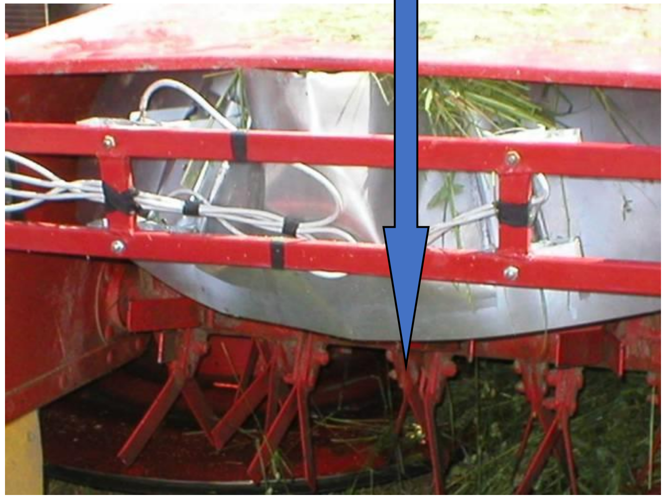
6. LESSON

CAPACITIVE YIELD SENSORS

In previous presentations it was stated that none of the system for forage crops yield mapping is used in practice today. There are several reasons:

- forage crops are very inhomogeneous and therefore complicated in terms of throughput measurement,
- technical solutions are not universal enough (some systems can only be implemented to machines with a belt conveyer row compiler),
- most of these methods are based on contact principles,
- the price of measuring systems is still high compared to the price of the machine.

Unfortunately, we were faced with some disadvantages of contact measurement methods.



The cobblestones were hidden in the harvested grass. It completely destroyed the measuring sensors. Non-contact way of the measurement is advantageous.

And, also from a previous presentations, there is no commercially available system for measuring the yield of root crops on the market. Reasons for it:

- root crops are grown on relatively uniform and flat fields,
- first generation of sensors was implemented into the technological process of existing machines (many compromises had to be made - negatively affected both the accuracy and functionality),
- accuracy of the sensors, especially in often difficult harvesting conditions, should be improved and stabilized,
- the functionality of the sensors must be simplified, especially calibration.

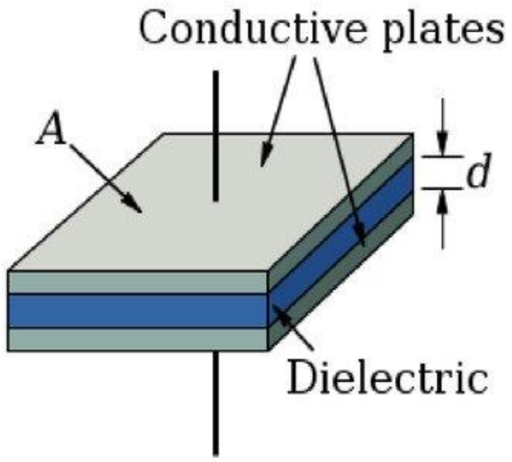
Possible solution: using of capacitive throughput sensor

Advantages of capacitive sensor:

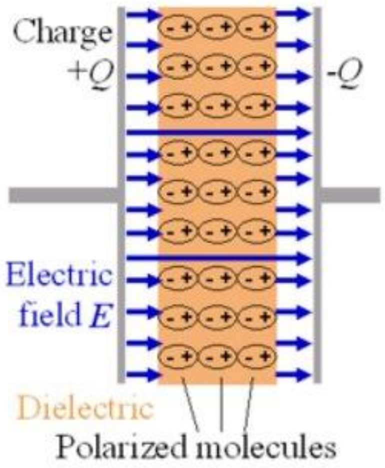
- relative simplicity suitable for often complicated operating conditions of agricultural machines,
- minimal impedance to the flow material,
- non-contact way of measurement,
- low cost.

Capacitance sensor techniques can be used for the determining different properties (moisture content etc.) of a range of plant materials.

The function of capacitance sensors depends on the fact that the dielectric constant of an air/material mixture between two parallel plates increases with material volume concentration increasing.



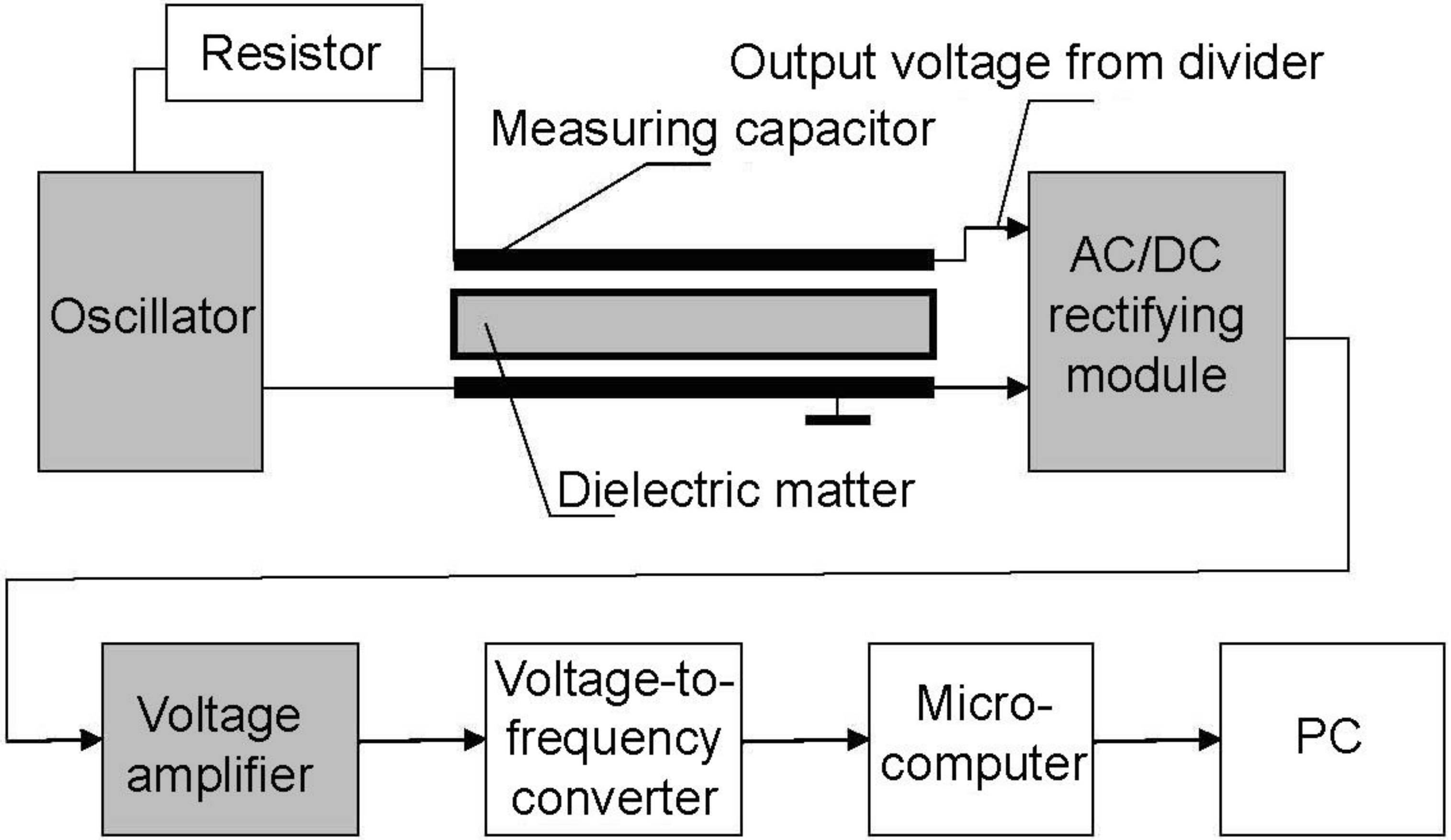
(a)



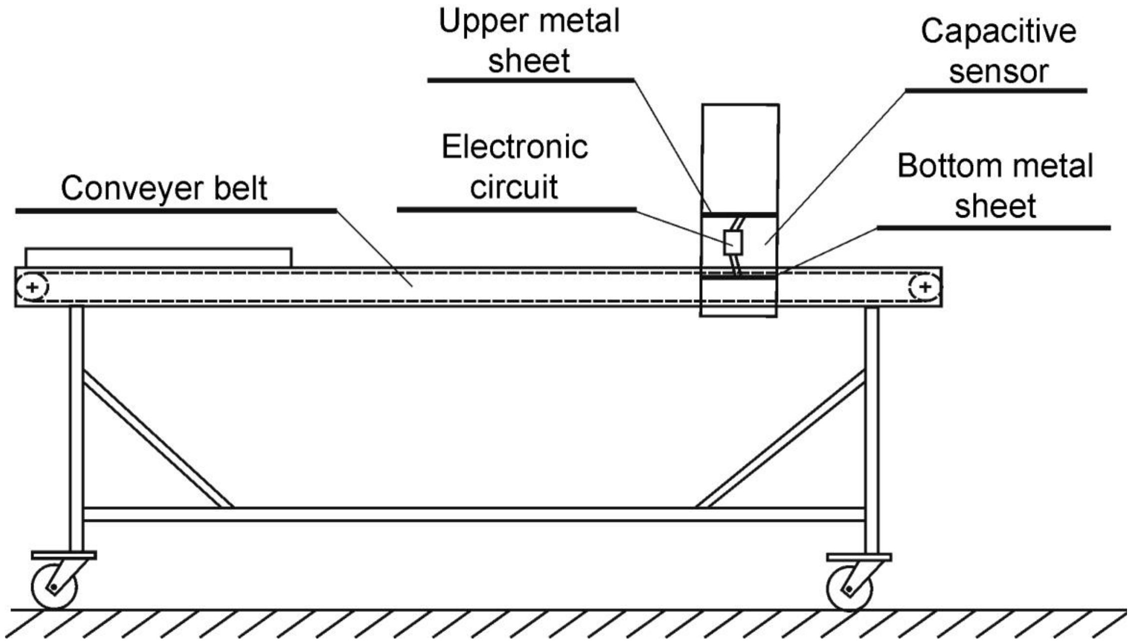
(b)

Parallel plate capacitance sensor:

- two metal sheets 2 mm thick (830 x 260 mm)
- 180 mm distance
- sides - 10 mm thick acrylic glass
- sensor was driven at 27 MHz frequency.

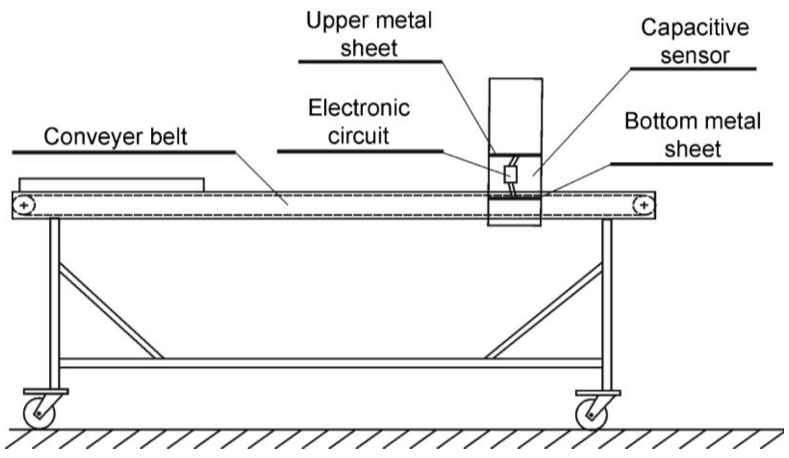


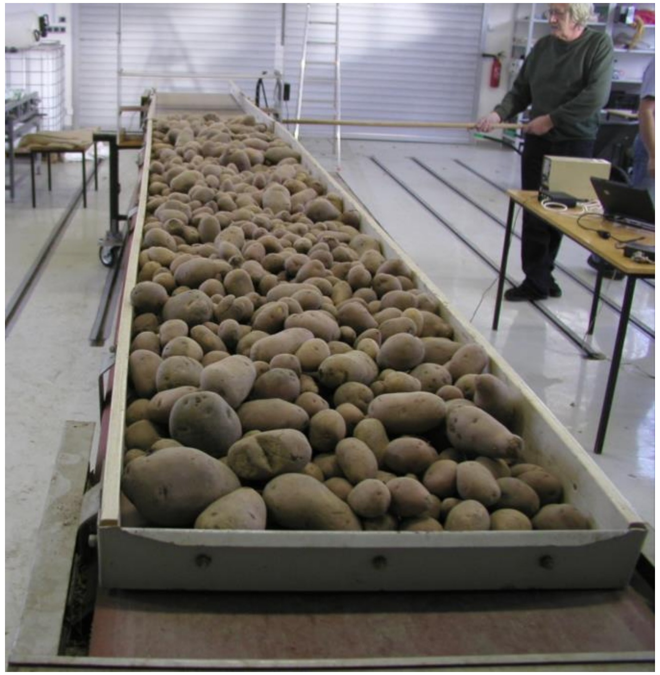
Block diagram of electronic apparatus arrangement for material feed rate measurement.



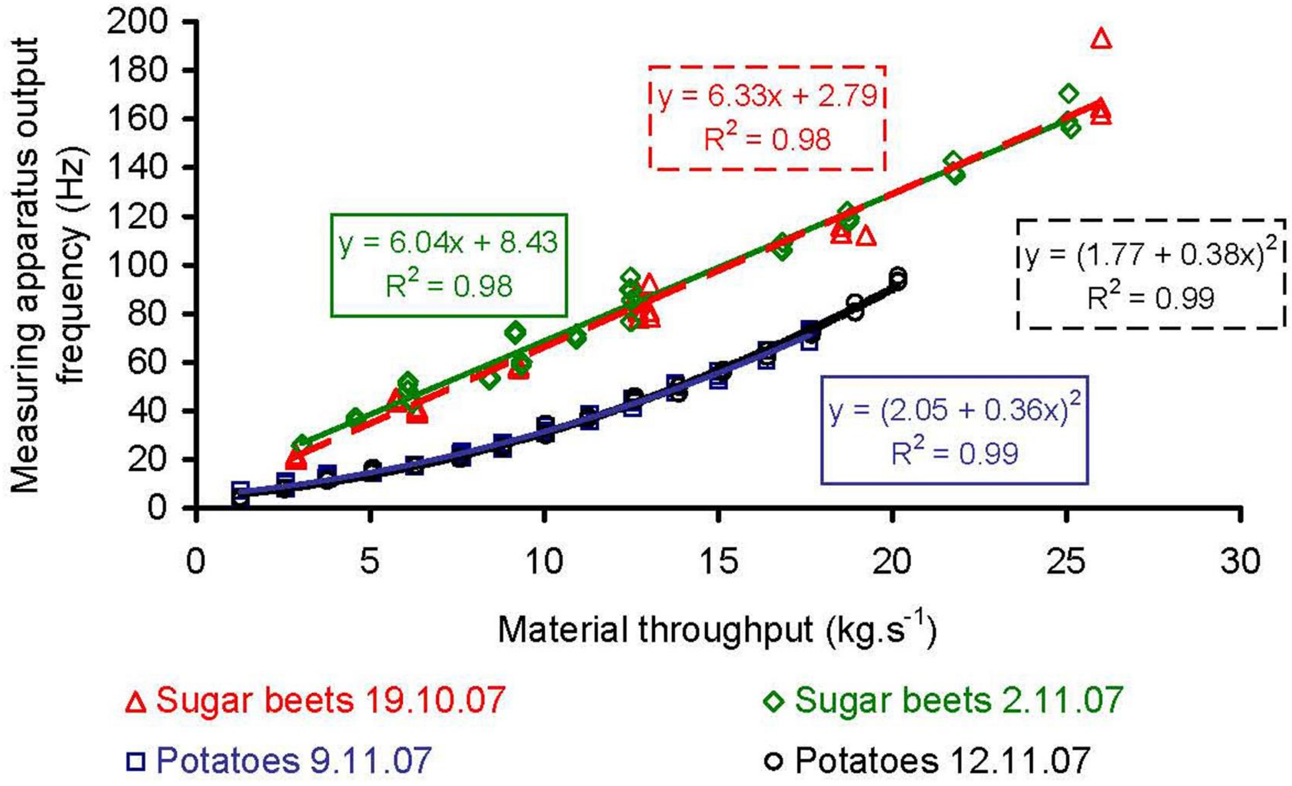
Arrangement of measurement device for laboratory tests after improvement. Measurements with forage crops. Capacitor plates distance 300 mm.

Experiments with sugar beet and potatoes





Arrangement of measurement device for laboratory tests after improvement was used. Capacitor plates distance 180 mm.



Dependence of measuring apparatus output frequency (proportional to voltage and sensor capacity) on sugar beets and potatoes throughput.

Sugar beets

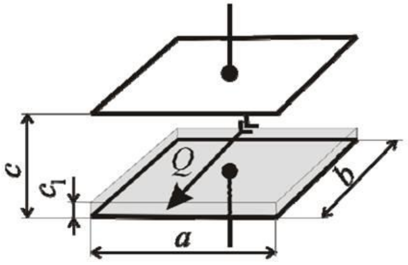
- Measured output frequency depended linearly on throughput
- Coefficients of determination - R^2 = 0.98 in both cases
- Repeatability of the measurements was very good

Potatoes

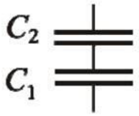
- Surprisingly, measured output frequency of the same measuring device on potatoes depended nonlinearly and for the comparable throughputs smaller frequency values were measured
- Obtained dependence was power function $y=(a+bx)^2$
- Coefficients of determination - $R^2=0.99$
- Repeatability of the measurements was also very good

Theory of capacitive throughput sensor

(Kumhála et al., 2009)



(a)



(b)

(c)

Layer filling (LF)

$$C_1 = \frac{\varepsilon_0\, \varepsilon_r\, a\, b}{c_1} \qquad C_2 = \frac{\varepsilon_0\, \varepsilon_{r(air)}\, a\, b}{c - c_1}$$

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} \Rightarrow C = \frac{C_1\, C_2}{C_1 + C_2}$$

$$Q = c_1\, a\, v\, \rho$$

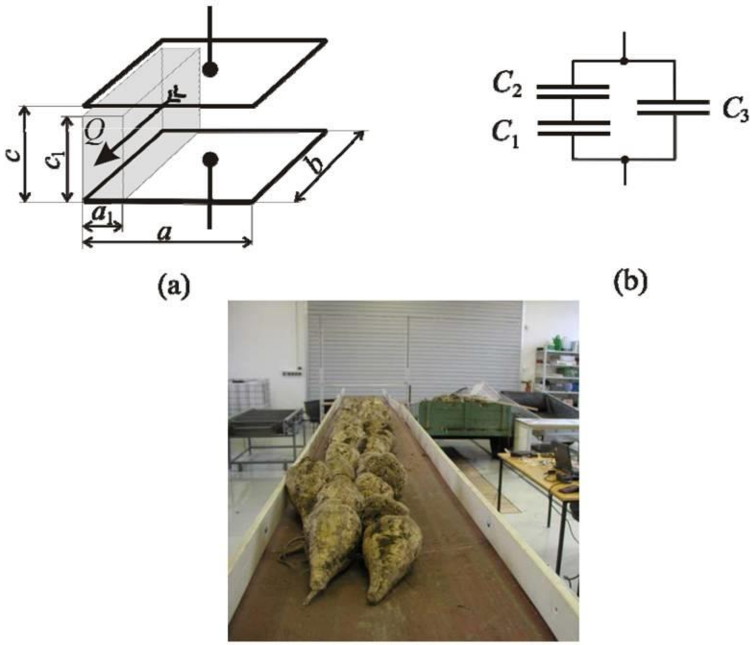
Resultant capacity:

$$C = \frac{\varepsilon_0\, \varepsilon_{r(air)}\, \varepsilon_r\, a^2\, b\, v\, \rho}{Q(\varepsilon_{r(air)} - \varepsilon_r) + \varepsilon_r\, a\, b\, c\, v\, \rho} = \frac{A_1}{B_1 + D_1 Q}$$

Shifted hyperbola

Theory of capacitive throughput sensor

(Kumhála et al., 2009)



(a) (b) (c)

Filling by simple particles (FSP)

$$C_1 = \frac{\varepsilon_0\, \varepsilon_r\, a_1\, b}{c_1} \qquad C_3 = \frac{\varepsilon_0\, \varepsilon_{r(air)}\, (a - a_1)\, b}{c}$$

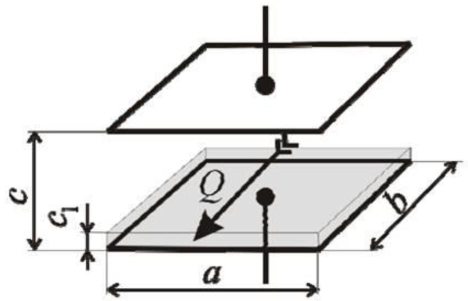
$$C_2 = \frac{\varepsilon_0\, \varepsilon_{r(air)}\, a_1\, b}{c - c_1}$$

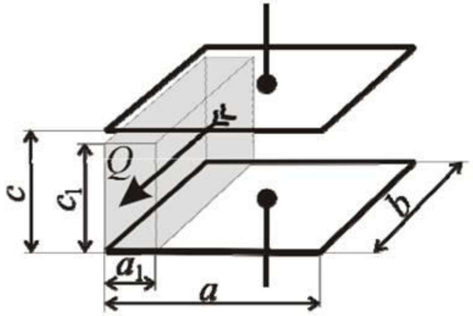
$$C = \frac{C_1\, C_2}{C_1 + C_2} + C_3 \qquad Q = c_1\, a_1\, v\, \rho$$

Resultant capacity:

$$C = \frac{\varepsilon_0\, \varepsilon_{r(air)}\, a\, b}{c} + \frac{Q\, \varepsilon_0\, b\, (\varepsilon_r - \varepsilon_{r(air)})}{c\, v\, \rho\, (\varepsilon_r\, c - \varepsilon_r\, c_1 + \varepsilon_{r(air)}\, c_1)} = A_2 + B_2\, Q$$

Linear dependence





In this case resulting capacity is mainly involved by the capacitor with smaller capacity:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} \Rightarrow C = \frac{C_1 C_2}{C_1 + C_2}$$

Example:

air water

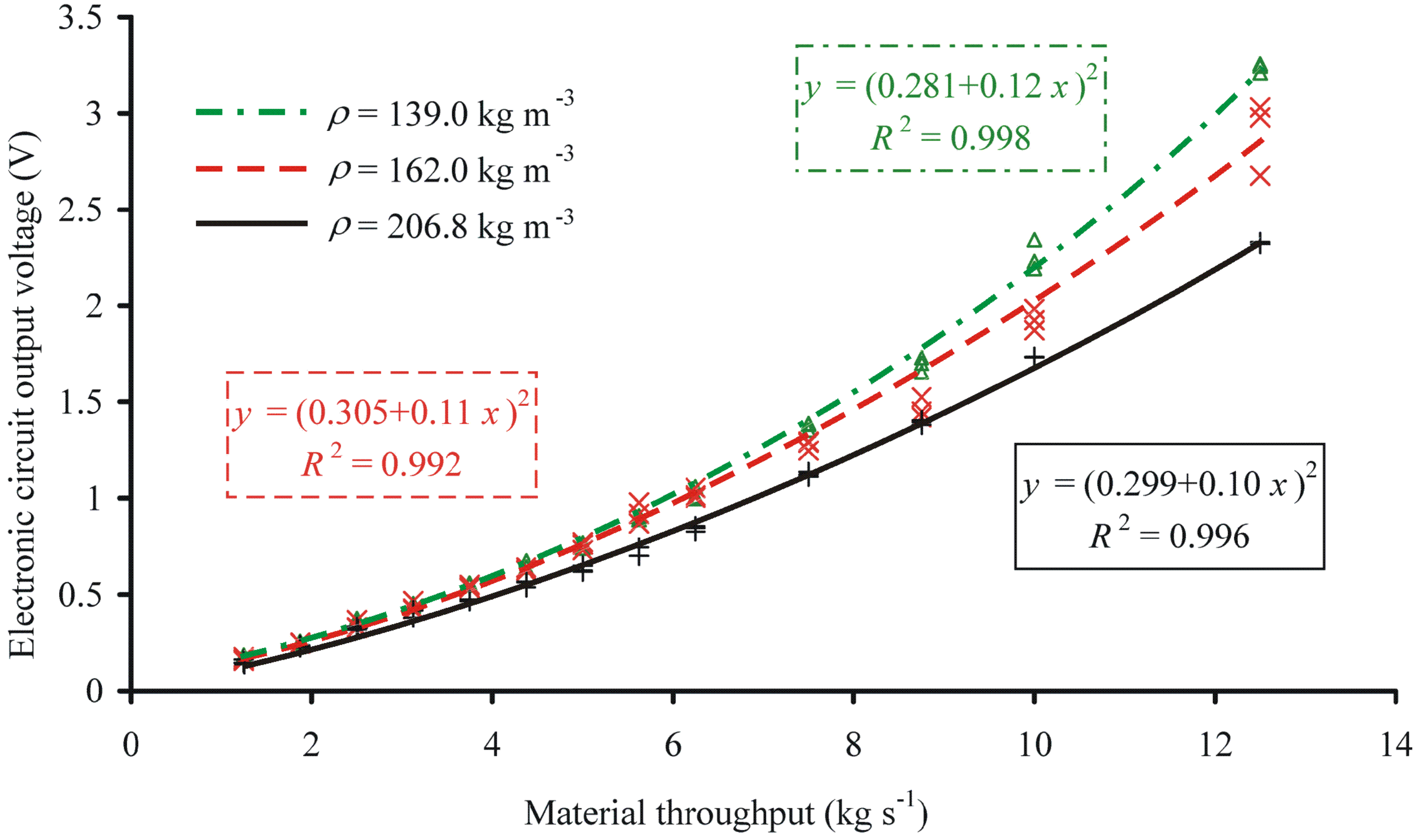
$C_1 = 1$ $C_2 = 80$

$$C = \frac{1 \cdot 80}{1 + 80} = \frac{80}{81} = 0.98$$

Capacitive throughput sensor is surprisingly not extremely sensitive to measured material moisture content changes.

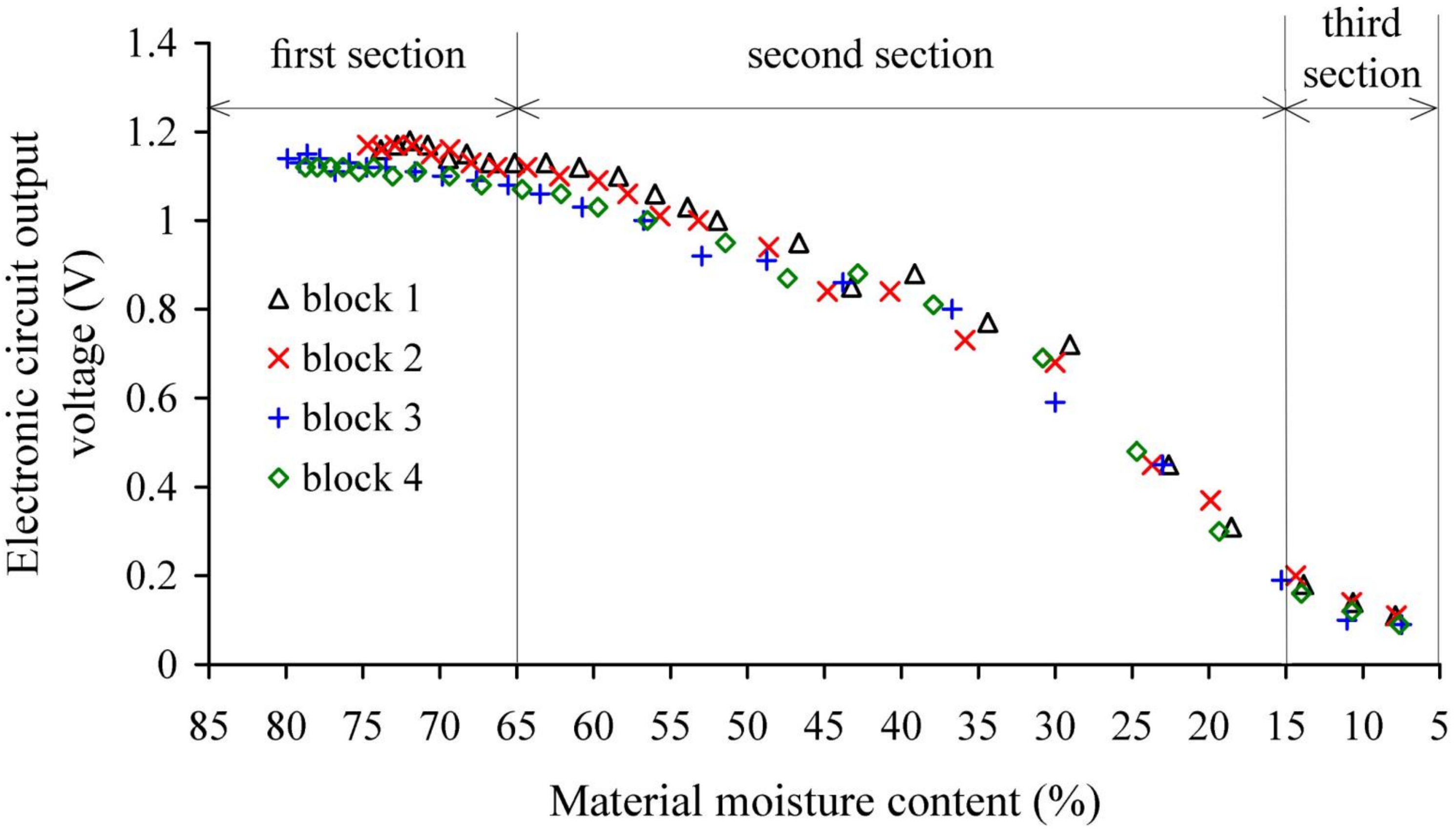
- Throughput measurement of sugar beet and potatoes by capacitance method is promising way.
- The relationship of particle size and the distance between capacitor plates it is necessary to take into account.
- The way of capacitive sensor filling is also very important.
- All these influences can be minimized by sensor design and its calibration.
- Measurement device worked satisfactorily – repeatability of the measurements was very good. It is possible to measure relatively small changes of capacities (from 0 to 50 pF) with adequate precision.

Capacitive throughput sensor was tested also with freshly shopped maize.



Dependence of measured capacitive sensor output voltage on chopped maize throughput. Chopped maize moisture content (wet basis) was 61.5% for material with 206.8 kg.m^{-3} volume density, 52.7% for material with 162 kg.m^{-3} volume density and 46.7% for material with 139.7 kg.m^{-3} volume density.

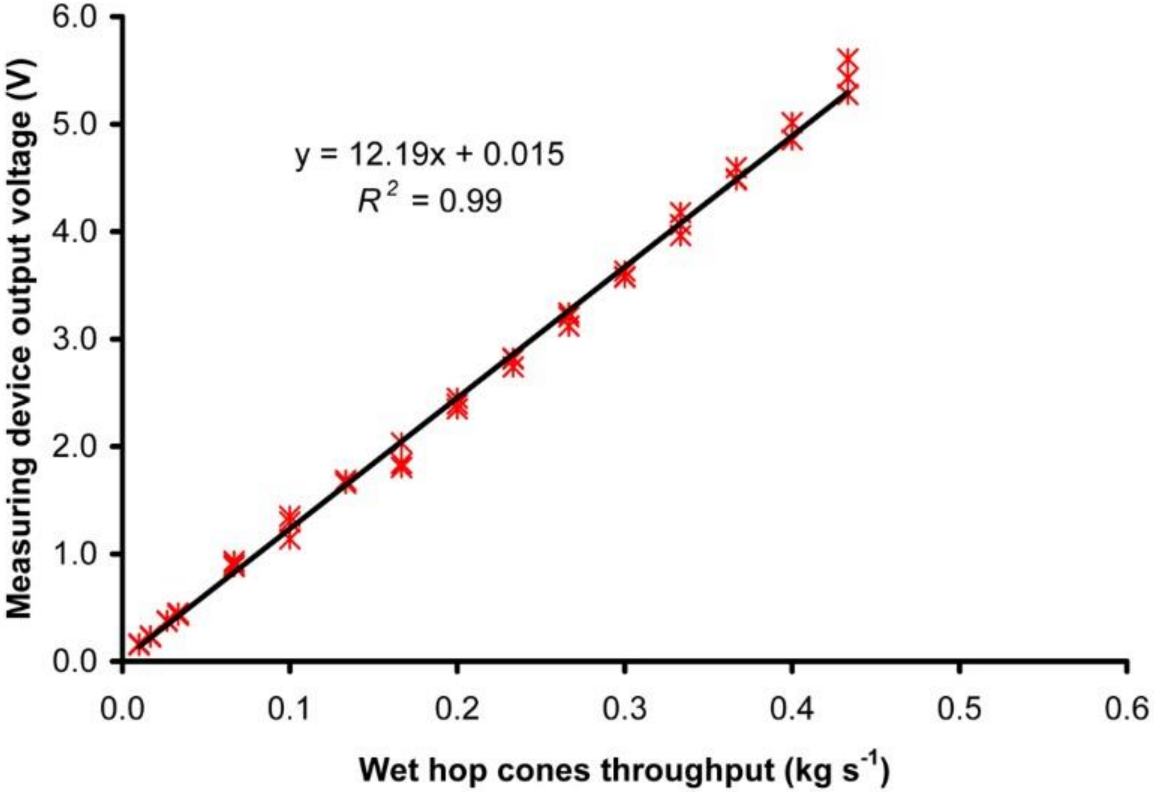
- Dependence was nonlinear. Good agreement with previous findings.
- For lower material volume densities were measured higher output voltage values
- For higher material volume densities were measured lower output voltage values.



Dependence of measured capacitive sensor output voltage on balsa blocks moisture content (wet basis) changes. Dry matter content of 1st balsa block was 4.79 g, of 2nd balsa block 4.83 g, of 3rd 3.71 g and of 4th balsa block 3.75 g.

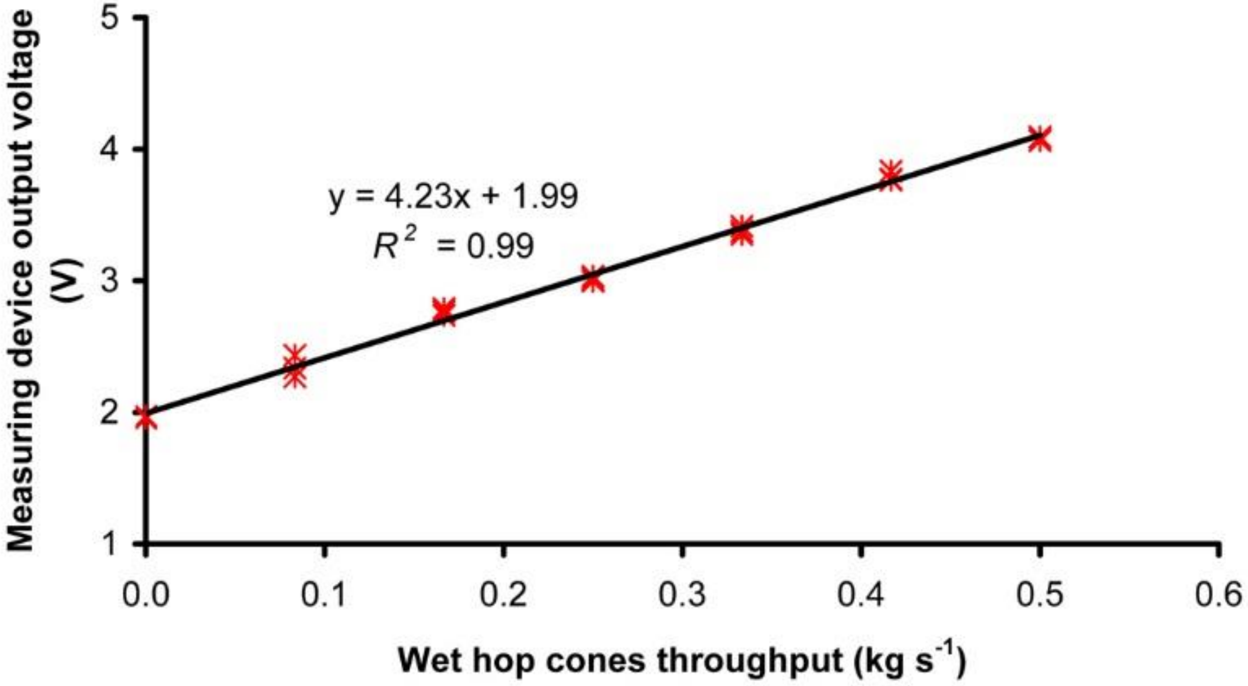
Unlike forages, sugar beets and potatoes, the moisture content of chopped maize is lower during harvest (70-90% vs. 30-50%). Therefore, the influence of changes in material moisture content on throughput measurement was monitored. It follows from the graph, that there is no important influence for moisture content from 85-65% and less than 15%.
In contrary, from 65 to 15% this influence exists and has to be respected.

Another measurements were arranged with wet hop cones.



Dependence of measured capacitive sensor output voltage on wet hop cones throughput under laboratory conditions. Saaz hop variety, moisture content (wet basis) 80.9%. Laboratory measurement.

- The dependence was linear fully in agreement with previous findings.
- Repeatability of the measurements was acceptable, even when very small throughputs were tested.
- Results encouraged us to arrange further experiments directly on the hop harvesting machine during the harvest.

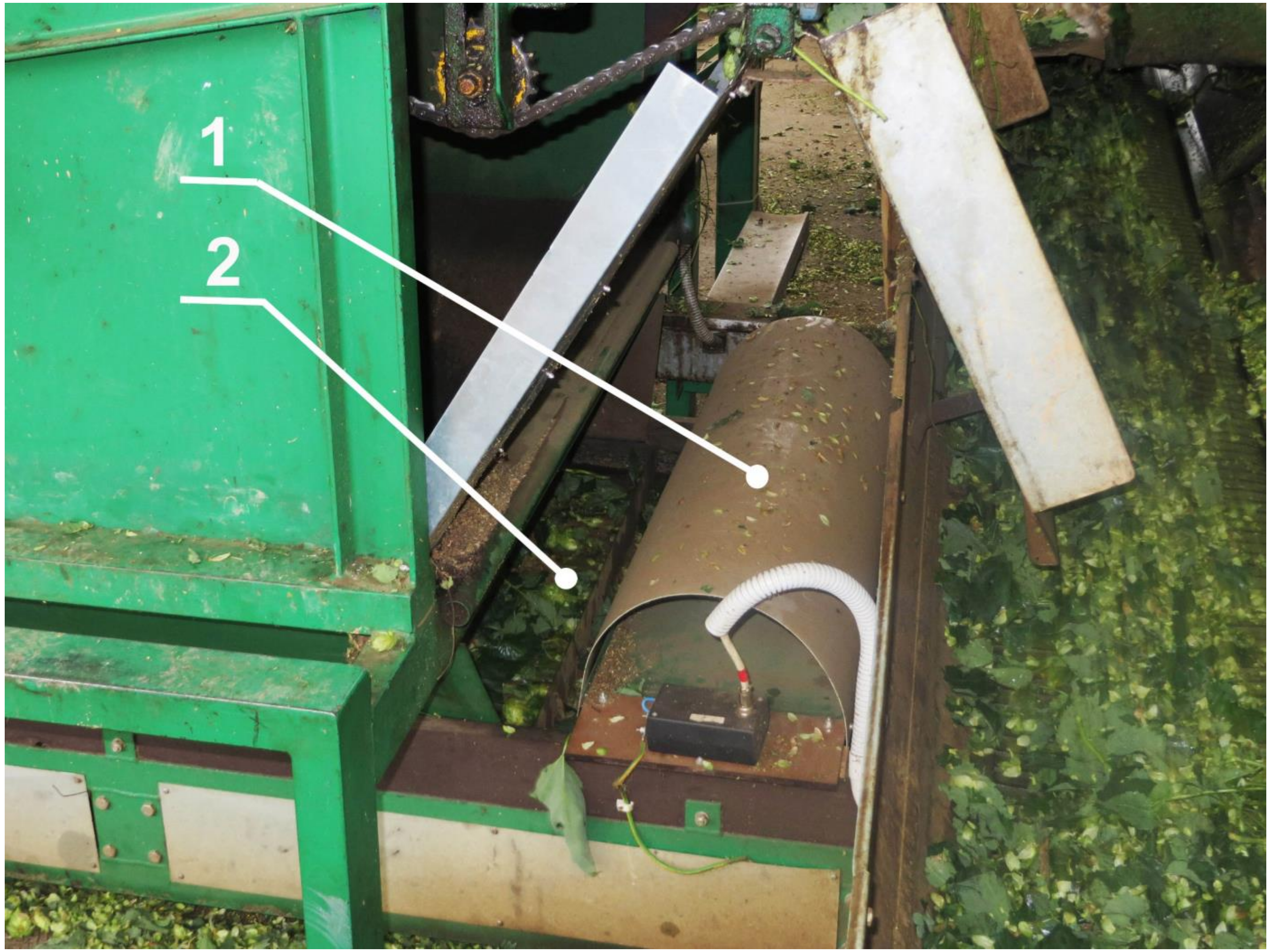


Location of capacitive throughput unit on the stationary hop picking machine PT-30 (highlighted by white rectangle).

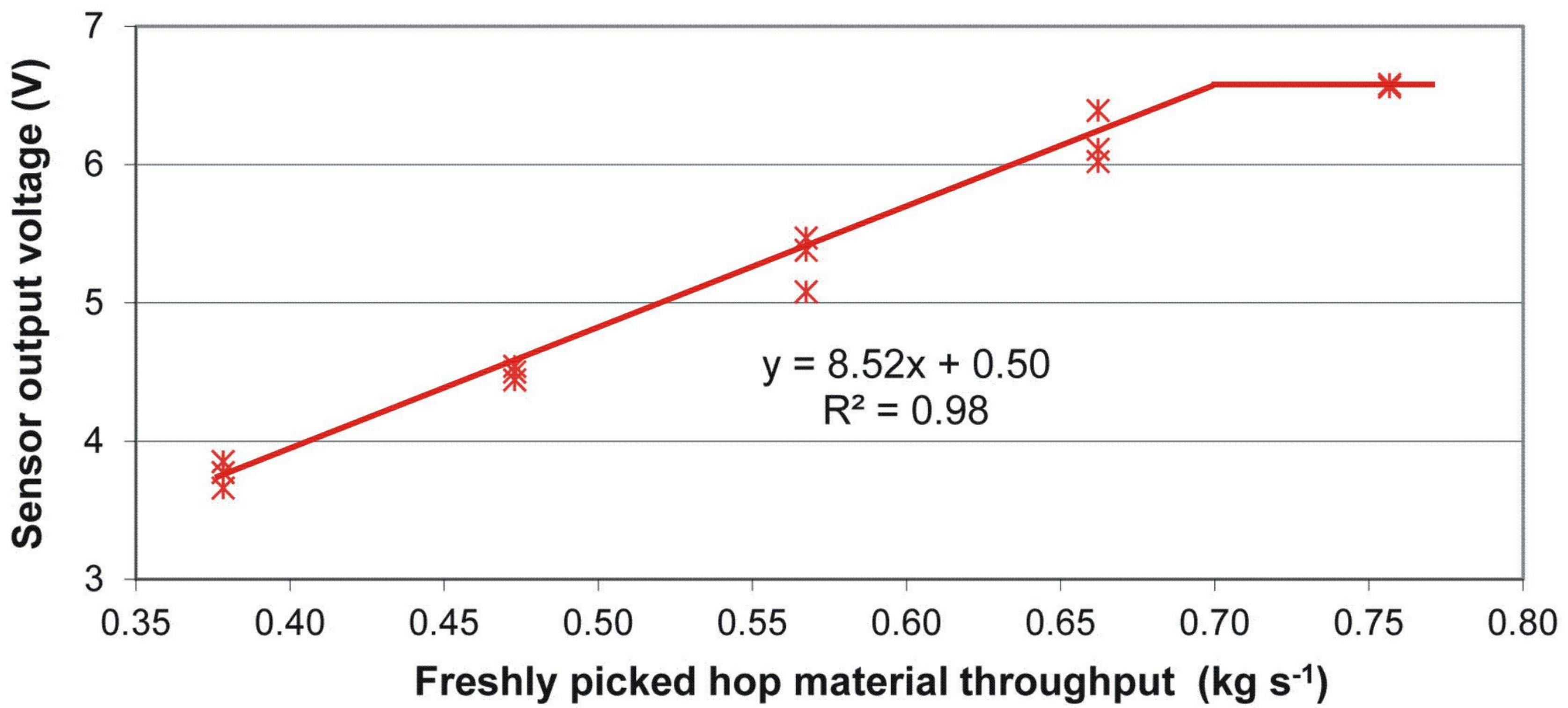
Dependence of measured capacitive throughput unit output voltage on wet hop cones throughput under real harvesting conditions – calibration curve. Rubín hop variety, moisture content (wet basis) 75.6%.

- Capacitive throughput unit can be applied to the conveyer of hop harvesting machine with only slight modification.
- Results showed suitable dependence of measured output voltage on wet hop cones throughput under both laboratory and harvesting conditions.
- Error of unit-predicted material weight was less than ±4%.
- Output voltage signal from capacitive throughput unit can be used for stationary hop picking machine throughput control with adequate precision under real harvesting conditions.

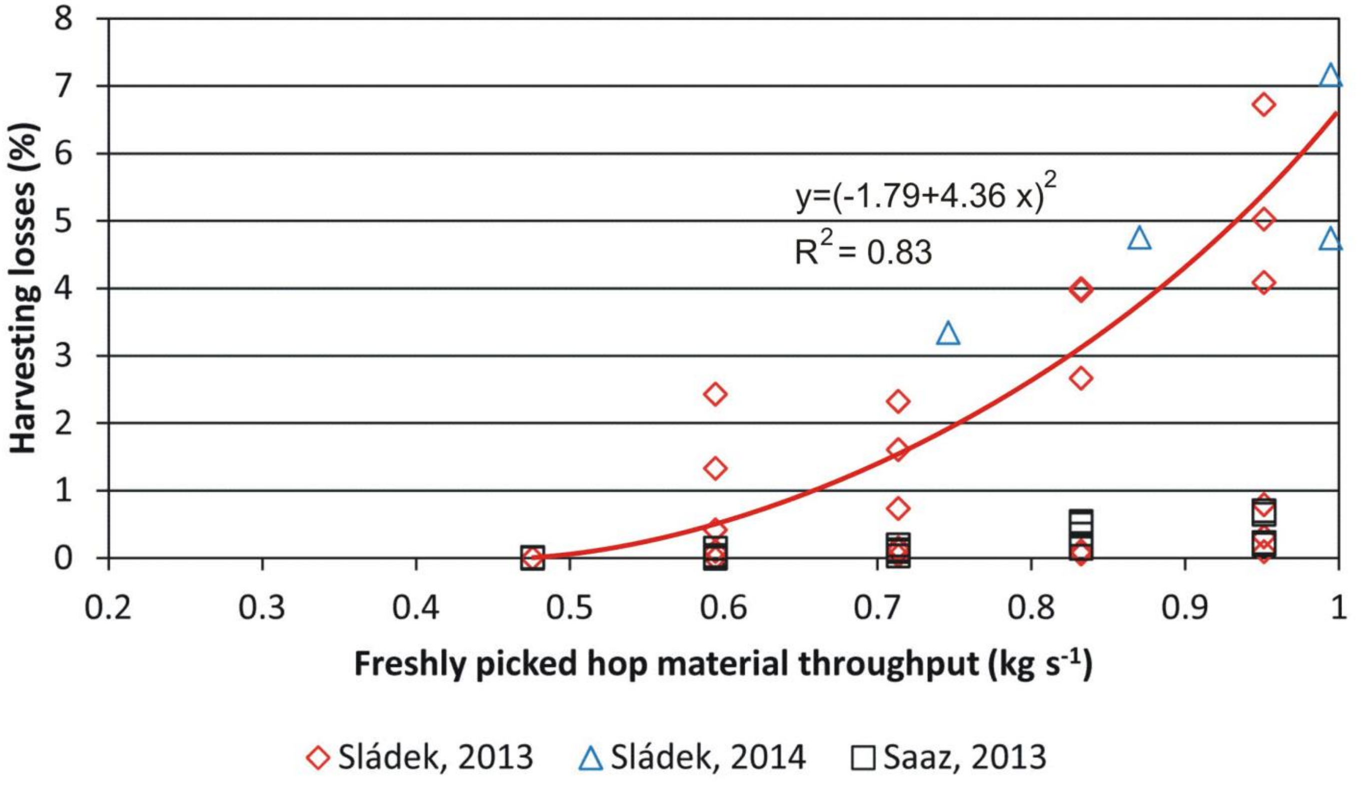
It was proved that capacitance throughput sensor can be used as a tool for hop picking machine control.



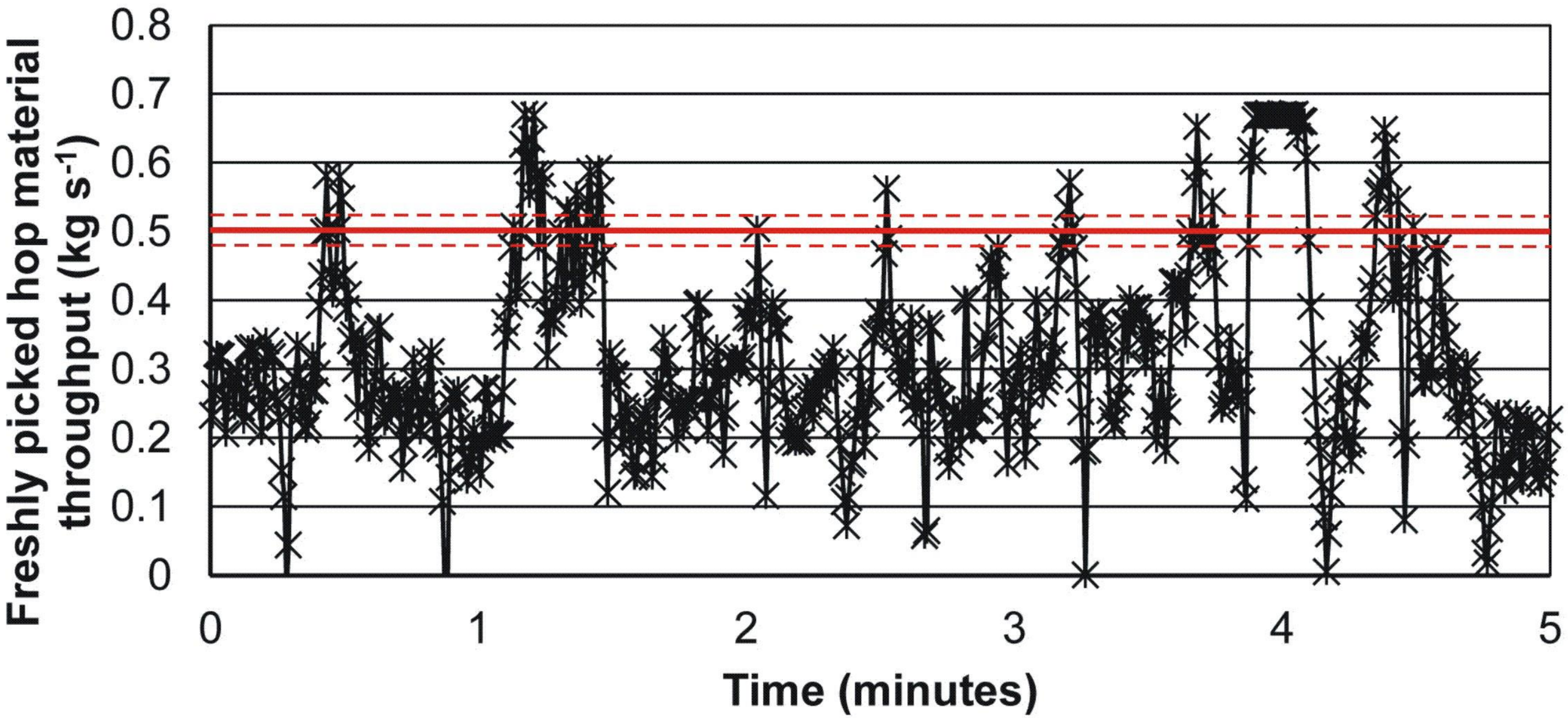
Location of the capacitance throughput sensor on the pocket belt conveyor of the PT-30 stationary hop picking machine. 1 – capacitance throughput sensor, 2 – pocket belt conveyor with picked hop material.



Dependence of the measured capacitance sensor output voltage on freshly picked hop material throughput – calibration curve. Sládek hop variety, moisture content (wet basis) 75.7%.



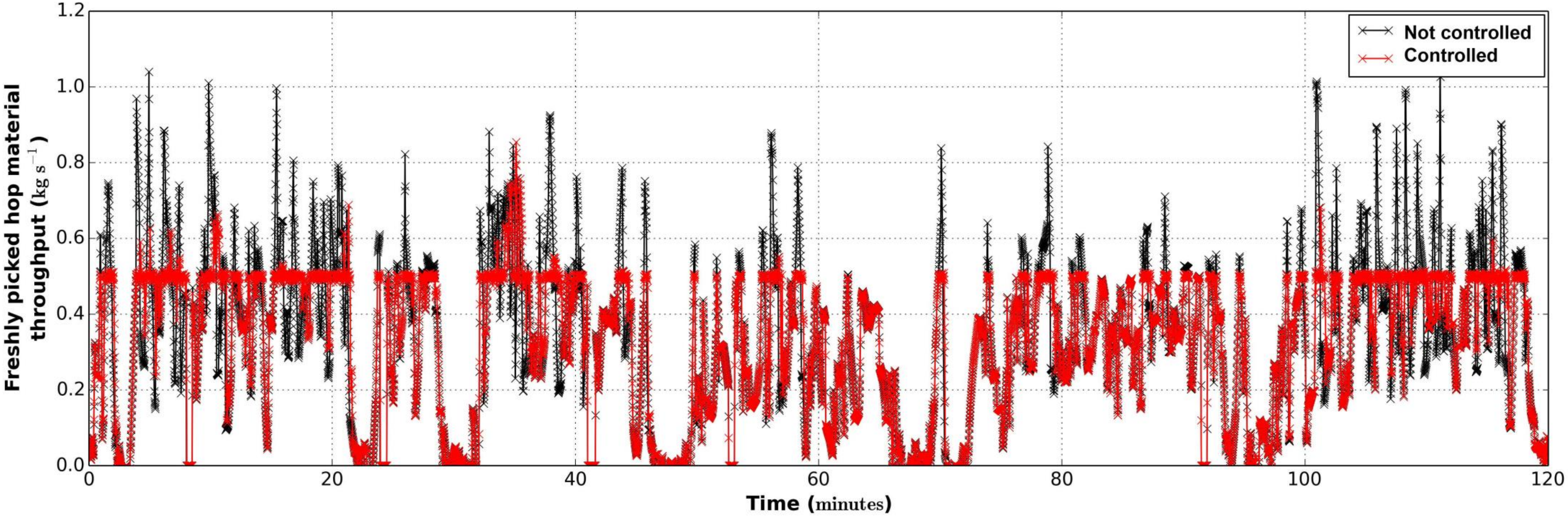
Dependence of harvesting losses on freshly picked hop material throughput. 2013 – Sládek hop variety, moisture content (wet basis) 75.8%, Saaz hop variety, moisture content (wet basis) 69.6%. 2014 – Sládek hop variety, moisture content (wet basis) 75.7%.



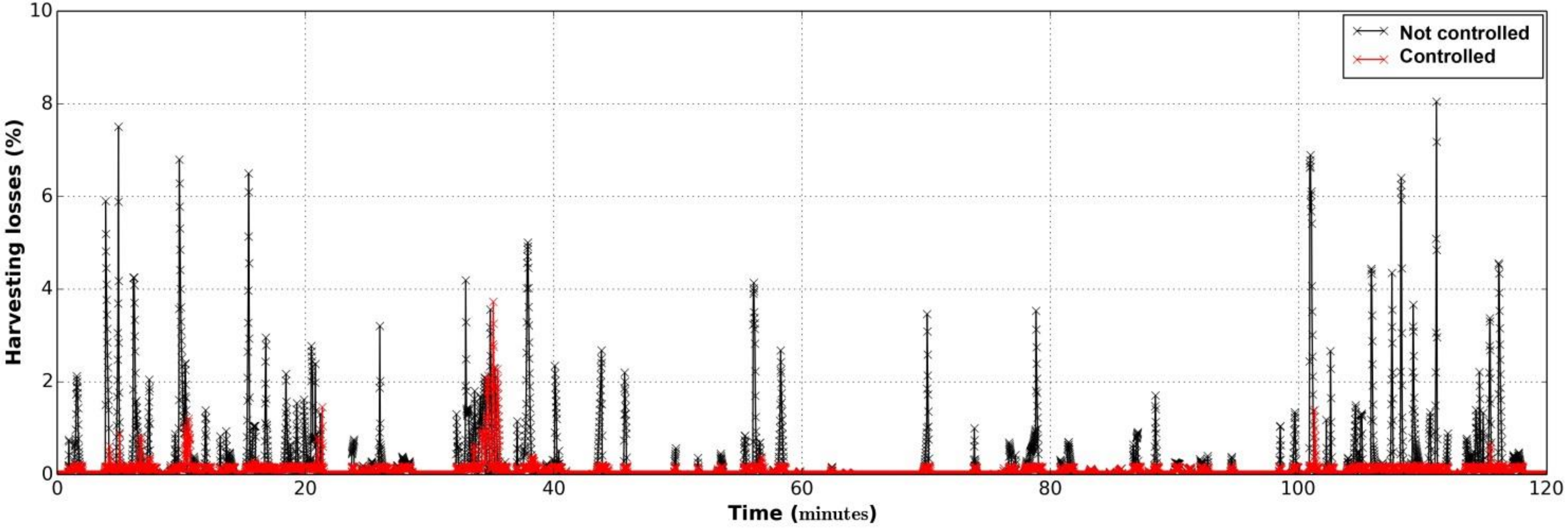
Example of the typical course of freshly picked material throughput calculated from capacitance throughput sensor data using the calibration formula for 5 minutes of machine work (solid black line). Logging time 0.5 s. Solid red line – control point derived from previous figure, dashed red line – maximum error (± 4%) in determining the control point by the capacitance throughput sensor.

Control unit integrated to PT-30 hop picking machine.

View of the graphic touch operator panel when the hop picking machine is in operation. In this case, the operator used the manual controls. The conveyor speed was set to 60% of the maximum speed.



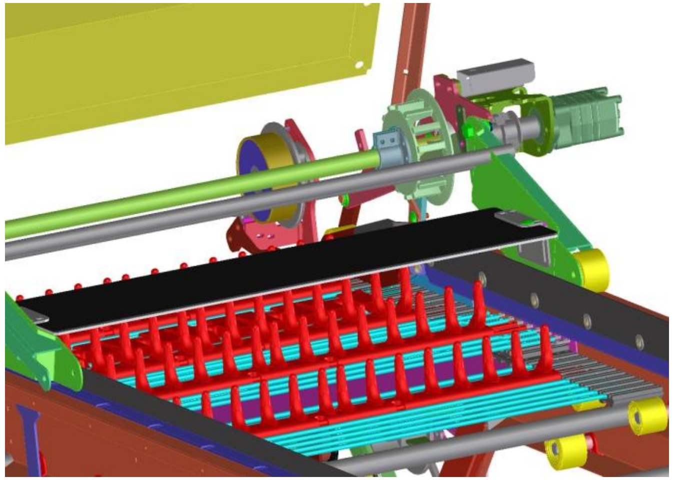
The course of freshly picked material throughput when automatic throughput control is used (red curve) and when it is not (black curve).



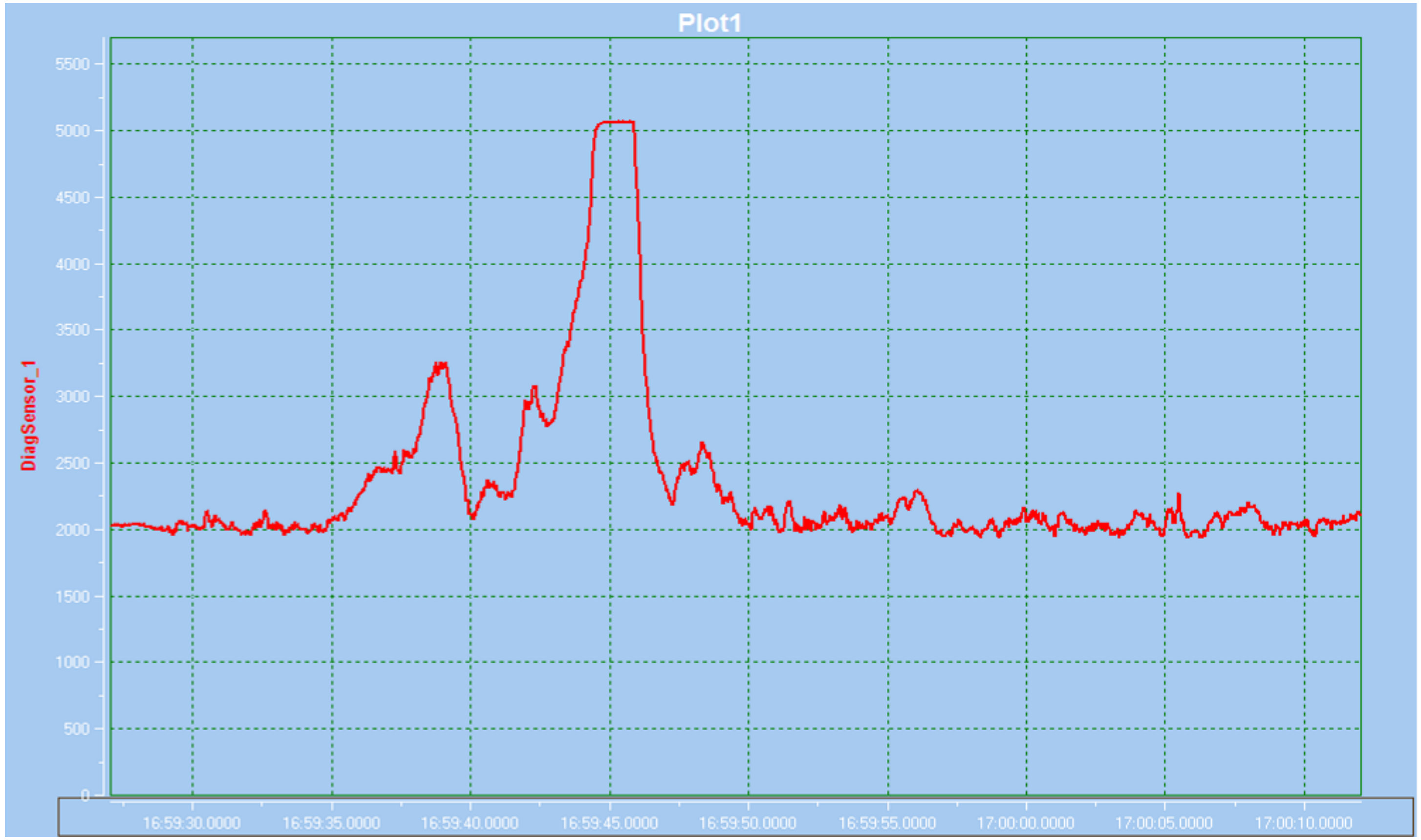
The course of calculated harvesting losses depending on harvesting time for the controlled picking process (red curve) and the non-controlled one (black curve). The calculation was done for the Sládek hop variety.

- Capacitance throughput sensor can also be integrated into a belt conveyor with metal pockets. Linear approximation model appears to be suitable for the description of the dependence of sensor output voltage on wet hop material throughput with an R^2=0.98 coefficient of determination.
- Simple mode of automatic control procedure can be proposed on the basis of wet hop material throughput and harvesting losses measurement.
- Simple application controller was able to maintain the set material throughput control point using the described automatic control mode during most of the testing time (116 min out of 120).
- Control system functionality can save over 2 percent of harvesting losses. When harvesting 30 ha per year with the average yield of 1 ton per hectare, this fact represents a saving of 0.6 tons of dry hop cones per one year. When calculating with the estimated control system price of 6,250 USD and the commodity price 6,600 USD per ton of dry hop, the return on investment should be less than two years.

Other practical applications of capacitive throughput sensor have also been tested.



Grimme Maxtron sugar beet harvester with integrated capacitive throughput sensor.



- Sensitivity was sufficient, ca. 1 V as offset for zero point, signal goes up to 5 V.
- At least two single beets are recognizable.
- Noise could be significantly removed by shielding the upper plate, removing the metal plate on the side and putting a capacitor in the output of the signal.

Sugar beets recognised on conveyer belt of Grimme Maxtron sugar beet harvester.

Thank you very much for your attention!

František Kumhála