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DEVELOPMENT OF A WATER CATCHER FOR HIGH PRESSURE WATER JET CUTTING OF AGRICULTURAL GOODS

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ABSTRACT Recently the cutting process of different agricultural goods by a high pressure water jet was examined and optimized at the Institute of Agricultural Machinery and Fluid Power. This technique is an alternative cutting method in agricultural engineering, which is especially suitable for cutting homogeneous goods like sugar beets. A cutting depth of more than 100 mm is easily attainable by pure water blasting. Due to the fact that the high pressure water jet is a permanently regenerating cutting tool a wearless, hygienic cutting process is afforded. Cutting forces can be reduced as well. To transfer this process to mobile working machines it is necessary to carry an amount of water on the machine which is sufficient for the cutting process. This requires space and increases the weight of the machine. In an ongoing project the feasibility of collecting and recycling cutting water is examined in order to reduce the amount of water which has to be carried. The presentation deals with the diffusion of the water jet after the cutting process and with the design of a catcher device. Test results show correlations between the spread angle of the water jet diffusion and the cutting pressure as well as the cutting speed. Further results show the water distribution in the diffusion area. The catcher has to be designed as a compact device, which allows the integration into the lifter unit of a self propelled sugar beet harvester. Simultaneously, the catcher device has to be sized sufficiently to catch most of the process water. A challenge is the material abrasion of the catcher device when hit by the water jet. This effect can be reduced by dissipating the water jet energy into kinetic energy of numerous small obstacles.

Keywords: Water jet cutting, alternative cutting technologies, catcher, sugar beet harvest

INTRODUCTION The purpose of the project supported by the German Research Foundation (Deutsche Forschungsgemeinschaft DFG) is to examine how to collect, process and return the cutting water from high pressure water jet cutting of sugar beets.

The project is divided in two main parts. The first part deals with the development of a catcher unit for the high pressure water jet. In the second part an appropriate water recycling process has to be identified to facilitate the cleaning of the soiled water so it can be returned to the high pressure pump. **Figure 1** shows the scheme of a possible recycling circuit for sugar beet harvest.

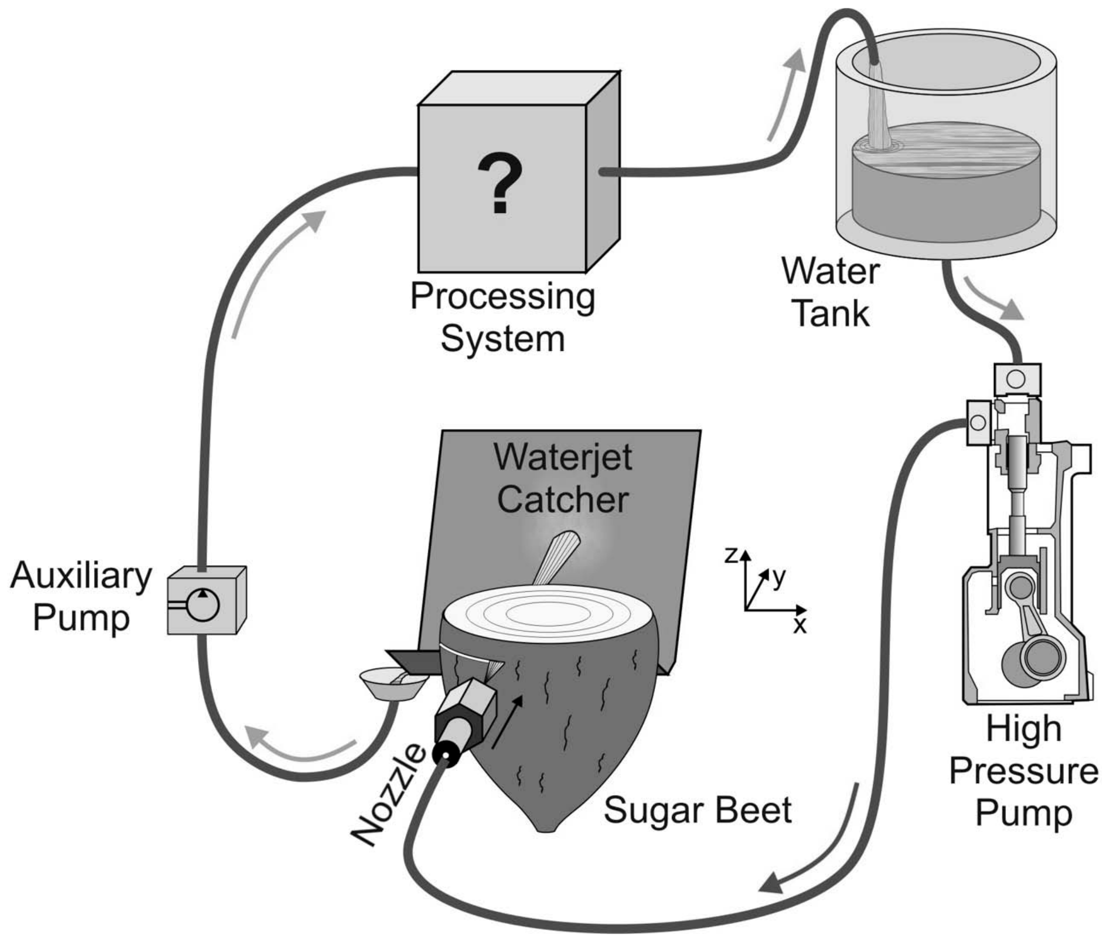

Figure 1. Possible recycling circuit for sugar beet harvest.

In the first step of this project a device to catch the water jet after the cutting of sugar beets is developed.

Against the background of the mobile application of this process on a self propelled sugar beet harvester there are two kinds of problems. The first one is the conflict of aims between a small sized and compact design of the catcher to satisfy the demands in a lifter unit and a design with a big opening cross section to collect a large quantity of water from the expanded water jet after the cutting process. The second problem when developing the catcher is the abrasion of the material hit by the high pressure water jet.

There are two cases for catching water. The first case occurs during the cutting process. Soiled cutting water in a fan shaped diffusion gets to the catcher. The second case occurs while the topping unit covers the distance between the sugar beets. In this case pure water in a compact and undamped jet reaches the catcher.

JET IMPACT **Figure 2** shows the damage of a titanium based alloy (Ti V15 Cr3 Al3 Sn3) at the stagnation point caused by a water jet hitting on the alloy surface in a right angle. This test is done with an untreated (shown in **figure 2a**) and a heat-treated (shown in **figure 2b**) alloy. The chosen values for the cutting pressure and nozzle diameter allow cutting depths in sugar beets between 80 up to more than 110 mm (Ligocki, 2005; Brüser, 2008). The test duration is 30 s and the distance between nozzle and titanium sheet is 150 mm. This is approximately the distance which is corresponding to the necessary distance between nozzle and catcher when topping sugar beets. In **figure 2** it is recognizable that the effect of the water jet is much higher with the parameter combination 150 MPa pressure and 0,6 mm nozzle diameter than with a pressure of 300 MPa and a nozzle diameter of 0,33 mm. The reason is in the higher water hydraulic power of the water jet with the parameter combination 150 MPa pressure and 0,6 mm nozzle diameter.

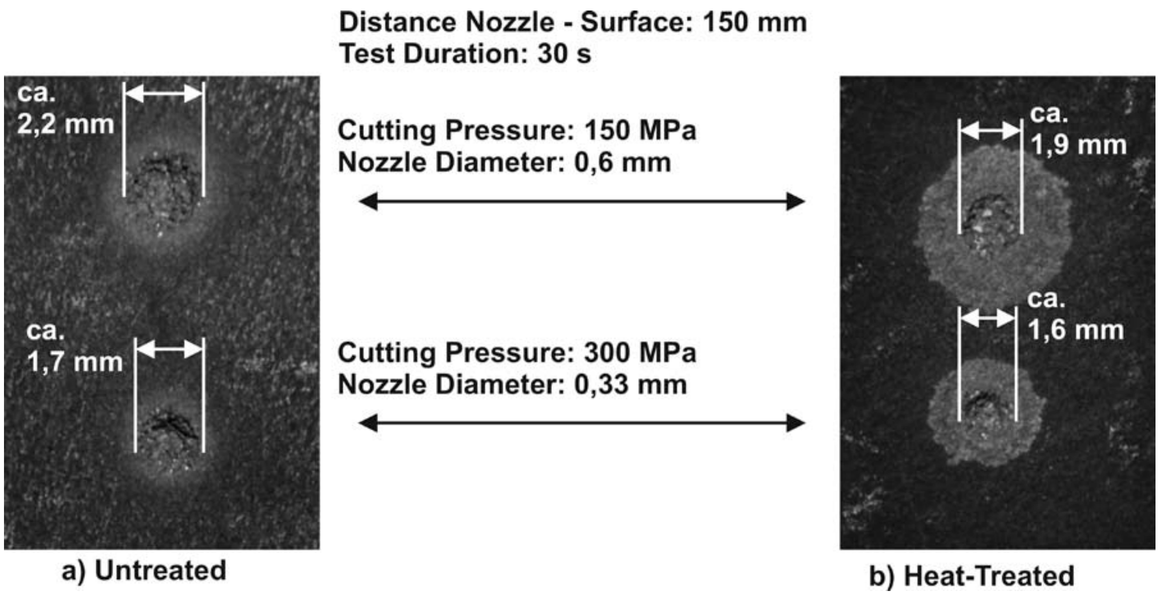

Figure 2. Effect of a high pressure water jet on a titanium based alloy (Ti V15 Cr3 Al3 Sn3).

The heat treatment of the work piece (**figure 2b**) to increase the hardness only leads to marginal advancement of the durability. Titanium sheets with a thickness of 3 mm are used for the test. It takes only a few minutes until they are completely permeated by the water jet. The endurance of conventional sheet steel is clearly shorter. E.g. an aluminium sheet stands only a few seconds.

According to Wulf (1986) a free jet leaving a nozzle can be divided into three zones. In the first zone after the nozzle is a compact water jet followed by the second zone with a drop shaped jet and the third zone with a spraying jet. This classification results from interaction between the water jet and the jet encircling air. The impact point of the water catcher is in the zone of the compact water jet. This compact water jet is surrounded by a cone of nebulisation. The cross sectional areas of compact water jet and surrounding cone of nebulisation exceed with increasing distance from the nozzle.

Because of the high water hydraulic power in the zone of the compact water jet it is necessary to use wear parts or movable objects for the impact point of the water jet. By that it is possible to decrease the effect of the hitting jet by converting jet energy into kinetic energy of objects which can be decelerated by damping elements.

At the moment two alternative solutions are tested. In the first solution brushes are used to decrease the jet energy. The brushes are fixed on one side and can evade the jet with the free end. Simultaneously this movement is retarded by the internal damping of the brushes. Tests show that it is possible to reduce the jet energy but the effect is not sufficient so it is difficult to design a compact device with this solution. Another problems are detached fragments of the synthetic brushes which get into the cutting water.

In the second tested solution the jet hits on hardened steel balls which are bedded moveable in a housing (**figure 3**). The jet moves the steel balls and jet energy is converted to kinetic energy. Slabstock foam in the housing decelerates the steel balls.

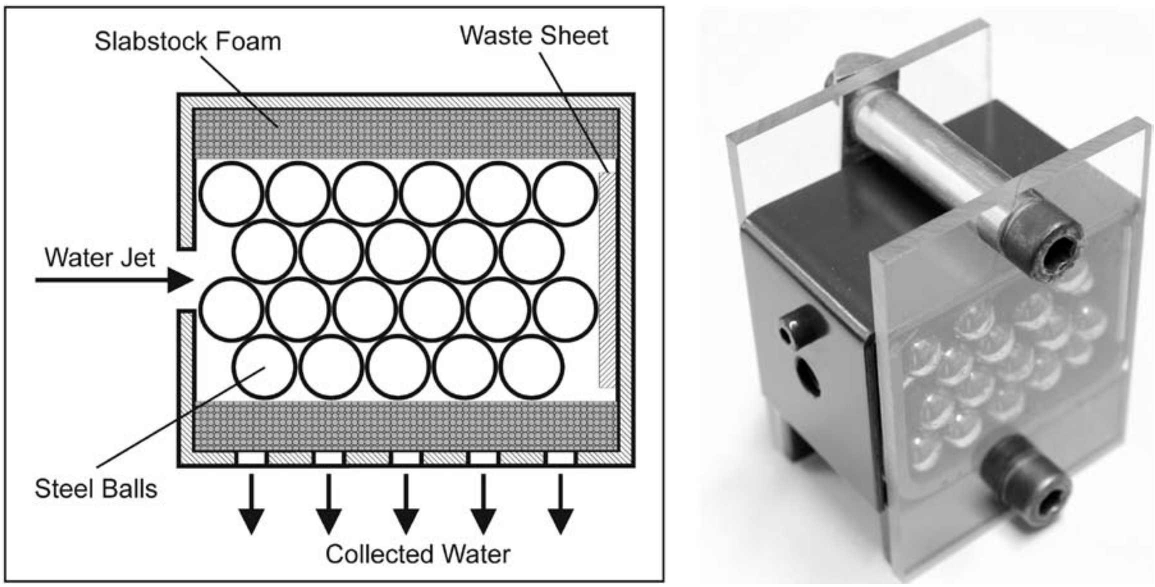

Figure 3. Catcher with movable steel balls to reduce abrasion.

At the back board of the housing a waste sheet is mounted. After a few minutes of test duration with movable steel balls the waste sheet shows heavy damages. On the one hand there is abrasion of the water jet and on the other hand there are deformations through the impact of the steel balls. These effects can be reduced by limiting the mobility of the steel balls. Thus the abrasion of this compact catcher can be reduced on an acceptable level.

JET DIFFUSION Several tests are pursued in order to get information about the diffusion of the water after the cutting process. With this information the required opening cross section of a water catcher can be identified. The diffusion is observed with a high speed camera in horizontal and vertical plane.

In several test runs the parameters pressure, nozzle diameter, cutting speed and cutting depth are varied. In order to make the tests comparable, they are pursued with a defined cutting depth. For this the used sugar beets are sized to widths of 50, 75 and 100 mm. This generates parallel cut sections and constant cutting depths.

Figure 4 shows exemplarily the top view of a cutting process of a sugar beet and the jet diffusion after cutting in a horizontal plane. The sugar beet is fixed while the nozzle moves horizontally with the velocity v_{cut} in direction of the x-axis of the given coordinate system.

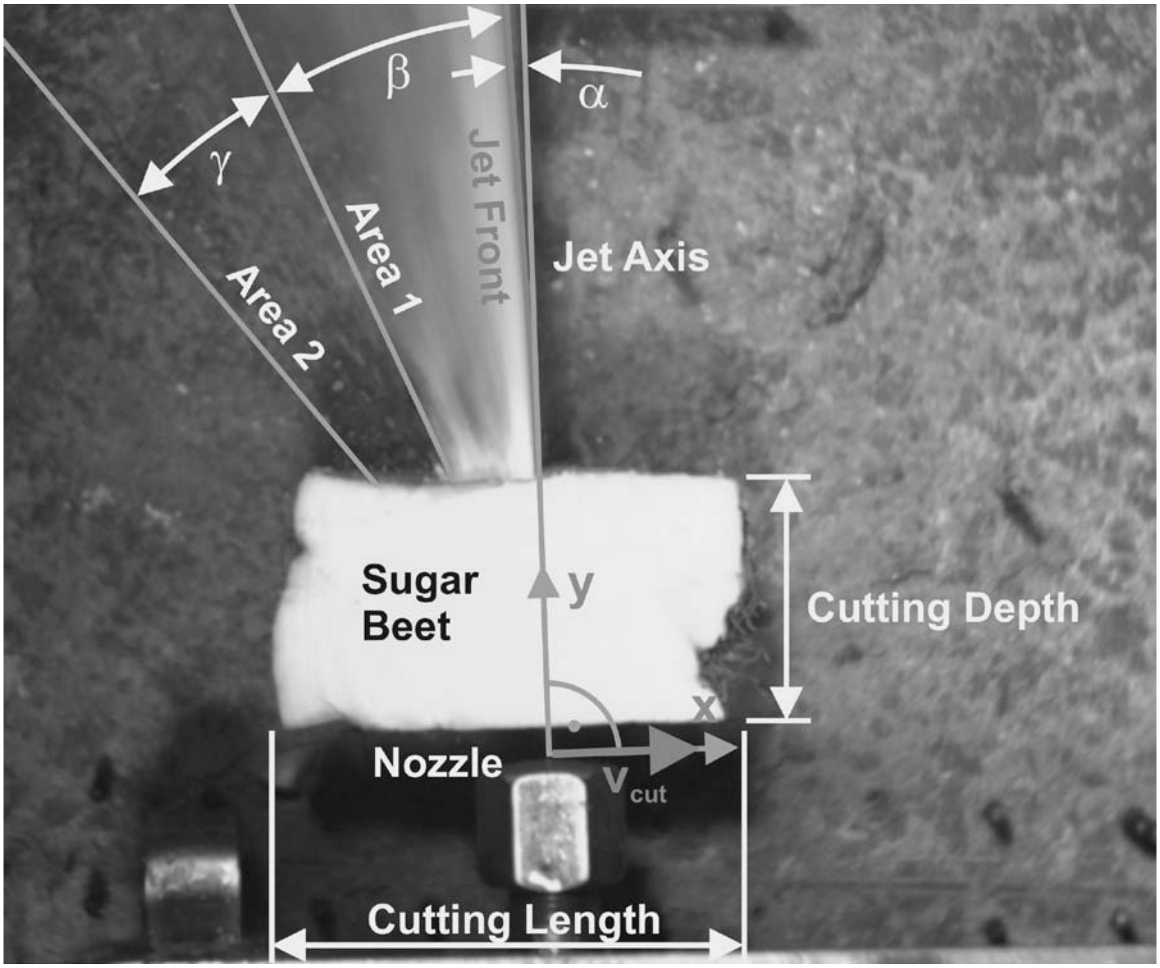

Figure 4. Jet diffusion after the cutting process.

The jet front which is well defined against the surrounding area runs at the angle α to the jet axis. The jet front is inclined from the jet axis away from the moving direction of the nozzle. The cutting water disperses fan shaped behind the beet. This water fan can be divided in two areas including the angles β and γ.

Area 1: The cutting water disperses in straight and continuously water threads, which are surrounded by water fog.

Area 2: The cutting water disperses in drop shaped threads. This threads are interrupted. Multiple drops have the same moving direction.

First test rows show relations between the described angles (α, β, γ) and the varied parameters cutting depth, pressure, nozzle diameter and cutting speed.

Figure 5 shows the relations between the angles of the fan shaped water diffusion and the cutting speed in horizontal plane (**figure 5a**) and vertical plane (**figure 5b**).

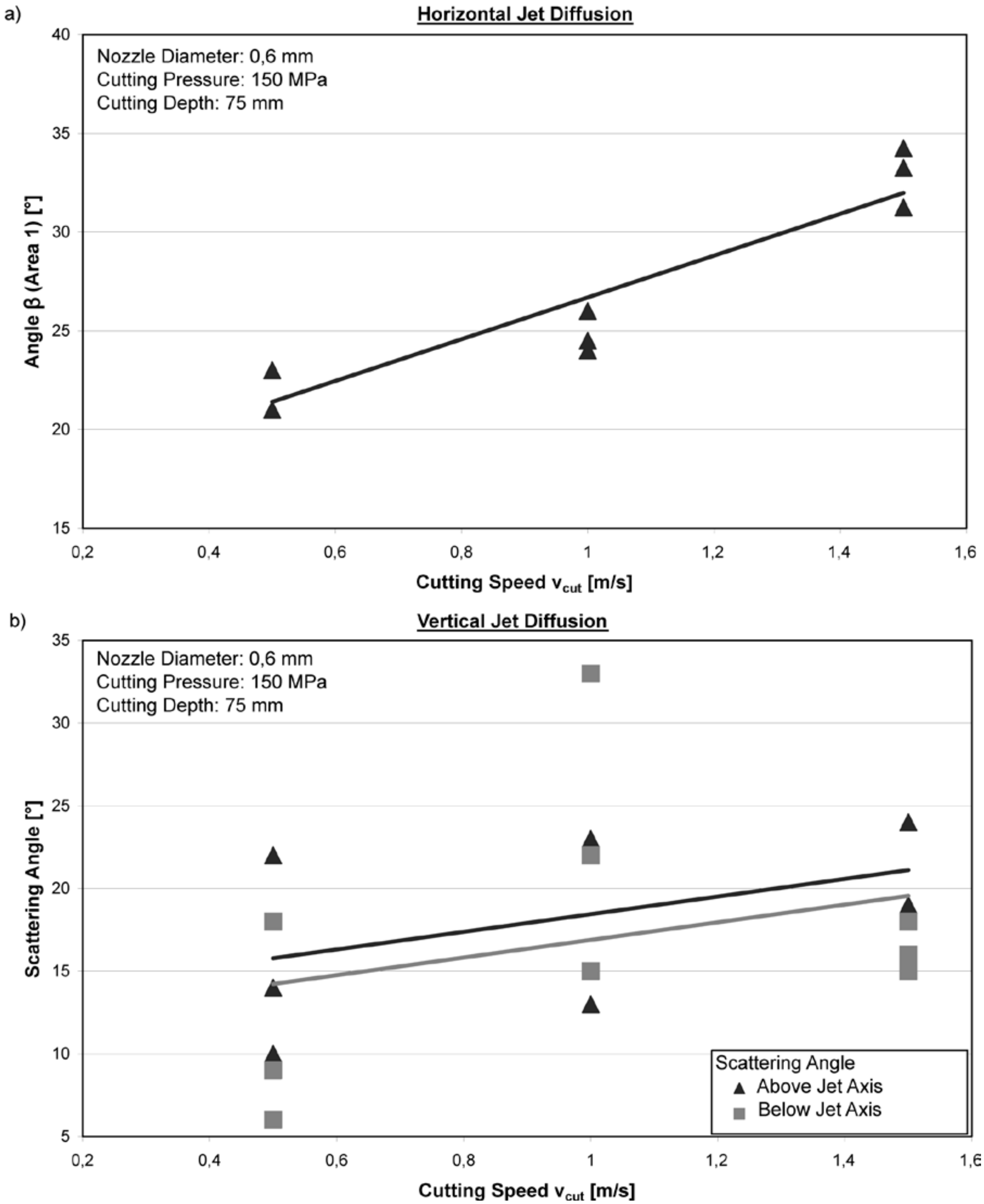

Figure 5. Effect of the variation of pressure and cutting speed on the beam width of area 1.

The results document a relative big mean variation between the test iterations. Nevertheless it is clearly shown for the applied parameter that the spread angle of the fan shaped diffusion increases with higher cutting speed.

WATER DISTRIBUTION In section "Jet Diffusion" the spread angles of the water jet diffusion are examined. Furthermore it is necessary to know something about the quantity and the consistence of the matter which is distributed in the fan shaped water jet after the cutting process. These quantities and water consistencies in defined sections of the jet diffusion are measured with an adjustable partial water catcher shown in **figure 6**. This catcher consists of four bent square hollow sections with an opening cross section of 26 x 26 mm. The wall thickness of these hollow sections is 2 mm. The single catcher devices, consisting of the hollow sections, can be adjusted in vertical and horizontal direction. The adjustable catcher is positioned opposite to the nozzle. The distance between nozzle and opening cross section of the catcher is 150 mm. Both, nozzle and catcher are fixed on the linear axis of the test rig so their relative positions are fixed. During the tests the sugar beets are cut in the 150 mm gap between nozzle and catcher. By adjusting the single catcher devices in horizontal and vertical direction it is possible to scan the jet diffusion in an array with the resolution of 26 x 26 mm and collect defined parts of the jet diffusion. In order to cut sugar beets the linear axis with nozzle and adjustable catcher passes the sugar beet with a defined velocity v_{cut}.

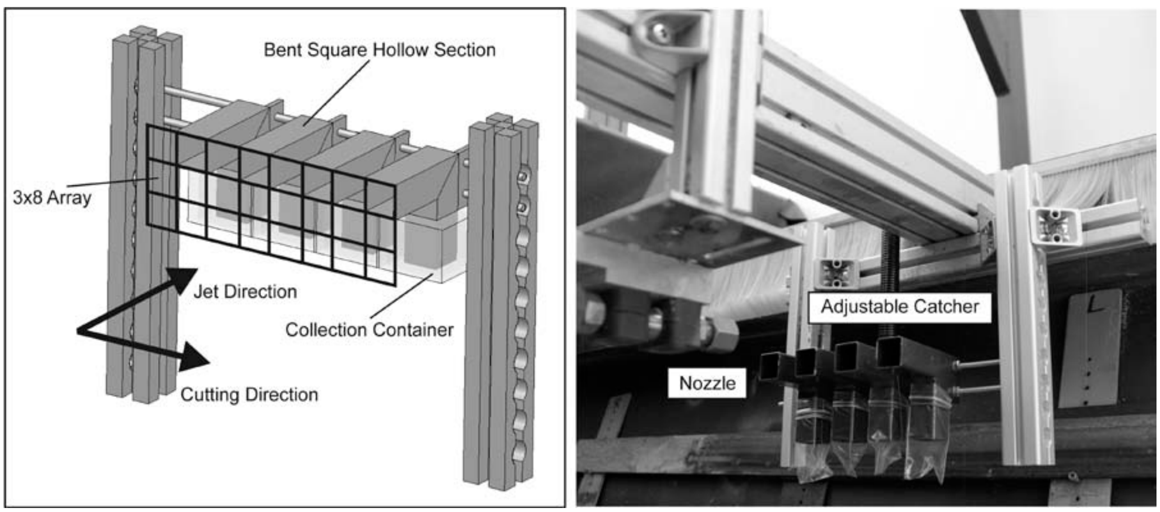

Figure 6. Adjustable partial water catcher.

An array of 3 x 8 fields is scanned with the adjustable catcher in test runs. The area of this array is 78 x 208 mm. For the tests sugar beets are cut several times in a horizontal plane and the quantity of the collected water is related to the cutting length so the unit is g/m. The average value of the maximum cutting depth of each sugar beet depending on the diameter of the beets is 95 mm with a standard deviation of 10 %. Additional deflectors ensure that the adjustable catcher only collects water that is used to cut the sugar beet. **Figure 7** and **figure 8** show the results of these tests. The three-dimensional graph in **figure 7** contains the water distribution in the 3 x 8 array. The arrow in direction of the z-axis corresponds to the high pressure water jet axis. This jet axis is perpendicular to the x-y-plane and points to the 0/0-coordinate in the x-y-plane. The relative position between jet axis and array is retained over all tests. The other arrow corresponds to the cutting direction and the black grid represents the array. The maximum point of the graph is displaced in negative direction of the y-axis contrary to the cutting direction. With the chosen parameters pressure, cutting depth, nozzle diameter and cutting speed shown in **figure 7** nearly all water from the fan shaped water jet after the cutting process can be collected in an area of 78 x 104 mm (**figure 7**). The test also shows that the collected mass is not only pure water.

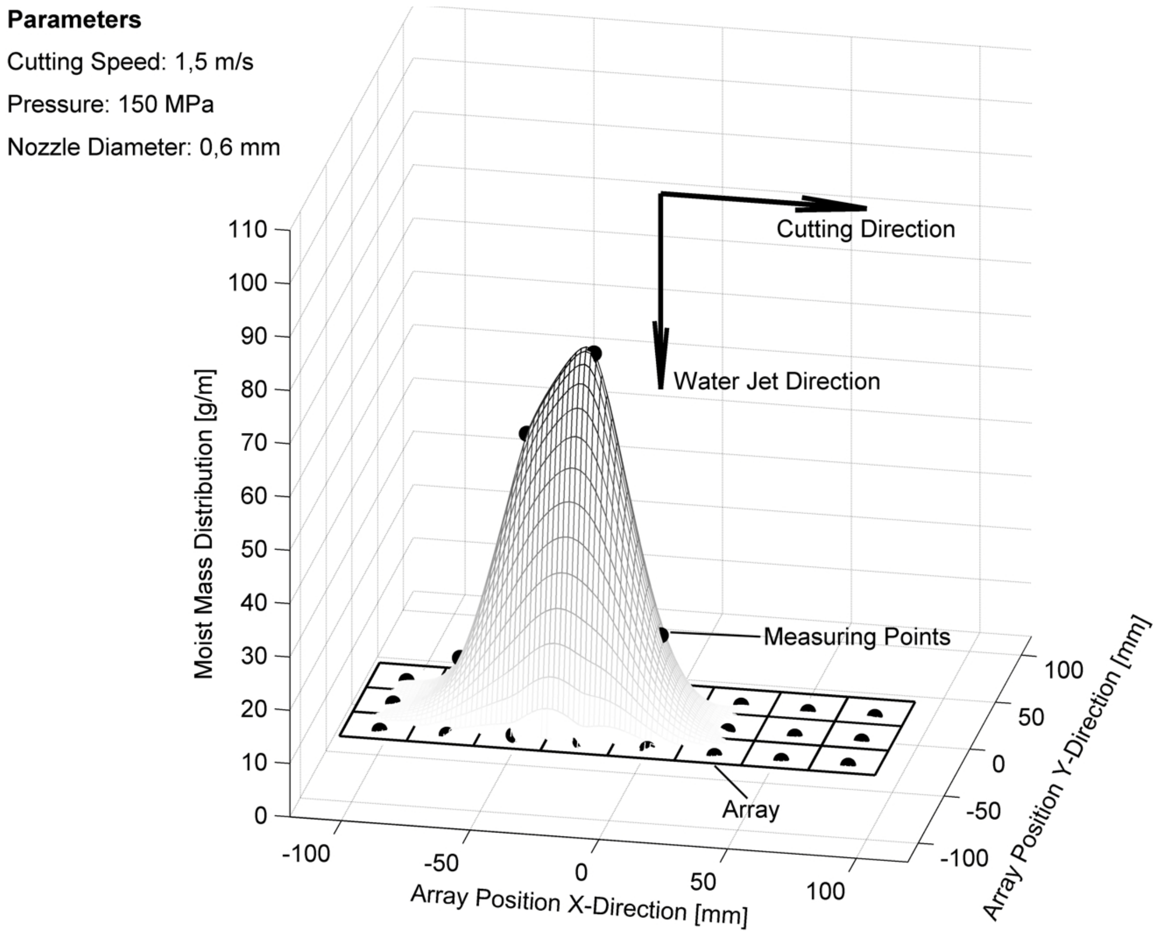

Figure 7. Moist mass distribution in the 3x8 array after topping of sugar beets.

The results of dry matter tests of the collected cutting water related to the array are shown in **figure 8**. The range of dry matter fraction is from 10 up to 55 % with the lowest dry matter fraction in the area between the jet axis and the maximum point of the collected quantity of cutting water. The white coloured fields of the array are not evaluated because the collected quantity is too low. The results confirm pictures of the high speed camera (**figure 4**) and allows to infer that the drop shaped jets in area 2 consist of beet mass.

According to the relations between cutting depth and spread angle of the fan shaped water jet it is likely that the distribution is more compact while the cutting depth decreases. That allows a smaller opening cross section of the catcher.

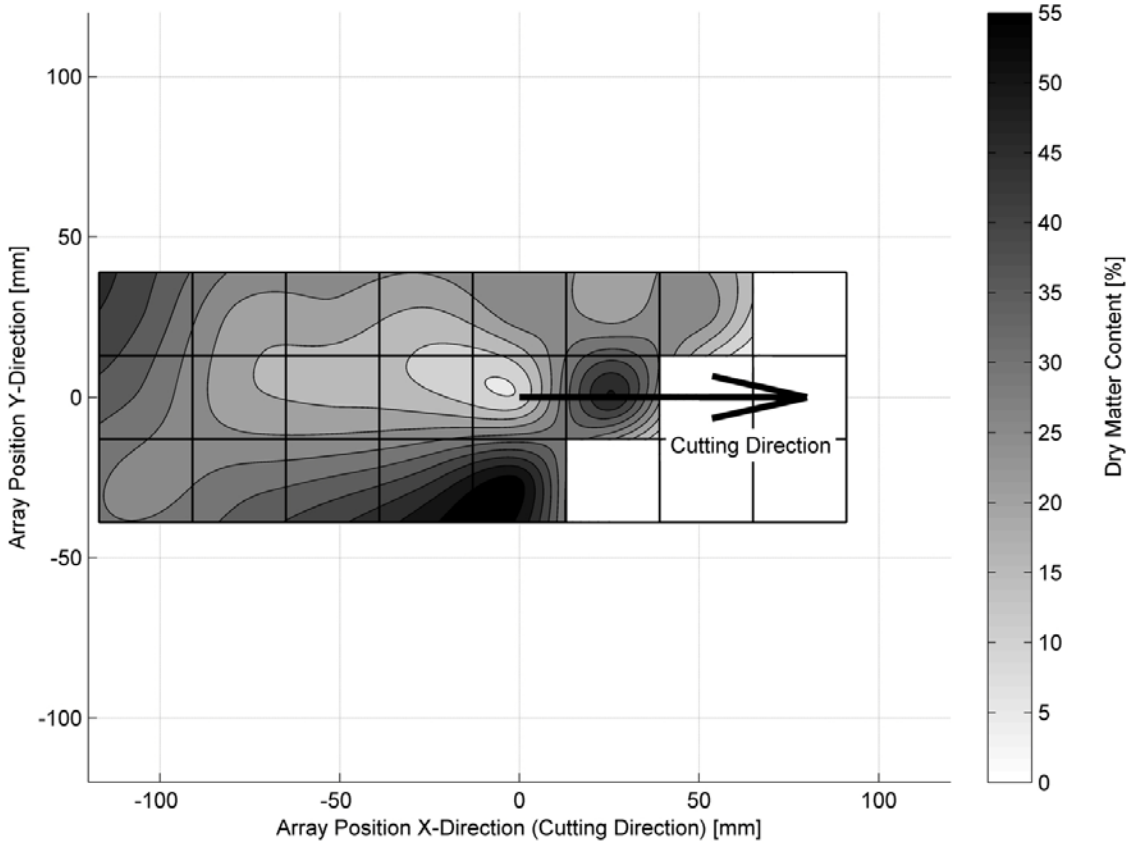

Figure 8. Dry matter content in the 3 x 8 array after topping of sugar beets.

CONCLUSIONS Based on the shown test results a water catcher for high pressure water jet cutting of sugar beets is designed. This catcher satisfies both main tasks: a high duration when hit by the pure water jet and collecting most of the soiled cutting water. Therefore the catcher is equipped with a steel ball box in the area of the impact point of the jet axis. Firstly the catcher has a good duration against the abrasive effect of the undamped and not deflected jet while no beet is cut and the jet hits perpendicular on the catcher. Secondly the catcher is designed very compact as the examination of the water distribution shows that nearly all soiled cutting water is in an area of 78 x 104 mm.

In the next step of the project the designed catcher will be used to collect water for further examinations to identify a possible recycling process for the soiled cutting water.

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