generates attenuation-equalized oscillations with an amplitude $A_o=A_{os}$, with both of the constants showing the same values. There are also cases when the tools have, first of all, to be brought into a respective static initial deflection to generate attenuation-equalized natural oscillations during the subsequent extinguishing of oscillations. Here, a harsh initiation of oscillation of the tools is concerned which unintentionally may lead to breaking of the tools. An essential prerequisite to an attenuation equalization of the spring-loaded tools is its controlling effect in forming curd particles. When used as a non-oscillating tool frequency $f_o^*$ in forming curd particles varies stochastically by an average. This represents a free relaxation oscillation. Owing to the foreign excitation resulting from it or the make impulse given by the tools penetrating suddenly into the soil on the boundary baulk the curd particle and oscillation motions, as a rule, marked by an integer resonance factor:

$$\eta_R = f_e/f^* \tag{9}$$

are synchronized. Here, a forced relaxation oscillation is concerned.

There have been also observed examples, with amplitude $A_o$=const. being small and $\varphi<90°$, where the combinations of effects had a damping effect. In the case of $\varphi>90°$ and the parameters of use being thus comparable an attenuation equalization was observed. In the case of an attenuation equalization occurring at $\varphi>90°$ the value of the resistance to oscillation will be bigger in the cutting phase than in the lifting phase.

If a small harmonic excitation with an excitation frequency of $\omega_E \neq \omega_e$ will become effective on an attenuation-equalized oscillating tool foreign excitation will absorb the attenuation-equalized natural oscillations. With the variation between the two circular frequencies increasing the amplitude of excitation has to increase to absorb the oscillations.

These prerequisites to exciting attenuation-equalized oscillations of a spring-loaded tool described are analogously also applicable to a few tools arranged on an equipment. Here, the tyres of the tractor and the support of the tool on the soil

**Table 1.** Influence of the phase angle $\varphi_p$ between the measuring instrument and the in-phase oscillating side tools ($\varphi=30°$, cutting angle $\sigma=20°$, length of the share plate $l_w$=58 mm, $A_o$=6.7 mm, $l_a$=100 mm, f=25 cps, $v_f$=1 m/s, working depth h=100 mm, width of the share plate $b_W$=250 mm, thickness of the share plate $d_W$=5 mm, resharpening angle in the share cutting edge area of all share plates: 15°, sandy clay with a water content of $w_B$=0.125 kg/kg and a humid density of $\rho_{WB}$=1 850 kg/m³, oscillating crank with $l_R$=590 mm) effective capacity ($F_{xo}$ pull force): $P=F_{xo}v_f+\pi F_s A_o f$

| $\varphi_p$ | $F_{xo}$ (N) | $F_s$ (N) | $F_c$ (N) | P (kW) |
|---|---|---|---|---|
| 0° | 405 | 30 | 160 | 0.41 |
| 90° | 440 | 70 | 180 | 0.47 |
| 180° | 480 | 110 | 200 | 0.53 |

through support wheels have also a damping effect. To comprehensively assess the proper motion of the individual loosening tools investigations were made relating, *inter alia*,

- the phase shift between the measuring tool and the side tools oscillating in-phase and at the same height as the measuring tool (Table 1),
- to the influence of the mode of operation on parameters of soil resistance (Fig. 2), as a function of angle $\varphi$ and
- to the influence of the parameters $A_o$, $f$ and $v_f$ on the parameters of the soil resistance (Fig. 3).

The experimental arrangement and the testing method were described in [5]. Testing of the actively oscillating soil loosening tools with an $x-y$ plane of oscillation allowed to investigate a form of natural oscillation with a minimum demand for oscillation energy.

## MEASURING RESULTS

The effective capacity $P$ of in-phase oscillating tools is the lowest and the attenuation-equalization of the tools is the highest (Table 1). The distance between the tools amounted to $b_a$=100 mm. Thus, the tools were coupled with each other through the interacting soil. By in-phase motion of the tools a tensile stress on the loaded soil is exerted by all tools in a uniform way in the whole soil area during the lifting phase. Thus the soil will get into a breaking condition if the demand for energy will be lower than that of tools oscillating dephased with each other. With phase shift increasing the influence of the pressure load of the tools entering increasingly the cutting phase is increasing during the lifting phase and *vice versa*. The cophasal motion of tools arranged in parallel represents a highly probable operating state.

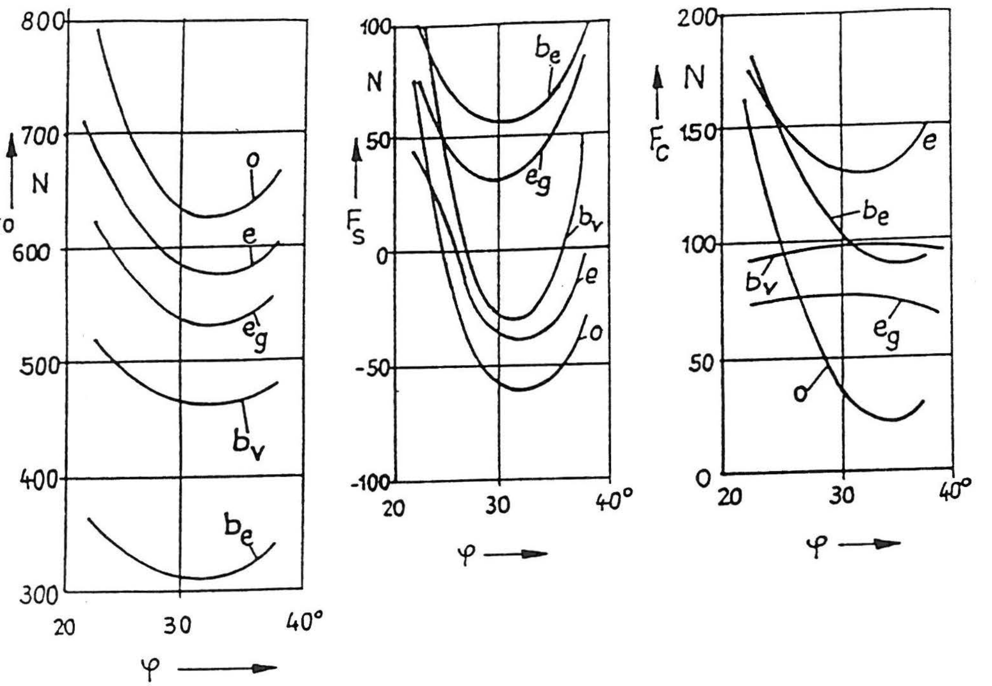


**Fig. 2.** Pull force $F_{xo}$, amplitude of damping force $F_s$ and amplitude of spring force $F_c$ as a function of the angle of oscillation. Modes of operation: o non-affecting, $e_g$ unilateral influence by a side tool, $b_e$ influence on both sides by two side tools, $b_v$ central back left untreated by two oscillating side tools with a distance $l_a$=100 mm, e individual use of the measuring instrument in the case of the soil being unilaterally pretreated; Parameters according to Table 1; $A_o$= 4.8 mm.

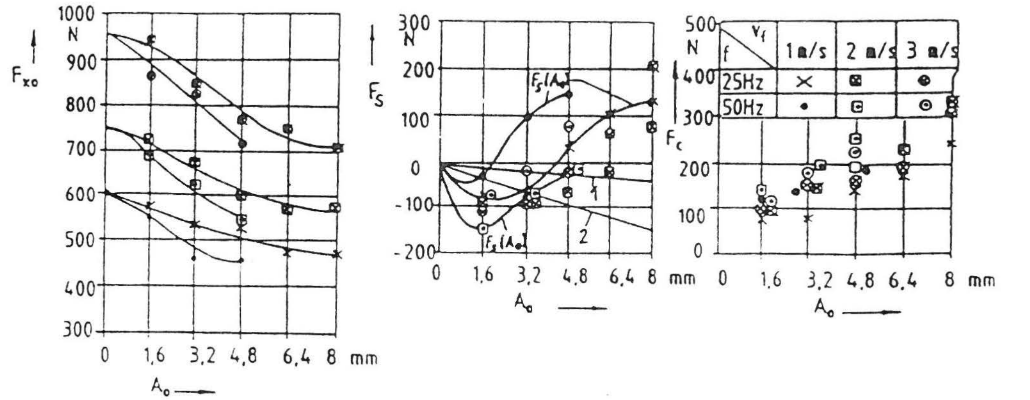


**Fig. 3.** Pull force $F_{xo}$, amplitude of damping force $F_s$ and amplitude of spring force $F_c$, with the mode of operation being $b_e$, as a function of the travelling speed $v_f$, frequency f, amplitude $A_o$ (curve 1: $F_{sF}(A_o)$ for $f_e$=25 cpm, curve 2: $F_{sF}(A_o)$ for $f_e$=50 cpm, $\sigma=10^o$, $l_w$=75 mm, $b_w$=250 mm, $l_a$=100 mm, $l_R$=575 mm, other parameters according to Table 1).

The mode of operation and oscillation angle affect the pull force $F_{xo}$, the damping force $F_s$, and the spring power $F_c$ (Fig. 2). Independent of the mode of operation the minimum effective capacity $P$ is about $\varphi=27.5^o ... 33^o$. The effective efficiency $P$ of a non-affected tool (mode of operation $o$) will be the highest, this efficiency will be lowest for a tool influenced on both sides (mode of operation $b_e$). The attenuation equalization of the soil interacting with the tools will be highest in the case of a tool being not affected and the smallest in the event of a tool being influenced on both sides. Value $F_c$ depending on the mode of operation allows to draw the conclusion that the proper frequency of spring-loaded tools fixed on the equipment frame in a stepped way is not constant. Attenuation-equalized natural oscillations may be only generated if the individual oscillators will mutually absorb their oscillations through the elastic equipment frame. The evidential value of the results of this investigation in assessing the influence which the mode of operation has on the parameters of soil resistance was only insignificantly affected on a width of about 0.65 m when preparing the compacted soil strip.

With the travelling speed $v_f$ increasing and the frequency f decreasing attenuation equalization will be increased by the soil interacting with the tools, with the values of $A_o$ being small (Fig. 3). With the travelling speed $v_f$ increasing and frequency $f$ and amplitude $A_o$ declining the pull force will be reduced. Comparing the pull forces $F_{xo}$, with the amplitudes being $A_o=A_{os}$ and $A_o=0$, will provide the foundations for assessing the reachable reduction of the pull force $F_{xo}$ of the tools set in a dephased motion by an insignificant harmonic excitation, unlike non oscillating tools, with the parameters of use being comparable. To estimate the ensueing amplitude $A_{os}$ the damping force amplitude $F_{sF}$ was plotted in the negative range for the covibrating mass $m_W$=3 kg and the attenuation measure $D_W$=0.03. The intersecting point of the curves $F_s$ $(A_o)$ and of force $F_{sF}$ $(A_o)$ plotted in the negative range of force $F_s$ results in an amplitude $A_{os}$. This leads to an increasing amplitude $A_{os}$ with the travelling speed $v_f$ increasing and the frequency $f$ decreasing. By means of investigations it was possible to prove the increasing reduction of the pull force, with the amplitude $A_0 = A_{os}$ increasing, as against non-oscillating tools. The temporal course of free and forced relaxation oscillation is affected, *inter alia*, by the mode of operation, travelling speed $v_f$ and frequency $f$.

## CONCLUSIONS

Proceeding from the investigations made a comprehensive development of spring-loaded tools which by an insignificant excitation $F_E(t)$ are set in a definite oscillation motion is to be recommended. This dephased motion results in a minimum damping of the tyres. When using these tools it is of disadvantage that frequency regulating equipment has to be applied to reach the resonance state.

Investigations relating to an optimization of the structure and parameters of the whole oscillation system and market economy investigations have to be carried through. Avoiding of spatial oscillations will, e.g., result in executing a more rigid equipment frame, thus increasing the material costs.

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