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Basics for tangential threshing devices – mathematical description of the curve characteristic of the concave clearance

The demands on throughput and harvesting quality of combine harvesters are still growing, so that improvements of the functional components are necessary. The tangential threshing device, which is used in conventional and hybrid combine concepts, is known for its high installation space and energy efficiency. Mostly there are just one or two parameters for adjusting the concave clearance of tangential threshing devices which is not adequate for describing the position of the concave and the analysis of the threshing process. With the mathematical description of the curve characteristic over the separation length it is possible to analyze especially multi-drum threshing devices, which is basis for further experimental research.

Keywords
Combine harvester, tangential threshing device, concave, concave clearance

Abstract
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The active principal of the tangential threshing device is nearly unchanged since its invention in 1788 in Scotland, [1].

From the feeder conveyor, which is the interface between cutterbar and threshing device, the crop is fed to the threshing system. Using a combination of beating, friction, and centrifugal forces the grains are detached from the infructescence to be separated at the threshing concave. The straw with the not separated grain is fed by an impeller to the residual grain separation.

The operation of the threshing device depends strongly, apart from the structural design, on the operating parameters of e. g. peripheral velocity and concave clearance.

For the single drum threshing device there are numerous studies, both for design and operating parameters. With an increasing number of threshing drums, the quantity of parameters rises significantly, leaving many questions concerning the design of threshing devices unanswered. More basic research focusing the adjustment of the concave is required.

State of research

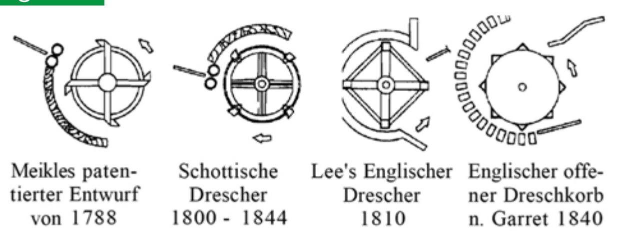
Previous investigations had the intention to increase the throughput while maintaining the separation efficiency, the quality and to reduce the energy demand.

Beside the designs, the different diameters and the positions of the threshing drum, the feeding system, the concave arc, and the number of drums as well as the setting for different conditions were considered in the past, in both laboratory and in field experiments.

Here studies of single- and multi-drum-threshing devices are listed exemplarily as references, dealing with the influence of adjustment and design of the concave, as a basis for further investigations.

By Arnold [2] several influencing variables on threshing were examined. Among other things, he varied the relation

Fig. 1



Development of the Scottish and British threshing devices [1] of input and output clearance from narrowing to widening. Caspers [3], also, analyzed the separation of a threshing device with narrowing and parallel characteristics of the concave. Both draw the conclusion that the adjustment of the concave influences significantly the threshing and the separation. Small (narrow) concave clearances allow to achieve high threshing and to perform a high grain separation, but result also in a higher percentage of damaged grain. It is therefore recommended to start with narrow clearances already at the front of the concave in order to increase threshing and separation there and to prevent the grain kernels from further impact.

Paulitz created a method to model the threshing process and its optimization, which was validated in experimental studies [4]. These investigations had the objective to optimize the threshing concave in order to increase the grain separation, minimizing the MOG separation, the percentage of damaged grain and the power requirement. In addition to the design parameters of the concave, the concave clearance and the peripheral speed were analyzed.

The mathematical description of the concave clearance progression is done over the separation length, but just for the single-drum threshing device and the radial part of the concave, leaving the inlet- and outlet-area of the concave unconsidered.

Regge [5] takes up these studies, evaluates them and gives some further detailed design recommendations. He also shows the calculation of concave clearance, which bases on the use of the cosine rule for the radial part.

With increasing demands of the farmers regarding a higher throughput, further drums in front or behind the threshing drum were added to the conventional tangential threshing device. Due to a larger separation area, a more uniform feed and the increased use of centrifugal forces the grain separation could be significantly intensified.

In Heidler's studies [6] the focus is the design of the transition area of the threshing- to the separation-drum. Different transition angles and different concave types were considered. The aim was to achieve, among other things, a separation in the grate-type transition area.

Büermann [7] later examined a threshing device with a threshing drum and an accelerator drum in front. He varied the position of both feeder and drums. The concave setting was, exactly as in Heidler's investigations, a constant parameter.

The most recently published studies to the topic of multi-drum threshing devices are written by Nguyen [8]. He connected two drums, one after the other, and fed them tangentially: The result was an S-shaped flow of crop. This enabled to increase the separation length considerably, without creating a strong change of direction for the material.

After the consideration of the literature it can be summarized, that there have been studies regarding the concave adjustment for single-drum-threshing-devices, but the multi-drum-threshing-devices are not comprehensively (or sufficiently) investigated. The description of the concave clearance is done in specific areas, although not for the entire multi-drum-threshing-device.

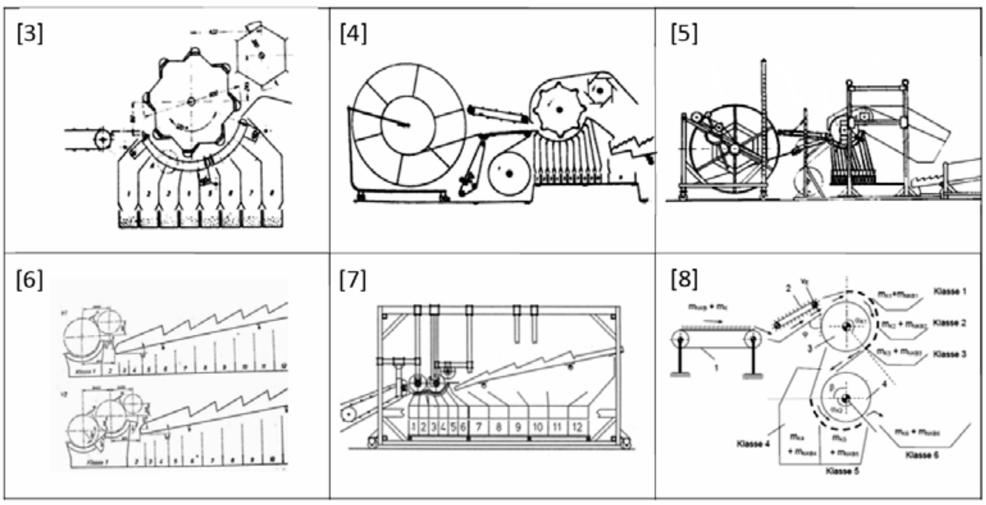
The table **Figure 2** shows an overview of different test rigs which has been used in the mentioned literature:

Mathematical description of the concave claerance

Assuming that the crop is exposed to intense stress by the deflection due to individual parts of the concave a closer look at the inlet and outlet areas of the concave is required. In the inlet area the concave clearance is narrowing, resulting in a high compression and acceleration of the crop. In the outlet area the concave is widening tangentially, the flow of the crop expands again and hits the following drum.

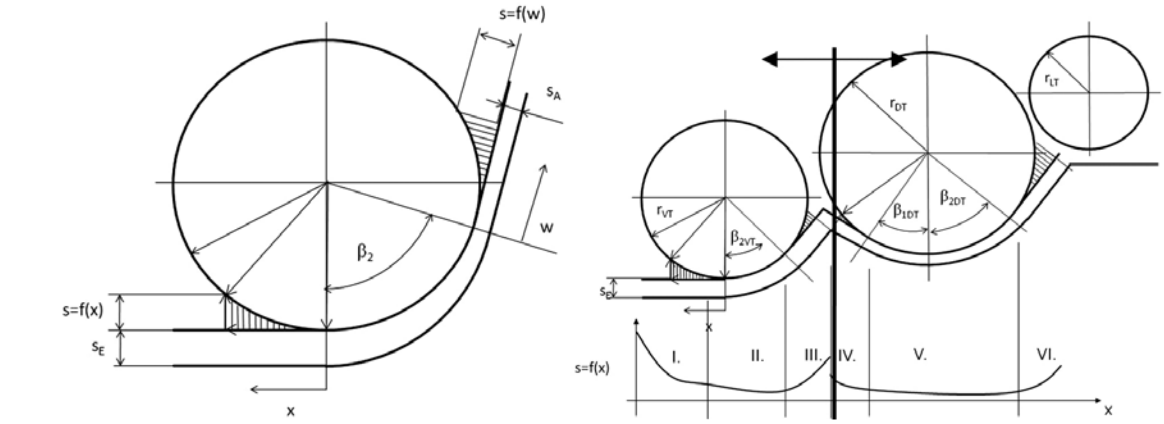
When the aim to enable the operator to a simple setting of the concave adjustment, with only one or two parameters, becomes less important, a more elaborate description of the concave clearance and its curve characteristic is necessary.

Fig. 2



Overview of the test rigs

Fig. 3



Concave clearance at single-drum-threshing device (left) and the schematic function of the concave clearance at a multi-drum-threshing device (right)

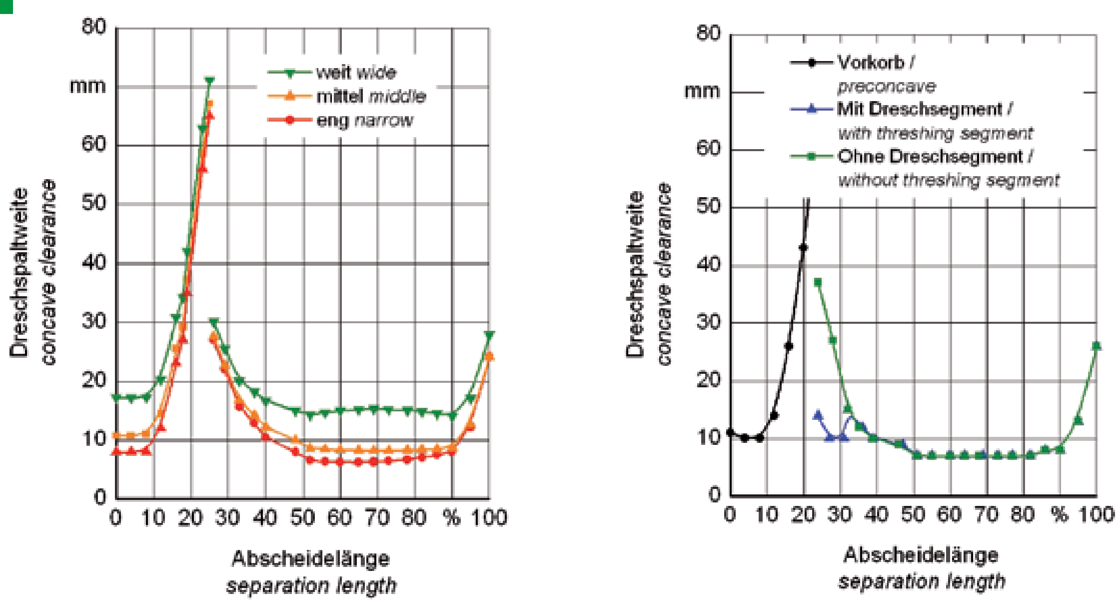
Caused by the constant radii of the concave and drum, strongly non linear curve characteristics of the concave clearance are generated. A representation of the concave adjustment indicating the inlet and outlet concave clearance is not sufficient to analyze the threshing process. For further investigations the function of the concave clearance, which allows an exact description of the concave clearance at any point of the separation length, should be used.

If we extend the calculation of Regge [5] to the inlet and outlet area, we get the fundamental curve for a single-drum-threshing device shown in **Figure 3** (left). The circles represent the circumference of the threshing-drum. The circular arc arranged below with the inlet and outlet shows the concave.

Applying the conditions of the single-drum-threshing-device to the multi-drum layout, we obtain the basic characteristic presented in **Figure 3** (right). In section I (inlet zone – preconcave) a strong narrowing is formed. Section II is the radial concave area, which depends on the setting of the concave-clearance, whether it is a narrowing, widening or parallel adjustment. Section III represents the discharge area of the acceleration drum and widens strongly. After the transition point (between III and IV), which characterizes the direction change of the material and causes a discontinuity in the mathematical function describing the concave clearance, the sections of the main-concave follows.

In **Figure 4** two graphs show the course of the function of the concave clearance at different settings. On the left side three different settings of the concave are shown and the concave clearance is plotted versus separation length. At a low concave clearance setting (8 mm) the width narrows over the course until the middle of the main concave (60 % separation length) and then widens again. With the wide setting (15 mm), the clear-

Fig. 4



Function of concave clearance - Comparison of different adjustments (left) and using the threshing segment (right)

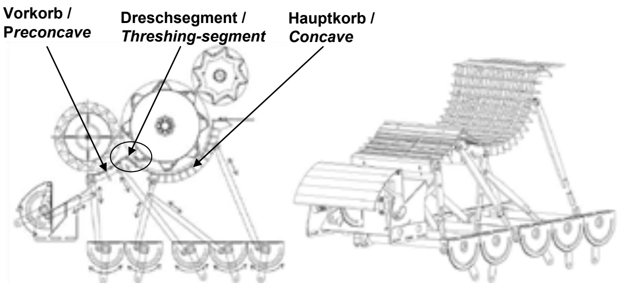


Fig. 5

Concave adjustment with three degrees of freedom for each concave of the new test rig

ance has got an approximately parallel characteristic (also until the middle of the main concave). Starting at 65 % there is also a little narrowing course noticeable which is strongly widening at 90 % again.

In the right diagram the influence of an additional threshing segment (additional geometry and change of friction to improve the threshing) is shown, which is mounted in the transition zone between pre-concave and main-concave reducing significantly the distance between drum and concave. The curve characteristic in the inlet area is changed by the additional element which might have influence on threshing, separation and damaged grain.

With the mathematical description of the concave clearance there are several options to analyze the threshing process. After differentiating it, we get the gradient, which enables to measure the widening or narrowing of the curve characteristic of the concave. With the integral it is possible to calculate the cross section area between drum and concave.

Concave adjustment

To ensure a specific setting of the concave clearance or the volume between drum and concave, an extension of the current common setting parameters is required (normally there are just one or two parameters to adjust the concave clearance for the concave of a multidrum threshing device). For a new basic test rig an adaptation mechanism was designed and implemented allowing a separate setting of pre- and main-concave. Furthermore, the input and output gap for each concave as well as the arrangement of the concaves in the longitudinal direction can be adjusted independently like it is shown in **Figure 5**.

Pre- and main-concave are each supported by two struts and held in longitudinal direction by further struts. A bottom-mounted lever offers the possibility to adjust the concave-parts in three degrees of freedom.

The independent adjustment of the pre- and main-concave and the possibility of influencing the curve characteristic of each concave (widening, parallel and narrowing) represents the basis for a new test rig. So the optimization potential of the concave adjustment can be detected.

Conclusion

The tangential threshing device always was and still is a key component in the modern combine- harvester concept. For today's highly distributed multi-drum-threshing devices there are very few basic studies. Therefore further research with the focus on the adjustment of the concave and the transition zones is required.

For a multi-drum-threshing-device the description of the concave setting with only front and rear concave clearance and the concave radius is not sufficient. So in the literature the course of concave clearance of single-drum-threshing devices was already demonstrated.

The description was limited to the radial part of the concave, not considering the front and rear area. Therefore, the mathematical function of the concave clearance in combination with the detection of the transition zones represents the basis for further investigations of tangential threshing devices.

For an exact setting of the concave in the laboratory, an innovative adjustment mechanism is used, which allows a separate adjustment of pre- and main concave, each with three degrees of freedom. Now it is possible to adjust or influence specifically the concave clearance to continue the investigations of the tangential threshing devices.

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