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Rotating grain-straw separation for combines with tangential threshing systems

The Horden straw walker is increasingly the performance-limiting element in combines with tangential threshing systems. This is mainly through gradual compacting of lower harvested material zones on the walkers. Presented in this article are the results of investigations with rotating gravity-based grain-straw separation systems with horizontal and vertical mattress agitation leading to substantially improved grain separation.

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Keywords

Combine, grain-straw separation systems

The mainly vertically applied impulses into the mattress on straw walkers gradually lead to a compacting of the lower mattress zones and associated worsening of grain separation conditions, a condition which has led to the introduction of so-called walker aids over many years.

Becoming more prominent in attempts to increase throughput performance of conventional combines is the substitution of straw walkers with more appropriate grain-straw separation systems, many of them rotating systems, while at the same time retaining the tangential threshing principle. In this context the only systems put forward so far utilise the principle of „separation in supplementary acceleration fields". Compared with gravity separation the advantages (lower increase in the throughput-loss curve, slope-independent operation) are unquestionable. The more intensive processing of the harvested material leads, however, to higher loads on the subsequent cleaning equipment (short straw) as well as substantially higher energy requirements. Additionally, separation performance decreases in low throughput areas. Results processed from the gravity-based rotating grain-straw separation system are presented below with particular attention paid to the relationship between mattress agitation and grain separation, as well as the influence of tine form on mattress agitation.

Investigated grain-straw separation systems

For clarification of the relationship between tine form, mattress agitation and grain separation, new systems developed at the TU Dresden for laboratory investigations – the „tine chain walker" and the „tine rotor walker" rotating separation systems (*fig. 1*) – were applied (detailed description in [1-3]).

The straight impulse generating elements (tines) of the tine chain walker apply an overlaying movement (translation and rotation portions) when the overturn lever turns to the cam and finally when returning to their original position actually move against the mattress flow. Tine rotor walkers with bent tines, on the other hand, carry out a pure rotational movement and always act in flow direction through the separation area.

From the literature [4] it is known that the strength of the impulses into the mattress and the agitation frequency (frequency of impulse introduction) has a controlling influence on grain separation results. Increasing rotor speed at the tine rotor walker unavoidably gave bigger impulses (higher tine circumferential velocity) and more frequent mattress agitation. Separate investigation of both parameters is not possible. On the contrary, impulse strength and agitation frequency are closely linked on the tine chain walker. Thus with increasing chain velocity (higher agitation amplitude), the resultant agitator frequency can be kept almost constant so that cam numbers are reduced. Conversely, with constant chain velocity the agitator frequency can be increased through a larger number of cams.

Additionally the tine circumferential velocity is so influenced by the cam shape that, at the time of the tine acting on the mattress a high vertical component ($\dot{s}_y$) is achieved and with upright tines a high horizontal component ($\dot{s}_x$) is reached (higher vertical or horizontal impulse, *fig. 2*).

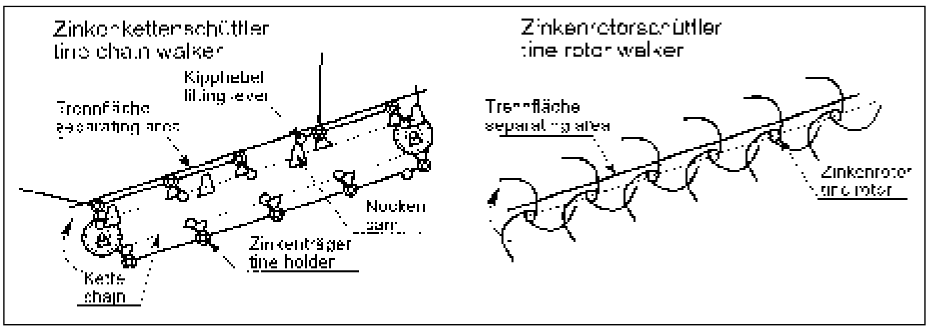

Fig. 1: Working principles tine chain walker – tine rotor walker

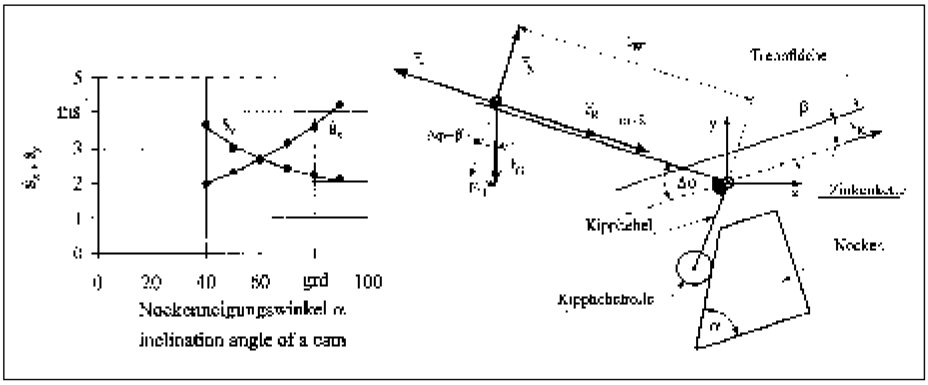

Fig. 2: $\dot{s}_y$ at the moment of tine mesh into the good and at the moment when the overturn lever turns over from the cam flank to the cam head depending on the inclination angle of a cam α

Results

Influence of tine form on material transport
The intensity of material transport is decisively influenced by the form of the impulse-causing element. If one reduces the material mattress on the moving tines to an elementary mass, it would loose contact with the tines precisely when the normal force $F_N \leq 0$ acting on the elementary mass applies. The force effects presented in *figure 3* as well as equation 1 and 2 apply for the tine rotor walker with straight or bent tines. Applying for the tine chain walker equipped only with straight tines are the acting forces in *figure 2* and equation 3.

Tine rotor walker:

Straight tines

$$F_{Ni} = F_G \cdot \cos(\varphi_{0i}+\omega \cdot t - \beta) - F_{Fi} \cdot \sin\delta_i \quad (1)$$

Bent tines

$$F_{Ni} = F_G \cdot \cos\eta - F_{Fi} \cdot \cos\sigma \quad (2)$$

Tine chain walker

$$F_N = F_G \cdot \cos(\Delta\varphi - \beta) \quad (3)$$

The normal force is reduced by a centrifugal force proportion for the tines of the tine rotor walker only. This means that with the same kinematic parameters a mass moved on the tine rotor walker can be raised from this even where tine setting is shallower whilst an elementary mass agitated by the straight tines of the tine chain walker can only theoretically be raised from these when the tines are vertical to gravitational pull. Through transference of the overturn lever from cam flank to cam head the movement of the straight tines is, however, strongly slowed so that at this point the elementary mass breaks away from the tines.

With the same centrifugal force and identical friction effects a flow on bent tines is, according to figures 2 and 3, more likely compared to straight ones. Alongside the lower normal force on the bent tines, the slope-drive components of gravity help in such a case. The investigations showed that alongside the more timely lifting, also the greater possibility of the flow of the material layer along bent tines led to a less aggressive material transport. The in-part substantially higher circumferential velocity of the straight tines as well as their aggressive material transport action created mattress areas with more markedly higher and lower compacted areas (more marked horizontal „pulsing“ of the material train).

Impulse strength and grain separation
If the mattress is agitated by rotating tines the following separation conditions can be observed:

1. At the time of tine action in the mattress its vertical circumferential velocity components are relatively large in comparison to the horizontal ones. These mainly led to an acceleration of the mattress in a vertical direction. The greater inertia of the grain compared with the straw layer slowed thereby the movement start by the former. This caused grain from higher mattress layers to travel down and lodge in lower layers whilst grain from the lower layers dropped from the mattress and moved in the direction of the separation area.
2. During the movement of the tines through the mattress, the material lying before the tines was compacted. Because of the resistance forces within the mattress (interlocking of straws) a part of the material train which was behind the acting tines was also accelerated, although at a much slower rate. In such areas this led to a loosening of the mattress and thus to an improvement in grain throughflow conditions.
3. From a certain point of time (dependent on tine form and mattress properties) the accelerated proportion of the material was subject to a more or less marked throwing action.

Depending on the length of this throw, the accelerated portion of material hits either the following engaging tines or the separation area. The grain, which is slower than the mattress, takes a longer time moving towards the separation area and is subject to the same separation process as described in point 1.

All three separation phases have very different effects on grain separation. If a tine acts on a lower horizontal compaction area within the mattress the total effect is a more intensive grain separation, along with the grain movement to the lower mattress zones (setting of the grain). Tine action in areas of the higher-situated mattress compaction also leads, alongside the setting of the grain, to intensified grain separation, whilst actual tine movement within the mattress strongly reduced grain separation. Loosening of the material layer on its own was not sufficient to allow good separation through gravity. The loosened mattress layer zones did have the effect, however, of allowing a more efficient separation during subsequent vertical impulses on the mattress.

The high vertical impulses when tines met mattress and the horizontal impulses within the mattress benefited the said separation phases with both separation systems. The extremely high horizontal loosening at the tine chain walker is not necessary in that gravity alone when acting on the free-moving grains is not sufficient to overcome the still existing material resistance. Additionally, the strong horizontal mattress acceleration led to high average material velocities which, through

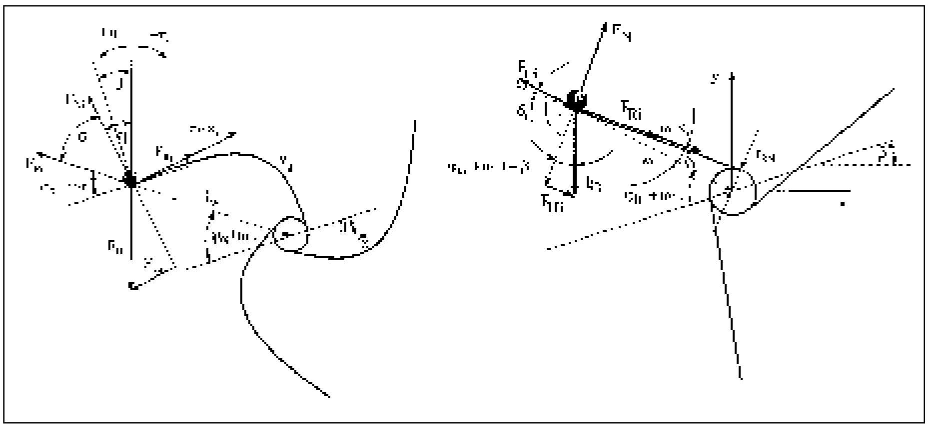

Fig. 3: Dynamic-effects on an elementary mass at a tine rotor walker

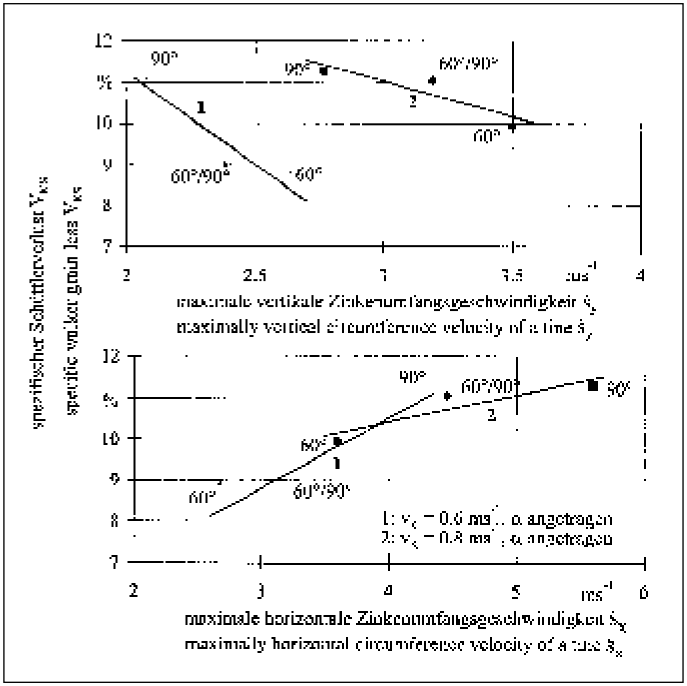

Fig. 4: Specific walker grain loss depending on the components of the circumference velocity of tine on top of a tine

the associated reduction in time spend by the material in the separation system and reduced impulse transmission, led to substantially higher grain losses. *Figure 4* confirms these relationships using the example of the tine chain walker.

A high vertical tine circumferential velocity at moment of entry into the mattress led to lower grain losses, whilst high horizontal tine circumferential velocities at the end of the tine movement within the mattress substantially worsened grain separation.

Impulse density and grain separation

The less aggressive material transport by bent tines means they always have an effect in the area of more-compacted mattress zones in that, with increasing tine length, the mattress at the time of tine insertion can be lifted as well as sliding along its length. More compacted mattress zones are not reloosened by the action of straight tines because of their aggressive material transport effect. This strongly reduces the possible positions for impulse transmission for straight tines.

The substantially higher tine circumferential velocity on the tine chain walker therefore compares with more than double the impulse density with the tine rotor walker. Despite this the average material density (scale of material mattress resistance) in relationship to throughput reaches similar values. For a specific total throughput of 6 $kgs^{-1}m^{-1}$, it lay, e.g., between 12 and 15 kg m^{-3}. The investigation showed that, with the same material resistance to be overcome, higher impulse densities (more separation-encouraging throw movements) realised a more effective grain separation compared to larger impulses.

Summary

The extent of increased mattress agitation (impulse density) and a high impulse difference between mattress and agitating elements (impulse intensity) acting on grain separation are very strongly dependent on the form of the impulse-creating element. Bent tines present more suitable grain separation conditions with regard to continuity of action as well as location where tine impulses are delivered.

Literature

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