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Vibrated Tillage Tools for Energy Saving

László FENYVESI, Zoltán HUDOBA
Hungarian Institute of Agricultural Engineering, Gödöllő, Tessedik út 4., Hungary,
hudoba@fvmmi.hu

Abstract: Soil tillage is one of the highest energy requiring agricultural operation. Significant part of researches aiming reducing draught force was focusing on utilizing vibration in the process.
There was no energy saving achieved via applying vibrating soil tillage tools operated by external drive. Research results are convincing to use different "self-vibrating" applications (e.g. vibration generated against a spring).
We carried out test with four different vibrated parts of plough bodies. The first test tool was a plough body with leaf-spring system, the second one was a special beam, which assures the turning of the plough body around an axle, the third one was a beam with parallel moving system and the fourth we vibrated the share. The research was expanded to development of field cultivators, which play significant role in conservation tillage.
We assumed that the vibration of one of the components of the tool and the draught force would result in energy saving. Various promising research results led us to the development of a plough body vibrating by soil induction. The spectral examination of tractive force of ploughing shows no characteristic energy transfer frequency. So the resonance frequency of the cultivation tool always finds a corresponding soil load frequency up to fifty Hz. For this reason we can reduced the natural frequency of tillage tool 50 Hz below. Based on the test result we can state, that the draft force requirement of the experimental vibrating tool is smaller significantly than the rigid one's.
Key words: tillage, drought-force, energy, vibration, measuring

INTRODUCTION

Draught force plays a key role when developing an active, vibrating tillage tool, and it depends non-linearly on the parameters of the soil tillage. Both analytic and numeric procedures describing draught force express this effect. "Draught resistance" was first described *by Goryachkin (1927)* in an analytic way. This is a rather simple expression that consists of rational terms

$$F = F_1 + F_2 + F_3 = f \cdot G + k \cdot a \cdot b + \varepsilon \cdot a \cdot b \cdot v^2 \qquad (1)$$

Where:

f G = F_1 is the "no-load" resistance of the plough, which depends on a constant (f) and the weight of the plough (G). A number of researchers have measured f, which may take a value in the range of 0.29 – 0,5. For example the modifying factor was established for taking into consideration of the fast ploughing impacts *(Bánházi, 1964)*. Its depending on the tilling speed is known at different soil types *(Sitkei, 1968)*.

k a b = F_2 is the actual "deformation" resistance. Here "a" equals the work depth, "b" is the work width, whereas "k" refers to the deformation resistance factor, which may also vary in a wide range, between 20-50 kN/m^2 !

Finally, the third term ε a b v^2 = F_3 is the force actually required for moving the furrow-slice, where ε depends on the type of the soil, and the shape of the plough, so its value may vary in a wide range: 0,7-12 kNs^2/m^4!

The Goryachkin relation may be used primarily for the analysis of the draught resistance of normal tillage tools, mainly ploughs. The great advantage of this method is that it is useful in the analysis of the basic processes, but, on the other hand, it is too general. Due to its universality, the concrete value of all the parameters varying in a wide range must be defined.

As far as the numeric methods are concerned, the used material equations *(Kushwaha, 1998)* may be characterised with plastic or elasto-viscoplastic relations. A simple material model cannot be formulated *(Chancellor, 1994)*, as the parameters of the model are influenced by too many factors (e.g. humidity, structure), which can only be defined through experiments. A great disadvantage of the calculations carried out with the "infinite element" or "discrete element" method is that they only make the simulation of individual conditions possible.

The periodic nature of the occurring draught force originates from the processes of cutting, compacting and moving the substance *(Cooper, 1984)*. This periodicity decreases over a given, critical speed *(Stafford, 1988)*. When undisturbed soil is under tillage, the absorbed draught force may be featured as a random process *(Soehne, 1956)*. Simulating the draught force is only possible to a limited extent, no universally valid process characteristics are known. Characterising the measured draught force with statistical methods may make more universal statements.

By employing the measured draught force, power spectral density of the draught force may be defined. By defining the diagram, *Summers (1984)* stated that the delivery of performance is the greatest at the frequency of 9.99 Hz, there are smaller maximum values at the frequencies of 995 Hz and 1187 Hz. It turned out however, that the features of the delivery of performance realised by draught force are influenced by a number of factors: the type of soil, humidity and the soil condition *(Sakai at al, 2005)*.

The PSD curve is an interesting result *(Borsa, 1991)*, which was defined on the basis of the measurements carried out on a wheat stubble field with a medium-deep plough with very rigid, robust cast-steel beam (Fig. 1). Between 0-50 Hz the curve has monotonous decreasing without local extreme value. Therefore the "clean" draught resistance may be described thus, that the delivery of performance occurs between 0-50 Hz in a homogenous way without a particular frequency. Thus any component of the draught force that may be regarded as periodic, may resonate with the natural frequency of the springy tillage tool within the given range.

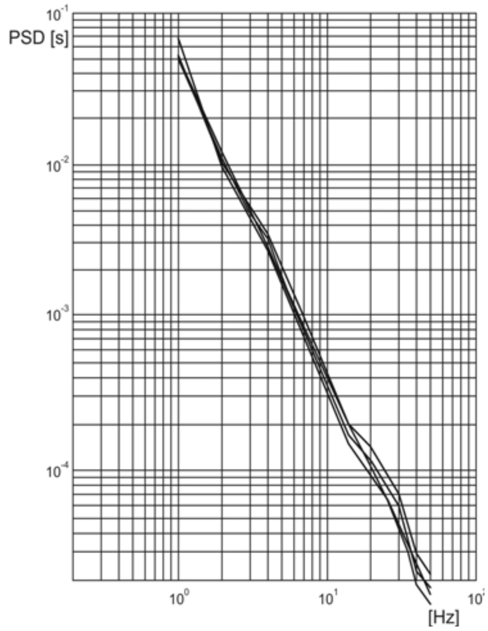

Fig. 1. The development of the power spectral density on a (compact-soil) land (Borsa 1991).

MATERIALS AND METHOD

Developing the test equipment

According to Eggenmüller (1958 b) the individual structural parts of the tillage tool have differing effects when vibrating. Preceding the development of the experimental tillage tools, we constructed a plough on which only the share vibrated, whereas the mouldboard did not. According to the result of the measurements carried out in a soil bin, a perpendicular vibration on the share is more favourable than the edgewise one *(Fenyvesi, Mezei, 1996)*. Only the vibration of the share seems to be favourable, however, it is rather difficult to realise on the plough field with a device used in normal operational duty.

This is why we carried out the modification of tillage tools used in normal operation, and we provided the vibration by the means of a spring.

In accordance with Figure 1, a tool had to be developed, whose frequency fell in the range of 0-50 Hz, and ideally it ranges between 20-25 Hz at the basic tooling. As the tillage is carried out on a stubble field (on compact soil), we can assume that there is no special frequency in the domain of variability (Fig. 1.) so the tool must be resonating in the selected domain with the respective draught force components. This may result in saving energy.

However, the given domain of frequency is rather low, this is why a relatively soft spring had to be applied. At the same time, the average value of the draught force (Fig. 2) is so high in the tillage work, that the vibration could not be realised with soft springs.

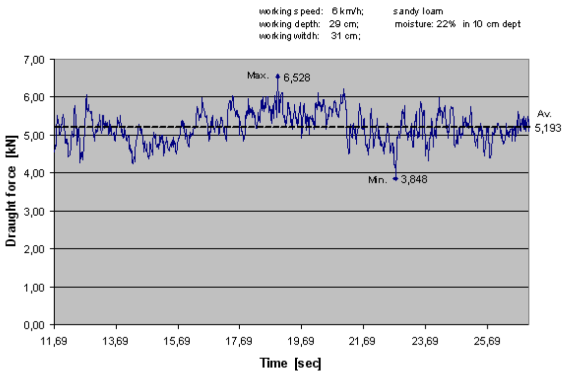

Fig. 2. A typical draught force section of the plough

When developing the test equipment, a mechanism had to be applied that could reduce the effect of the draught force at the spring.

We constructed four versions for the test of the plough and one model for the cultivator. We adapted a plough body with laminated spring that is currently available on the market, by decreasing the number of the laminated springs. Thus the plough body performed the oscillating motion against the spring (Fig. 3).

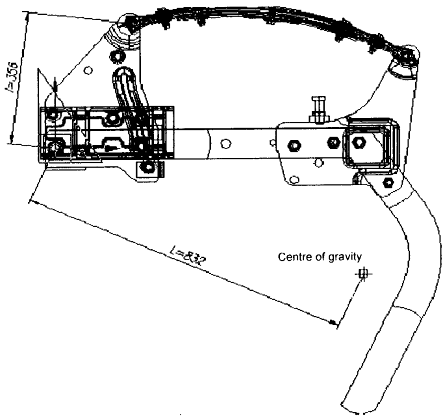

Fig. 3. Adapted vibrating ploughs with spring

By adapting the plough body, we created a structure that ensured the vibration of the body in the direction of displacement against a cylindrical spring (Fig. 4).

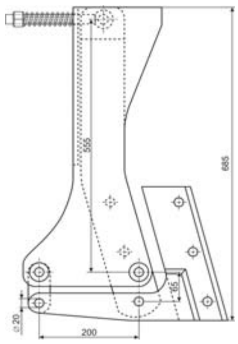

Fig. 4. Alternating in the direction of movement

The third solution for the plough ensures the rotating movement of the plough body around an axle, also against cylindrical springs (Fig. 5).

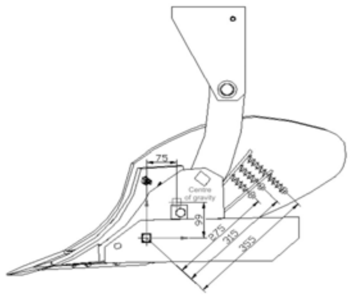

Fig. 5. Adapted, plough performing alternating rotary movement.

Disc springs were installed between the share and the saddle (Fig. 6), thus the share could move in a perpendicular direction to the edge. The disc springs are able to take up great forces with little movement. Changing the number of springs and their method of placement may modify the spring constant.

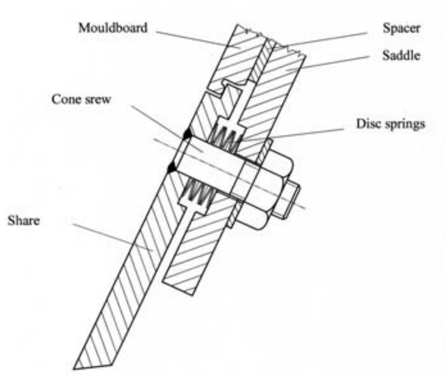

Fig. 6. Placing disc springs between the share and the saddle

Defining the characteristic frequency of the test tools

The modified spring-trip shank. We could use suitable force transmission, and spring characteristics. In the first step we have estimated these data with calculation than we have looking for the correct properties of tools with modification. In our case the ploughs have only one degree of freedom, because we can describe the motion with rotation angle. Using Lagrange equation of motion we can calculate the approaching natural frequency.

Disregarding the deduction the natural frequency is:

$$\alpha = \sqrt{\frac{a^2}{\Theta c}} \left[\frac{1}{s}\right] \qquad (2)$$

c: spring constant (mm/N),

a: distance between spring and returning axle (mm)

Θ: moment of inertia calculated on the pivoting point (kg/m^2)

Measuring conditions

The measuring could not be carried out in well-defined conditions, for example in a soil bin, for, as demonstrated above, the draught force depends on the soil characteristics, especially the mechanical conditions. Therefore the measuring was carried out on a plough field, non-tilled soil and on a vegetated stubble field on the testing site of the Hungarian Institute of Agricultural Engineering (MGI).

The experiments were performed with a 3-share, semi-suspended plough, the draught force was measured at the middle and the closing body. The draught force was measured with a strain gauge. The measuring points and the connection of the bridge were formed in such a way that it would be only sensitive to the required force component at the appropriate level of sensitivity.

After the appropriate preparation the measuring of the vibration was carried out with an inductive displacement pick-up (Hottinger GmbH) in the form of displacement. Occasionally, the speed was recorded with a Correvit_H (Datron Messtechnik GmbH) speedometer without interruption. The sections of measuring were 200-250 metres, we measured in both directions and compared the recorded values. We worked with a MTZ 80 Tractor. We installed the control and vibrating plough bodies at the place of the second and third bodies on the three-bodied LCF-3-35 plough. Due to the local effect, we occasionally changed the bodies. No change was carried out with a system equipped with four cultivators.

We formed tensometric measuring points on the bodies and cultivators, only sensitive to the draught force. Prior to that, all measuring points were calibrated either with direct weight-load or with a verified measuring element. We followed suit with the beams of the cultivators. The tillage depth and width were manually sampled at random locations.

We employed the Spider-8 measuring system to amplify and record the signals (Hottinger, Germany), and used statistical methods for processing the signals. We always measured two bodies, installed at the place of either the second or the third bodies. The signals were originally recorded at the frequency of 400 Hz. The humidity of the medium-compact, sand-clay-soiled stubble field was identical at the compared measurements, as the measuring was practically carried out at one time. The average of the operational speed was 7 km/h, the average ploughing depth was 36 cm, whereas the width was 22 cm.

MEASURING RESULTS

With each plough body we found a setting at which vibration occurred. In these cases we also registered a decrease in the draught force.

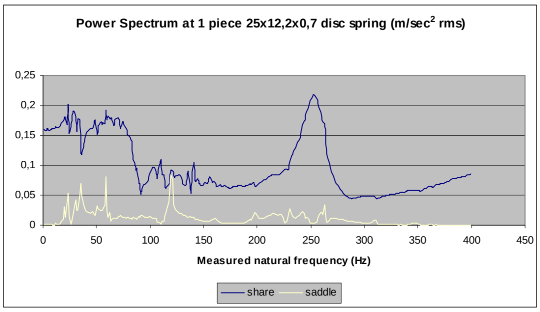

Fig. 7. Measured natural frequency at disc spring version

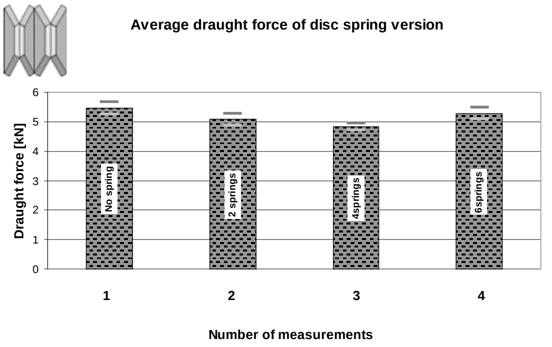

Fig. 8. Average values of draught force with 0.7 mm disk springs at the working speed of 6 km/h

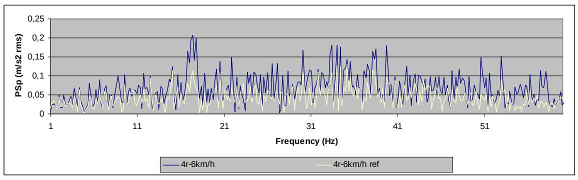

Fig. 9. Acceleration power spectrum of vibrated share

CONCLUSIONS

Based on the test result we can state, that the draft force requirement of the experimental vibrating tool is possible smaller than the rigid one's.

To confirm the first result we should make more field tests with wider speed range and different soil type and condition.

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