CUTTING-EDGE MECHANISATION

Automation of asparagus harvesting has been a long-time challenge because of the delicate nature of the crop. Cerescon has now developed the first selective harvesting solution for white asparagus, called the Sparter, which both reduces harvesting costs and significantly improves quality. What is characteristic and distinctive in the design is its underground detection of asparagus, using a box of probes that is attached to the machine through a well-thought-out suspension, while the design of the Sparter robot features an ingenious actuation concept.

AD VERMEER AND THÉRÈSE VAN VINKEN

Mechanising selective harvesting

Asparagus cultivation has been under pressure for years, partly due to the lack of manual workers for harvesting. The current manual way of working also has its limitations in terms of the quality of the harvested products. In a harvest round, asparagus spears cannot always be detected by eye, so by the next round they are protruding far above the sand bed. This causes the asparagus heads to fold open and exhibit violet discolouration, both of which result in lower sales value.

For almost all crops where the harvest is done in one go (bulk harvesting), the harvest is mechanised. Examples of these are grain, potatoes and sugar beets. Indeed, the first patent for a combine for the grain harvest dates back to 1831. Some crops, however, have to be repeatedly harvested for each part of the yield, which is called selective harvesting. This affects crops such as apples, mushrooms, strawberries and also asparagus. Still now, all selective harvesting worldwide is done manually, which makes these types of crops very labour intensive and more and more expensive. There is a clear need for the robotisation of selective harvesting.

Advantages

Cerescon has developed a selective harvesting solution for white asparagus, called the Sparter, which both reduces harvesting costs and significantly improves quality. What is characteristic and distinctive, is its underground detection of asparagus, after which the vegetable is removed from the sand bed by a robot.

The Sparter offers asparagus growers the following advantages when compared to traditional hand cutting:

- Better quality asparagus due to a patented underground detection system. This means that the asparagus is harvested before emerging from the soil, thus avoiding violet discolouration and reducing the number of open heads.
- Higher yield through improved quality, because the asparagus harvester restores the sand bed after picking, thus reducing the percentage of (discarded) bent spears caused by inhomogeneous compression of soil.
- Reduction of the harvesting frequency with subsurface detection to once every three days, thus tripling the harvesting capacity per passage compared to a (daily passage) system with detection upon surfacing.

Mode of operation

The machine has been designed as a one-row machine with an internal drive train. It is suspended by caterpillar tracks without additional castor wheels (like an army tank), which facilitates sharp turns. An operator drives the machine in the row with a remote control; see Figure 1, which also shows the handling of the plastic foil covering the asparagus beds. Once positioned in the row, both the steering and the speed control are switched to fully automatic for harvesting. The machine stops when it detects the end of the row. While harvesting, the operator's only tasks are to monitor the process and put the asparagus in crates.

For subsurface detection of the asparagus, on both sides of the machine a slider with a knife cuts into the soil at approx. 80 mm depth (Figure 2). A detection signal is injected into the soil making the asparagus detectable for sensors. The knife needs to reach wet soil, as very dry sand does not conduct the electric signal.

The detection module incorporates a number of probes with sensors that move through the soil at an adjustable depth (Figure 3). When a probe detects an asparagus spear via the sensor, the coordinate is registered and the probe is withdrawn at high speed to prevent the asparagus being damaged. In this way, the probes do not touch the asparagus spears.

AUTHORS' NOTE

Ad Vermeer and Thérèse van Vinken are the co-founders of Cerescon, a high-tech scale-up in agritech, located in Heeze (NL). Cerescon's mission is the development and marketing of advanced mechanised selective harvesting solutions.

ad.vermeer@cerescon.com
www.cerescon.com

Remote control of the Sparter by an operator. The inset shows the handling of the plastic foil. At the row entrance, the operator puts the foil in the machine; then further along the row, the Sparter picks it up and places it back on the bed at its rear.

Detection trigger at close proximity of an asparagus spear to a probe.

The measured coordinates are transmitted to the harvesting robot, which picks the asparagus from the top side of the bed, cutting and lifting it in one swift action (Figure 4). During this picking action, the robot moves synchronously in the opposite direction of the machine. Even during driving accelerations, the cutting knife is stationary relative to the soil while performing its picking action, so the machine does not have to slow down or even stop during harvesting. There are two robot heads to increase the capacity of the machine. While one robot head is picking, the other head is putting a harvested asparagus on an adjacent conveyor belt.

Asparagus that are placed on a conveyor belt are transported to the operator position on the rear platform of the machine (Figure 5). The asparagus are handled deliberately with some sand to avoid damaging the spears. This is a well-known trick in harvesting machines, also used for potatoes and sugar beets. Finally, the sand bed can be homogenised to ensure that the next asparagus spears will grow straight.

Steering and driving

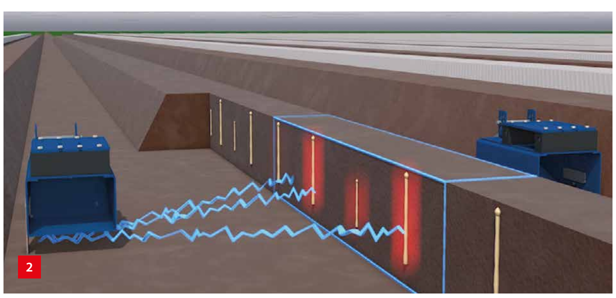
Steering is done by adjusting the speed of both hydraulically driven tracks via proportional valves, based on measurement of the lateral position of the machine in relation to the sand bed. At the front of the machine, two steering wheels follow the side of the sand bed. The movement of the steering wheels is measured with analogue position sensors. The control loop of the steering has been designed to adjust the driving direction only gradually, in order to secure the position accuracy between the asparagus detection and the asparagus picking robot.

The driving speed is also adjusted automatically based upon the number of asparagus detected. The maximum speed is configured at 0.6 m/s, but this speed is not often reached because the robot cycle determines the harvesting capacity. With subsurface detection, sufficient asparagus spears are detected to keep the robots occupied at a moderate driving speed.

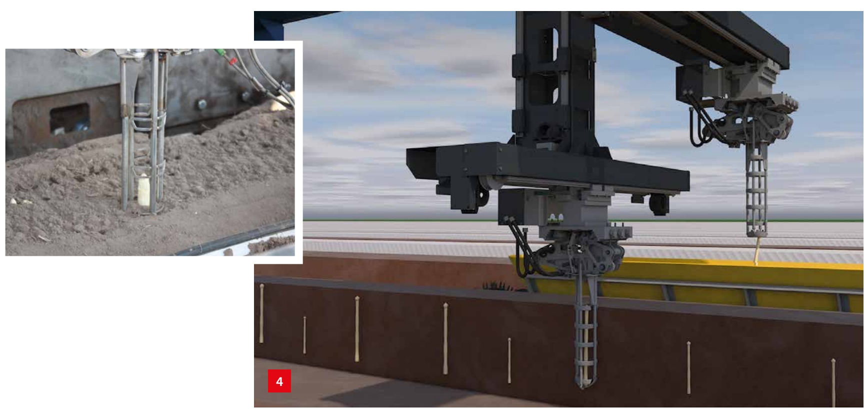
Detection

The detection module contains a number of probes that move through the soil at an adjustable depth (Figure 6). The depth adjustment and the sand bed tracking movement are realised by a control loop with ultrasonic sensors (the little green device at the top in Figure 6) and linear electric actuators.

In the first version of the Sparter, the box with all the probes was suspended using: three pivoting couplings that were to a large extent horizontally oriented in the X-direction, i.e. driving direction; one linear actuator oriented in



Injection of the detection signal into the soil.



Cutting and extracting asparagus spears from the top of the sand bed. The inset shows a live close-up.

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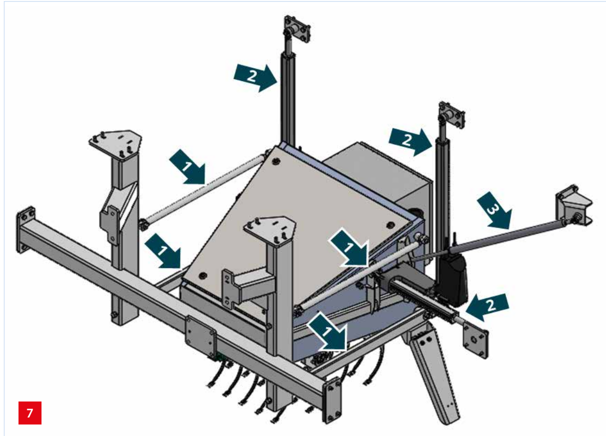
Asparagus transport.



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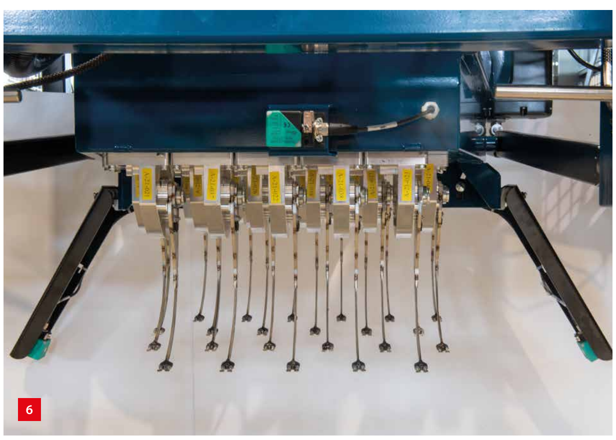
Detection module suspension with 1) coupling rods, 2) linear actuators, and 3) a gas spring.

the transversal Y-direction; and two parallel linear actuators in the vertical Z-direction (Figure 7). The Rx rotation was thus controlled by the synchronous movement of the two Z-actuators, not by a guidance. The suspension of the detection box was perfectly statically constrained, using six rods with ball joints, which worked very well in the sandy environment.

In the next iteration of this design, it was decided to allow torsional compliance of the box and add one more horizontal coupling rod for compensation, analogous to a table having commonly four legs (while an infinitely stiff table requires only three legs for a stable placement). In addition, one gas spring was added to eliminate backlash in all the ball joints, improving the stability of the box in the moving machine.

As the tips of the probes approach an asparagus spear, the signal measured by the probes increases rapidly with decreasing distance. This is based on the fact that the electrical conductivity of the asparagus, which consists almost entirely of water, is much higher than that of the



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Front view of the detection module. This is a prototype version, featuring four rows of five or six probes each. In the final version, the spacing between the detectors in the lateral direction has been increased, to prevent 'concerted' shoving of the soil by adjacent detectors. This resulted in seven rows of three or four probes each.

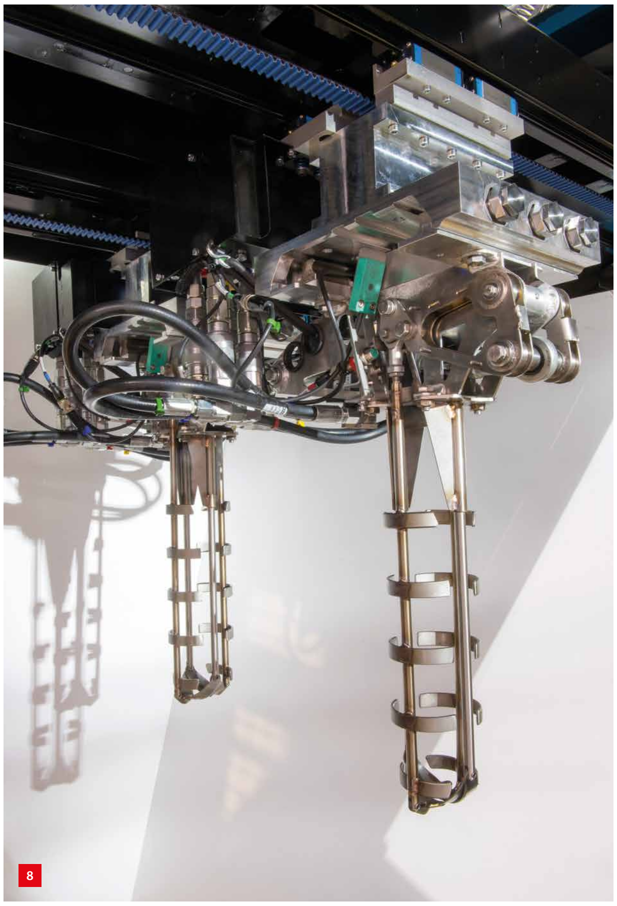
surrounding moist sand. At the same time, the sand must show some conductivity, otherwise there would only be current upon touching the asparagus. Fortunately, really dry soil does not occur in practice, otherwise nothing would grow.

Detection typically occurs at a distance of 3 to 6 mm. The threshold level of detection can be adjusted dynamically based on multiple input data, using an advanced proprietary algorithm that makes the detection process very robust. Almost no asparagus spears are missed and the number of false positives amounts to only a few per cent, so the system works very reliably in practice.

Once the asparagus has been detected, the probe is retracted immediately through backward rotation driven by a servo-controlled motor via transmission gears. The gearbox has been custom designed to fit 23 probes in the box space. The transmission is non-blocking to external forces on the probe, so if it bumps on a mechanical obstruction, the probe is pushed back. This is detected and an automatic reset procedure follows.

Robot

A detected asparagus spear is approached by the cutting robot from the top of the sand bed. The robot then takes out the asparagus in one movement and puts it on an adjacent conveyor belt. The asparagus is transferred on the conveyor belt by a Y-movement. The robot has two cutting heads (Figure 8), each one equipped with a combined Y/Z-drive. This configuration turned out to be well balanced, as cutting (Z down, hydraulically driven cutting action, Z up, and then moving to the next cutting position of the other knife) takes about the same amount of time as the Y movements to the conveyor and back. For this reason, it was decided to place both robot heads with their own Y/Z degrees of freedom on one common X-slider. The knife that is cutting determines the X-position, the offloading can be done at any X-position.



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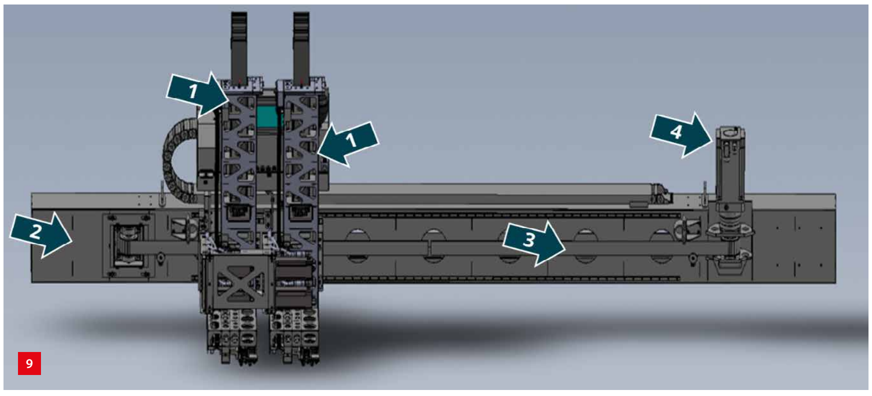
The two cutting knives.

The cycle time per asparagus is approximately 1 s. The length of the X-axis was designed to be long enough to cover clusters of up to four asparagus at close X-coordinates without the need to slow down. This reduces drive speed fluctuations and helps to keep the robot heads busy.

The Y-Z drive design of the cutting heads is based on one timing belt driven by two servo motors (Figures 9 and 10), which is a very suitable solution in this machine for several reasons. The crux of the actuation concept is that both Y/Z-motors do not move in either the Y- or Z-direction, which limits the moving mass. The Z-movement requires a high force of 300 to 900 N for penetrating the cutting knife into the soil. On top of that, high accelerations are needed, up to 20 m/s^2. Both servomotors contribute evenly to the Z-force. The Y-movement can only start after the upward Z-movement has (almost) finished, so again both servomotors work together, in this step to reach high accelerations up to 30 m/s^2.



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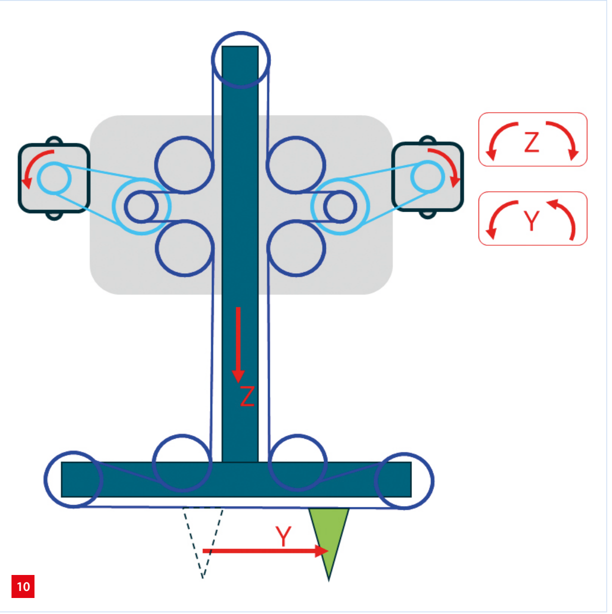
Robot with 1) Y/Z-modules, 2) X-beam, 3) X-timing belt, and 4) X-motor.



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Drive train of the Y/Z-module. Y- and Z-movement are achieved by both motors turning in the same direction or in opposite directions, respectively.

Linear guides

A specific challenge in the design was posed by the linear guides. The ones used typically in high-tech machines with recirculating balls are not the best choice. If sand penetrates the guidance carts, it limits the lifetime. That is why Cerescon selected roller guides for the X-movement. The roller bearings can be effectively sealed, while the rails and the outer surface of the rollers can still be affected. To prevent this, wipers are installed. If wear occurs on these surfaces, the system can still be used until the end of the season, so that maintenance can be planned later. The results over the coming years will indicate how serious the remaining problem is.

Asparagus transport

The cut asparagus is placed on a conveyor belt and transported to a collection bin (Figure 5). Due to the conveyor belt movement, almost all asparagus fall in the same direction, with the cut in the direction of transport. This is desirable in order to prevent as much damage as possible to the sensitive heads of the asparagus during further handling. At the end of the conveyor belt is a sand-asparagus separation function, which returns the sand to the sand bed. In this way, the sand bed is better maintained throughout the season than with manual harvesting.

Introduced by Cerescon; the first selective mechanised harvesting system in history that has made it to the market.

Conclusion

Cerescon has introduced the first selective mechanised harvesting system in history that has made it to the market (Figure 11). Many other selective machines for different types of crops will follow, as there are many projects in the research phase awaiting market introduction. This is a great opportunity for the Netherlands as a country strong in both agritechnology and mechatronics.

The user advantage of subsurface detection

The total capacity of the Sparter measured in hectares of asparagus field is determined by the capacity per day multiplied by the number of days between two consecutive harvesting cycles. An important advantage of subsurface detection is that many more asparagus spears are harvested per meter per cycle.

Some figures can illustrate this effect. A normally skilled manual worker can detect asparagus just before they surface, typically as of –1 cm with respect to the top of the sand bed, because the worker can recognise small features like sand cracks and bulbs caused by the asparagus heads. To maintain their quality, asparagus heads should not be allowed to grow higher than +3 cm above the surface. So, the range that can be harvested is 4 cm. This is, on average, close to the asparagus growth rate per day. The Sparter detects asparagus at maximum –10 cm, so the range for the Sparter is 13 cm, over three times more than with the manual process.

The average harvesting frequency that users will choose with the Sparter is therefore expected to be three days. Compared to a machine that uses optical detection, the harvesting frequency advantage is even greater, as optical detection only works once the asparagus heads are really visible.