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The overlaid cut in a disc mower – results from field tests and simulation

Modern rotary mowers are well known in green forage harvesting. These machines are powerful and reliable, but energy consumption is high and cutting quality is restricted. To optimize the process, an overlaid cutting principle was developed and realized as functional prototype. This cutting method is characterized by two vertical arranged mowing discs with several blades. Thus with reduced cutting speeds the energy efficiency and the cutting quality could be improved.

Abstract
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4 references

■ Rotary mowers are widely used and established in green forage harvesting due to their better performance compared to cutter bars. Disc mowers have to work with high energy consumption and losses [1] because cutting speeds of up to 80 m/s are needed to use stiffness and inertia forces of grass stalks as counter forces for the cutting process. Only with this high speed grass is cut even under challenging conditions for example with blunt knife blades. Reducing the cutting speed in order to improve energy efficiency and decrease crop losses would worsen mowing quality and operational safety.

One approach to reduce energy losses is to modify the cutting process. Conventional rotary mowers work without any counter knives. Integrating a second blade level into the process results in an overlaid cutting process, basically a combination of a conventional cut and a shear cut. The overlaid cutting principle was built up as a functional model on a machine and tested on a grass field. In parallel a simulation model based on the Discrete Element Method (DEM) was developed to analyse the cutting process without external influence.

Preliminary considerations and design of the test machine

The overlaid cutting process is realised by additional blades on a second blade level below the conventional knives. Grass stalks are cut either by an upper or lower blade (conventional cut) respectively by both blades at the same time. When rotating in same direction the discs' angular speeds differ in order to generate a relative cutting speed between the two blade levels. The slower blades act as counter blades when the shear cut appears. With counter-rotating discs, the knives absolute cutting speed can be reduced without thereby changing the relative cutting speed.

Two stacked cuttings discs form the "cutting unit" with two blade levels. Rotational speed and direction of rotation can be varied independently from any gear ratio because there is no gear box between the discs.

Figure 1 exemplarily shows four cutting units with different blade configurations. The legend below specifies the

Fig. 1
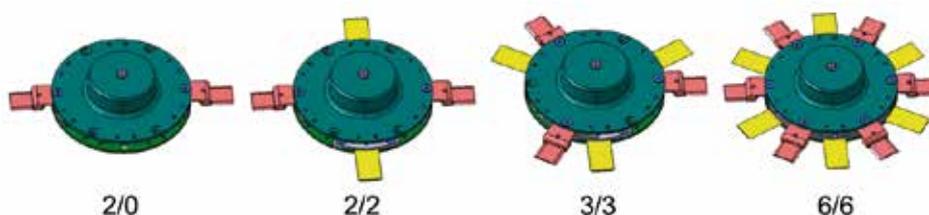
Blade configuration of the cutting units (No. of upper/lower blades)

Fig. 2

Test machine with functional prototype mower (left) and mower bar with cutting units "2/2" (right) (Photos: S. Kemper)

amount of blades on upper (first digit) and lower (second digit) discs. Two, three or six knives can be mounted per disc. The maximum number of knives per disc was restricted to provide enough free space for meshing blades. A pendulum motion around the blades' fixing point is only possible to a limited extent. During the field tests the pendulum motion was blocked to ensure comparability of the measurements. In this cutting unit the conventional cut can be realised by disassembling all lower discs and knife blades. Further information on how the mower bar is designed and driven can be found in [1].

A mobile test rig at the Institute of Mobile Machines and Commercial Vehicles of TU Braunschweig was equipped with a frame structure and a mower bar with three cutting units aligned side by side (**Figure 2)**. This wagon is connected to a tractor and supplied by it with hydraulic and electric energy. The working width of the machine is limited to 1.1 m. The diameters of the discs were reduced compared to usual sizes in order to keep the trajectories of the blades within the working width.

Upper and lower discs are driven by hydraulic motors for maximum flexibility regarding cutting speeds and directions of rotation. Pressure sensors in flow and return line of the hydraulic motors and integrated speed sensors in the hydraulic motors are used to calculate the driving power for a relative comparison of different test configurations.

Furthermore for certain parameter variations the test machine was equipped with video and high speed cameras for visual observation and documentation of the crop flow.

Field tests

The overlaid cutting process was analysed in several test series on an annual ryegrass field. To distinguish the different test configurations the field was divided in several trial areas with an upstream accelerating and downstream decelerating lane. Thus an approximately constant mowing speed of 12 km/h could be achieved.

The test machine offers a wide range of configurations. In order to reduce the large number of test settings to a manageable level the Design-of-Experiments-Method (DOE) was applied.

With this statistical approach the influence of input parameters on the output can be investigated and the number of tests can be limited. By this procedure two test series were derived, each including a defined number of experiments [2].

The task within the first DOE test series was to identify the cutting speeds and amount of blades needed on upper and lower discs for a cutting process with the least power requirement. Therefore co- and counter-rotating discs were investigated and cutting speeds were varied from 20 m/s to 50 m/s. During the test either two, three or six blades were mounted. Measurements showed that installing many knives on the upper discs and few on the lower discs reduces the power requirement. Co-rotating discs require less power compared to counter- rotating discs.

Based on these results a second test series was defined with fixed blades and direction of rotation. All upper discs were equipped with six blades and all lower ones with two. The aim was to examine the influence of the cutting speeds of both blade levels on the required driving power. The lowest cutting speed was halved to 10 m/s compared to the first test series. This is the minimum cutting speed of the test machine.

Additionally to the power measurements all trial areas were evaluated to achieve information about the mowing quality. The mowing quality was defined as a key figure, giving information about the cross section of the test area, cutting surface of the stalks and swath deposit. The cross section of the field was given a higher priority than to the cut surface of the stalks. Following criteria were evaluated:
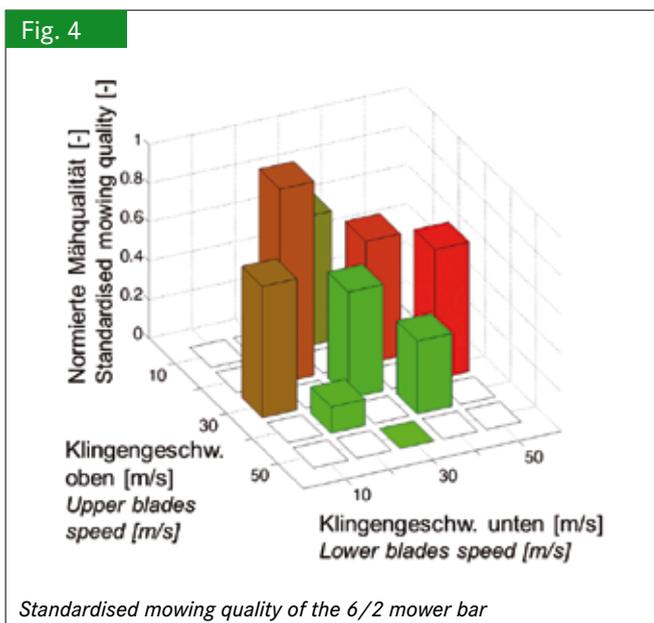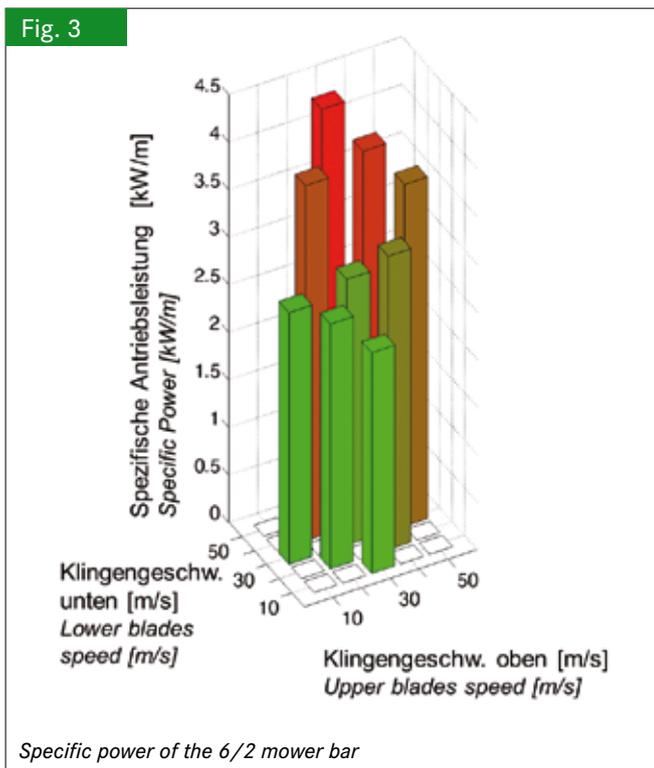
- Length distribution of the cut stalks in direction of travel and crosswise
- Difference in height between leaf and stem
- Cutting area (smooth cut or fraying cut)
- Existence of uncut stalks and
- Form of swath deposit

A planar stubble length distribution was evaluated as positive and a waved one as negative. Also, significantly varying heights between leaf and stem were rated as negative. Depending on the mower configuration and cutting speeds no or more uncut

stalks were found. The swath deposit was rated positively if a swath deposit was visible and negatively if it was spread across the working width. A smooth cutting area was rated better compared to a fraying area. All criteria were evaluated by grades, 1 was best and 5 worst. The evaluations were averaged over all persons and for each trial area and test configuration. These values were standardised to the best value and used as key figures for the mowing quality.

Test results

Figure 3 shows the measurement results for the driving power. The specific power was determined by the sum of the driving power for the upper and lower discs with regard to the working width. Higher cutting speeds increase the power requirement. This applies to the upper and lower discs. As it can be seen, the lower discs have a stronger influence on the driving power than the upper discs. For example the operation point 40 m/s cutting speed for the upper knives and 20 m/s for the lower requires less power as vice versa. The specific power measured for the second test series covers a range of 2.3 to 4.3 kW/m.

In **Figure 4** the standardised mowing quality referred to the best value is shown. High values stand for bad mowing quality. The diagram axis in **Figure 3** and **Figure 4** are transposed. The best mowing quality can be achieved with a cutting speed of 50 m/s for the upper and 30 m/s for the lower blades. In general a higher power input leads to a better mowing quality (**Figure 3**). By considering standardised power in conjunction with mowing quality with an equivalent weighting the best configuration is 40 m/s on upper blades and 20 m/s on lower blades. This operating point is a compromise between mowing quality and power requirement.

The measurements of the specific power cover a range of 2.3 to 7.6 kW/m. For the conventional cut 5.5 kW/m were measured in reference tests with a cutting speed of 75 m/s and only two blades on upper discs. For these tests all lower discs of the test machine were disassembled.

Mowing quality is in a range of 2.1 to 3.4 (1 is best and 5 is worst) for the overlaid cutting process. The conventional mower achieved a value of approximately 2.5. The differences in mowing quality are based on the fact that in case of low cutting speeds some stalks are cut while overrunning the mower bar instead of in front of it.

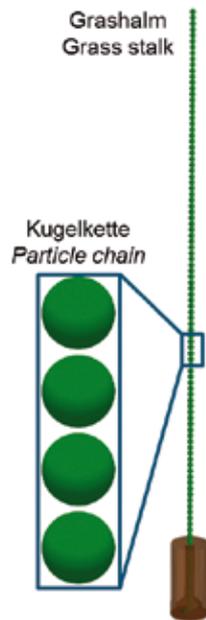## Discrete Element Simulation of the mowing process

Beside the field tests the overlaid cutting process was analysed with the Discrete Element Method (DEM). Simulation models were developed containing the geometries of mowing discs, mower bar and knives as well as grass stalks consisting of several particles. The focus was on analysing the overlaid cutting process for different blade configurations and on the crop flow.

Grass stalks are modelled by single particles aligned side by side with a diameter of 3 mm. These particles are connected by flexible bonds (**Figure 5**). Based on various DEM simulations and parameter variations a realistic behaviour of the stalks and the cuts can be achieved. For a 345 mm stalk approximately 100 particles are needed with respect to particle distances. The parameters for the model are partially derived from the publications of Ahlgrimm and McRandal [3; 4].

Like in the field tests, three cutting units are aligned in the model. In order to limit computing time only a small field part is considered for the crop flow with a mowing speed of 12 km/h. In this study the Software EDEM® from DEM-Solutions Ltd. was used.
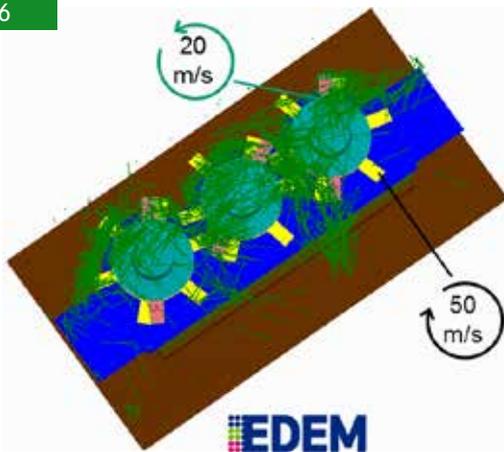
Figure 6 shows a screenshot of the overlaid cutting process including stalks, mower bar and three cutting units. The upper blades (in red) rotate with a slower cutting speed of 20 m/s than

Fig. 3

Specific power of the 6/2 mower bar

Fig. 4

Standardised mowing quality of the 6/2 mower bar

DEM simulation model of a grass stalk

Crop flow simulation of the overlaid cut „2/6"

duced compared to the conventional cut with equal mowing quality. Beside this basic research for a practical application, further research questions have to be answered. Especially with counter-rotating discs there is a higher risk of foreign contacts and blade damages. In addition, the blades' wear and deformation can lead to blade contacts during operation because of the small vertical gap of approximately 2 mm between the knives.

For detailed investigations the mowing concept was modelled with the Discrete Element Method. Grass stalks were formed by a chain of single particles. The model is used to analyse the crop flow over the mower bar for different rotational speeds and blade configurations. Changes in blade, disc and mower bar design as well as in cutting speeds can be simulated and evaluated in a very early development stage before practical use.

References

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the lower blades (in yellow) with 50 m/s. With six knives on the lower discs there are three times more blades than on the upper discs. This operation point is characterized by a strong interference effect on the crop flow. It can be seen that upper discs have a dominating influence on the crop flow. The converging upper discs (**Figure 6**, right) transport the largest share of the crop flow compared with the converging lower discs on the left side. This result was also observed during field tests.

Conclusions

The overlaid cutting process in a disc mower consists of two stacked cutting discs. It was shown that the driving power of the overlaid cutting process with two blade levels can be re-