Dynamic laboratory measurement with dielectric sensor for forage mass flow determination

F. Kumhála[1], Z. Kvíz[1], J. Kmoch[1], V. Prošek[2]

[1]*Department of Agricultural Machines, Faculty of Engineering, Czech University of Life Sciences in Prague, Prague, Czech Republic*
[2]*Department of Machines Utilization, Faculty of Engineering, Czech University of Life Sciences in Prague, Prague, Czech Republic*

Abstract: A new parallel plate capacitance sensor was built consisting of two metal sheets. The sensor – a capacitor and the whole oscillating circuit was driven at 27 MHz frequency. Dynamic laboratory experiments were performed with grass from a natural meadow in order to evaluate the possibility of the forage mass flow determination by means of this sensor. The results revealed a relatively strong linear relationship between the feed rates of the wet forage crop material passing through the sensor between its plates and the measured capacitance sensor circuit output frequency. The coefficients of determination (R^2) varied from 0.9 to 0.96. Further improvement of the electronic circuit connection and further investigation of the sensor can be recommended.

Keywords: precision agriculture; yield mapping; capacitance sensor; mass flow; grass and forage

The capacitance sensor technique can be used for the determination of different properties of plant materials. The function of the capacitance sensors depends on the fact that the dielectric constant of the air/material mixture between two parallel plates increases with the material density. The capacitance sensors could be used for the plant material moisture content determination (Lawrence *et al.* 2001).

Eubanks and Birrell (2001) determined the moisture content of hay and forages by using multiple frequency parallel plate capacitors. The frequencies used were in the range between 900 kHz and 13 MHz. They found out that the prediction error was greater for the grasses than for the two legumes measured (alfalfa and clover). Another important finding was that the amount of the material in the sensor does not affect the moisture content prediction in the materials tested. This sensor was capable of predicting the moisture content of materials with unknown density. On the other hand, the moisture sensor developed was specific for each crop measured and had to be calibrated for each particular crop.

Osman *et al.* (2002) built a parallel plate capacitor with a variable spacing for hay and forage moisture measurement. An integrated circuit timer (LM555) was used, in which the parallel plate capacitor acted as an external capacitor. The timer worked as an unstable multivibrator. The sensor output was recorded as the difference between the capacitor operating frequency with no material between the plates (833 kHz) and the actual frequency when the forage was placed between the plates. The results indicated that the sensor could not directly estimate the moisture content. However, a good correlation was observed between the sensor output and the amount of water within the capacitor volume. The frequency drop and the amount of water correlated better at a low moisture content than at a high moisture content.

Snell *et al.* (2002) used a radio-frequency application device for sensing dry matter content of various agricultural products. They found out that the density of the material had a significant influence on the precision of the estimate. Using a mass and density independent measuring system, the water mass could be estimated much more precisely than the dry matter content using the described method of measurement. For that reason, different sensors measuring different parameters (e.g. total mass,

Supported by Ministry of Education, Youth and Sports of the Czech Republic, Project No. MSM 6046070905.

water mass and temperature) should be combined. According to these results, it was possible to estimate the dry matter of unknown lots (variety, machine capacity, distribution of particle size, etc.) with sufficient precision by means of the existing calibration.

Wild and Haedicke (2005) found out that the accuracy of the moisture content determination by using a parallel plate capacitor was greatly affected by the contact pressure.

Stafford *et al.* (1996) used a capacitance sensor for the determination of grain mass flow. According to their research, the effect of the moisture content can be compensated by measuring capacitance at two widely spaced frequencies. One section of the sensor was driven at 10 kHz and the other at 2 MHz frequency.

Martel and Savoie (1999) observed a capacitance controlled oscillator placed at the end of the spout of a forage harvester to measure the changes induced by the forage particles. The oscillator was a high frequency timer (880 kHz, model TS555CN, SGS Thomson Microelectronics). This equipment showed a linear drop of the oscillator frequency as the wet mass flow increased. A number of calibration parameters would be required to cover a broad range of crop species, maturities and chop lengths. Savoie *et al.* (2002) used a similar capacitance controlled oscillator for their measurement. This device proved a proportional frequency drop in the dependence on the amount of moisture flow between the capacitor plates. Nevertheless, the frequency drop of the capacitance controlled oscillator was poorly correlated with the mass flow rate (R^2 = 0.486). The device described correlated better with the water flow rate (R^2 = 0.624).

Kumhála *et al.* (2006) designed a parallel plate capacitance sensor for the forage weight determination. The sensor operated at 27 MHz frequency. The results showed that there was a relatively strong linear relationship between the weight of the material and the data obtained from the measuring circuit. The coefficients of determination (R^2) reached mostly the value of 0.95. The results of the measurement were not influenced by the type of the harvested material while the material moisture content as well as the material compact pressure between the plates influenced the results.

On the basis of these findings, the main aim of our research was to find a non-contact method for the forage material mass flow measurement. Because of its relatively low purchase cost and quite promising results obtained and described before, the capacitance type sensor appears to be suitable for this purpose. The measurements described in this paper were realised in order to find out whether some relationship exists between the mass flow of the wet plant material passing through the capacitance sensor and its output signal. The possibility of the mass flow determination could be useful for the aim of forage maps creation.

MATERIAL AND EXPERIMENTAL METHOD

On the basis of the results obtained (Kumhála *et al.* 2006), it was decided to improve the design of the sensor and to arrange dynamic laboratory measurements with the improved sensor. A novel parallel plate capacitance sensor was designed for that purpose. The parallel plate capacitance sensor consisted of two metal sheets 2 mm thick with the dimensions of 830 mm in length and 260 mm in width. The distance between the plates was 300 mm. The inside parts of the metal sheets were insulated by two plastic sheets 1 mm thick with the same dimensions which were stuck on the metal sheets. The sides of the capacitance sensor were made from 10 mm thick acrylic glass. A shielding 2 mm thick metal plate with the dimensions of 830 mm in length and 280 mm in width was fixed to the mentioned acrylic glass sides in the distance 430 mm from the capacitor shielded plate (see Figure 2). This metal plate shielded the capacitance sensor from surrounding influences which could affect the measurement.

The dimensions of the sensor were calculated with the aim to keep the electrical parameters of the previously proved older sensor used for static laboratory experiments. Another goal was to design a new sensor just ready for the practical use on a small rotary mower equipped with a conditioner (ZTR 186, Agrostroj Pelhrimov Company). The novel sensor - capacitor and the whole oscillating circuit was driven at 27 MHz frequency as well. The exact connection of the measuring circuit is shown in Figure 1.

The capacitor was fed with AC-voltage from the oscillator via resistor or another capacitor with the same reactance. The resistor together with two measuring capacitor plates made up a voltage divider and thus the output voltage of that divider depended on the capacity on the measuring capacitor, and that capacity is dependent on the dielectric matter between the plates. The dielectric constant of the measuring capacitor varied according to the amount and the type of material placed between the plates, which means according to the proportion material/air. The AC output voltage of the divider was then rectified in an AC/DC rectifying module and amplified with an amplifier. Then, the rectified volt-

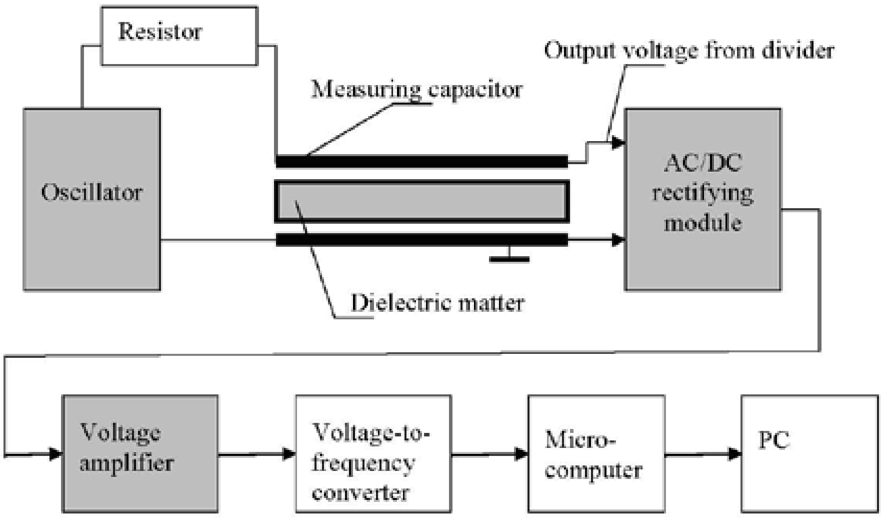

Figure 1. Block diagram of the electronic apparatus arrangement for the material feed rate measurement; oscillator worked at 27 MHz frequency; the capacitor (measuring capacitor with dielectric matter between its plates) was fed with AC-voltage via Resistor; AC output voltage was then rectified in AC/DC rectifying module and amplified by voltage amplifier; amplified voltage was proportionally converted into frequency in voltage-to-frequency converter; the counted pulses were transferred by microcomputer to PC and saved

age was converted into frequency by an electronic measuring apparatus developed in our laboratory. The output frequency was directly proportional to the voltage measured. The pulses from the converter were counted during the time interval equal to 0.5 s by means of a one-chip microcomputer and the results were transferred into a PC.

The laboratory set-up consisted of a conveyer belt carrying the measured quantity of material into the improved sensor equipped with the electronic measurement apparatus (Figure 2). The material from the conveyer belt passed through the sensor between its plates. The material was transported through the parallel plate capacitance sensor during approximately five seconds in each test run.

Grass from a natural meadow was used for the purpose of determining the relationship between the output frequency of the capacitance measuring device and the material feed rate through the capacitor. The signals from the capacitance measuring device were measured every half second, so 10 values were obtained in one single test run. The measurements started with the material feed rate of to 0.8 kg WM/s. The test run with the same defined amount of the material was then repeated minimum three times. For the next measurements, the transported amount of the material was increased by an increment of approximately 0.3 kilogram per second, up to 4.5 kg WM/s feed rate. Ten values from each test run were averaged to obtain the final result for a particular feed rate value. The calculated data were used for further statistical processing using MS Excel and Statgraphics for Windows.

The material moisture content was determined by means of a standardised method in each material tested. One sample of the material was taken at the beginning of each day of the measurement for that purpose.

The measurements were carried out during 5 days, July 11th, 12th, 13th, and 21st, and October 17th, 2006. During the measurements from July 13th, the signals from the capacitance measuring device were measured every 5 s instead of 0.5 s as used in all others measurements (will be discussed later).

RESULTS AND DISCUSSION

The first measurements with the improved capacitance sensor were carried out on July 11th. The main aim of these measurements was to get more familiar with the function and characteristics of the newly designed capacitance sensor. The measurement procedure was as described above. Just the first tests on July 11th were realised with up to 3 kg WM/s material feed rate only. The material moisture content was 77.2%. The measurements proved a linear relationship between the capacitance sensor frequency and wet material feed rate as predicted. The coefficient of determination was R^2 = 0.91 (see Figure 3, dashed and doted lines).

On the basis of the results obtained, it was decided to repeat the measurements next day, July

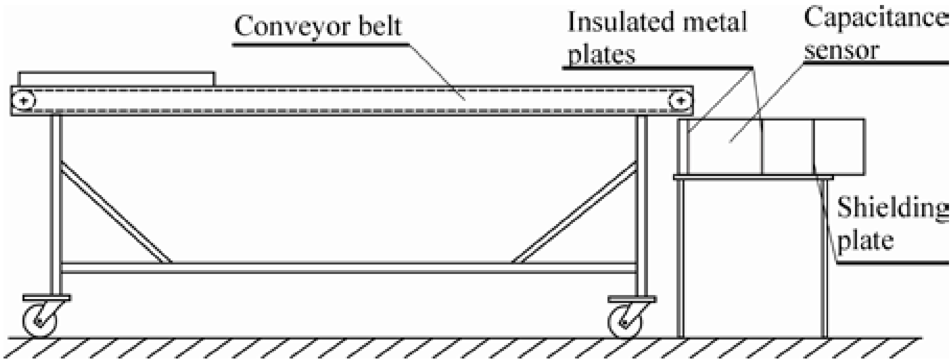

Figure 2. The arrangement of the measurement device for laboratory tests; the conveyor belt carried weighed amount of material into the capacitance sensor between its plates for five seconds; shielding plate insulated capacitance sensor from surrounding influences

12th, with grass from the same natural meadow but using a higher material feed rate. The final amount of the material transported was then increased up to 4.5 kg WM/s. The dimensions of the capacitor, as well as the arrangement of the laboratory device, did not allow to use a higher value of the material feed rate. Nevertheless, the amount of the material tested was comparable with the amount usual under common harvesting conditions using the mower mentioned (ZTR 186). The material moisture content was 77.5% in that case and the coefficient of determination was improved to $R^2 = 0.96$ (Figure 3, continuous line).

Because the results obtained from both previously described measurements were quite satisfactory, new measurements with the partly modified measurement device were made on July 13th. The modification of the measured device was as follows. The signals from the capacitance sensor were recorded every 5 s, which corresponded better with the real situation in the case of infield measurement. Only one value was recorded from each test run in that case. Those values were used for charting after subtraction of zero value (Figure 4). It followed from this graph that the calculated coefficient of determination was slightly lower ($R^2 = 0.90$) in comparison

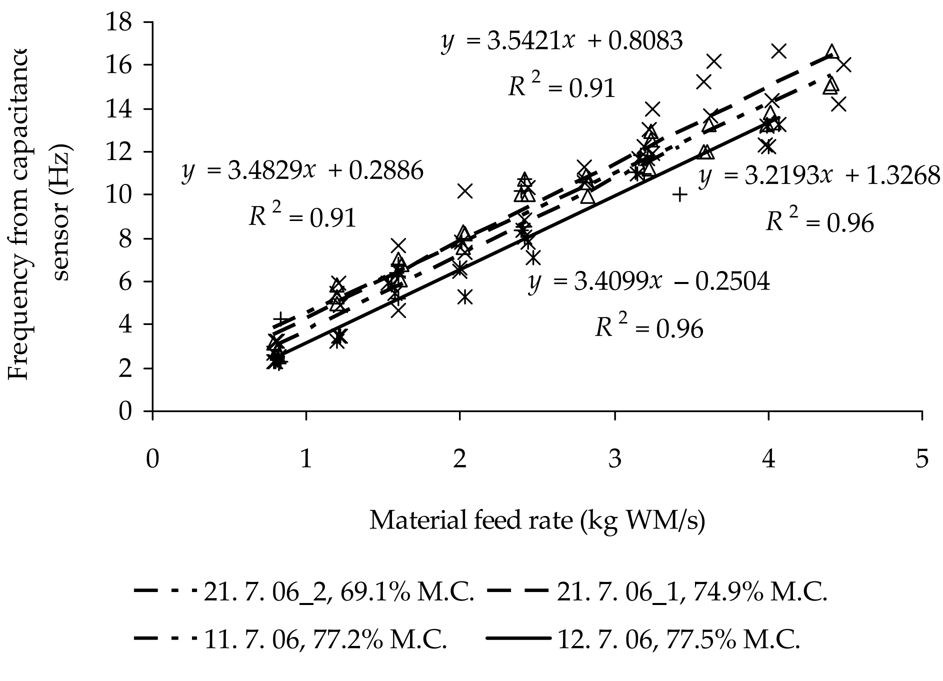

Figure 3. The dependence of the measured circuit output frequency on the plant material mass flow (11th, 12th and 21st July 2006); recording time 0.5 s

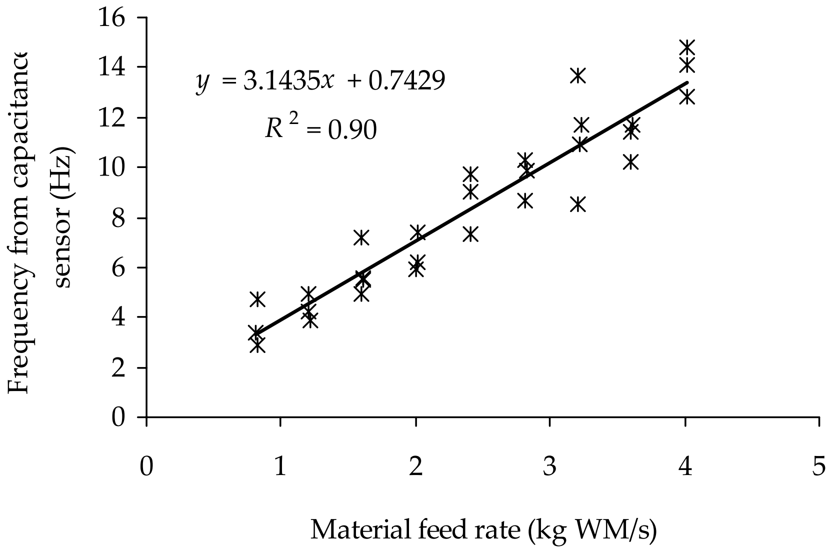

Figure 4. The dependence of measured circuit output frequency on plant material mass flow (July 13th, 2006); recording time 5 s.

with the previous measurements. On the other hand, the values obtained were within the same range from 2 to 16 Hz as in the previous measurements (comparing Figure 4 with Figure 3). Because of the lower final coefficient of determination, it was decided to return to the recording time of 0.5 s used before. In this case the values fluctuation during one single test run could be observed which seemed to be advantageous in comparison with the measurement device modified later.

Two tests were made on July 21st. A material with the moisture content of 74.9% was used for the morning measurements and the same material after moderate wilting with the moisture content of 69.1% was used for the afternoon measurements. The morning measurements resulted in the value R^2 = 0.91 and the afternoon measurements in R^2 = 0.96, respectively. Because the output values from those measurements were in the same range as those from the previous two measurements, it was decided to chart all four measurements together in one chart (Figure 3).

The morning measurement (Figure 3, dashed line), which had a lower value of the coefficient of determination, was made with early morning freshly mowed grass with drops of dew on the leaves. That additional moisture could be the reason for the resulting smaller value of this coefficient. Some drops of dew could have stuck on the capacitor metal plates and their influence on the measurement accuracy was very difficult to estimate. This can be one of the disadvantages of this type of capacitance based material feed rate measurements.

The afternoon measurements (Figure 3, dashed and double dotted lines) with a considerably higher coefficient of determination were made with partly flaccid grass with no drops of dew or water on leaves. In spite of this, the material moisture content was somewhat smaller in that case in comparison with the other measurements, the resulting curve was in good agreement with the previous ones. This underlines the previous findings (Kumhála *et al.* 2006), mainly, that the small difference in the material moisture content (about 6% only) did not influence the results. The influence of the material moisture content was observable only when the difference between two measurements was higher than 30–40% of M.C.

Because of the relatively warm July in the year 2006, the outside air temperature in our laboratory reached the values from 29°C to 33°C in all cases.

The problem accompanying all measurements carried out concerned the zero value – when no material was in the sensor. The measuring apparatus used recorded relative values, which is quite common for these types of measurements. Absolute values had to be calculated as the difference between the values recorded and the zero value. The zero value was necessary to be set up before the measurements. The problem was that the zero value unfortunately changed during the measurements and it was necessary to re-check it or set up again before each particular test run. From the laboratory measurements point of view, this problem is not so serious because it is no problem to re-check the correct zero value and use it for precise calculation. Nevertheless, under real harvesting conditions it represents a serious problem because re-checking of the zero value is almost impossible and thus the zero value should be as stable as possible. This is the reason for the future improvement of the electronic circuit connection.

CONCLUSION

The forage mass flow determination by means of the newly designed parallel plate capacitance sensor driven at 27 MHz frequency appeared to be a promising way. The results revealed a strong linear relationship between the feed rates of the wet forage crop material passing through the sensor between its plates and the tested measuring capacitance sensor circuit output frequency. However, the results obtained showed that an improvement of the electronic circuit connection and further investigation of the sensor can be recommended.

References

Eubanks J.C., Birrell S.J. (2001): Determining moisture content of hay and forages using multiple frequency parallel plate capacitors. ASAE paper No. 01-1072, ASAE, St. Joseph, Michigan.

Kumhála F., Kvíz Z., , Kmoch J., Prošek V. (2006): Laboratory measurement with improved dielectric sensor for forage weighing. Acta Technologica Agriculturae, **9**: 51–54.

Lawrence K.C., Funk D.B., Windham W.R. (2001): Dielectric moisture sensor for cereal grains and soybeans. Transaction of ASAE, **44**: 1691–1696.

Martel H., Savoie P. (1999): Sensors to measure forage mass flow and moisture continuously. ASAE Paper No. 991050, ASAE, St. Joseph, Michigan.

Osman A.M., Savoie P., Grenier D., Thériault R. (2002): Parallel-plate capacitance moisture sensor for hay and forage. ASAE Paper No. 021055, ASAE, St. Joseph, Michigan.

Savoie P., Lemire P., Thériault R. (2002): Evaluation of five sensors to estimate mass-flow and moisture of grass in a forage harvester. Applied Engineering in Agriculture, **18**: 389–397.

Snell H.G.J., Oberndorfer C., Lücke W., Van den Weghe H.F.A. (2002): Use of electromagnetic fields for the determination of the dry matter content of chopped maize. Biosystems Engineering, **82**: 269–277.

Stafford J.V., Ambler B., Lark R.M., Catt J. (1996): Mapping and interpreting the yield variation in cereal crops. Computers and Electronics in Agriculture, **14**: 101–119.

Wild K., Haedicke S. (2005): Improving the accuracy of moisture sensors for forage crops. In: Book of Abstracts 5 ECPA–2 ECPLF, JTI Sweden, 326–328.

Received for publication April 24, 2007
Accepted after corrections May 21, 2007

Abstrakt

Kumhála F., Kvíz Z., Kmoch J., Prošek V. (2007): **Dynamické laboratorní měření s kapacitním senzorem pro měření průchodnosti pícnin.** Res. Agr. Eng., **53**: 149–154.

Pro měření okamžité průchodnosti pícnin bezkontaktní metodou byla vyvinuta nová konstrukce kapacitního čidla. Čidlo bylo vyvíjeno kvůli mapování výnosů při sklizni pícnin žacím strojem. Jeho konstrukce je uzpůsobena tak, aby ho bylo případně možné bez úprav namontovat na rotační žací stroj ŽTR 186 vybavený čechračem. Čidlo – deskový kondenzátor – a jeho oscilační obvod pracovaly na frekvenci 27 MHz. Pro otestování funkce nově navrženého čidla – jako přístroje pro určování okamžité průchodnosti – jsme provedli dynamické laboratorní experimenty, při kterých jsme použili čerstvě posečenou luční trávu. Výsledky měření ukázaly, že existuje relativně silná lineární závislost údajů získaných z kapacitního čidla na průchodnosti vlhkého pícninného materiálu. Koeficienty determinace (R^2) dosahovaly při provedených měřeních hodnot od 0,90 do 0,96. Na základě výsledků měření je možné doporučit vylepšení dosavadní měřicí aparatury a měření znovu zopakovat, abychom získali potvrzení dosažených výsledků.

Klíčová slova: precizní zemědělství; mapování výnosů; kapacitní čidlo; průchodnost; pícniny

Corresponding author:

Doc. Dr. Ing. František Kumhála, Česká zemědělská univerzita v Praze, Technická fakulta, katedra zemědělských strojů, Kamýcká 129, 165 21 Praha 6-Suchdol, Česká republika
tel.: + 420 224 383 135, fax: + 420 224 383 122, e-mail: kumhala@tf.czu.cz