DIELECTRIC SENSOR FOR FORAGE WEIGHING*

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The parallel plate capacitance sensor consisting of two metal sheets was built. This measuring device was connected with capacitance meter MESTECH my-6013 driven at 800 Hz frequency. The static laboratory measurements were carried out with an aim to predict the weight of wet plant material between the sensor plates by means of a capacity sensor measurement. Measurements were influenced by relatively high error and should not be recommended for future research. Nevertheless, the insulation of parallel plates on the inner side can improve the measurement accuracy and can be recommended. Another important finding was that the frequency of measured circuit should be considerably higher in order to achieve better accuracy and independence on surroundings.

precision agriculture; capacitance sensor; weight; grass and forage

INTRODUCTION

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

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

Osman et al. (2002) built a parallel plate capacitor with 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's output was recorded as the difference between the operating frequency with no material between the plates (833 kHz) and the actual frequency when forage was placed between the plates. Results indicated that the sensor could not directly estimate the moisture content. However, a good correlation was observed between the sensor's output and the amount of water within the capacitor's volume. The frequency drop and the amount of water were more correlated at low moisture content than at high moisture content.

Snell et al. (2002) used radio-frequency application device for sensing the dry matter content in various agricultural products. They found out that the density of material had a significant influence on the precision of the estimate. Using a mass and density independent measuring system, the water mass can be estimated much more precisely that the dry matter content using described kind of the measurement. For that reason, different sensors measuring different parameters (e.g. total mass, water mass and temperature) should be combined. According to these results, it appeared to be possible to estimate the dry matter of unknown lots (variety, machine capacity, distribution of particle size, etc.) with sufficient precision by means of existing calibration.

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

Stafford et al. (1996) used a capacitance sensor for determination of grain mass flow. According to their research, the effect of 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 changes induced by the forage particles. The oscillator was a high frequency timer (880 kHz, model TS555CN, SGS Thomson Microelectronics). That equipment showed a linear drop of the oscillator's 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 similar capacitance controlled oscillator for their measurement. This device proved a proportional frequency drop in dependence on the amount of moisture flow between the capacitor plates. Nevertheless, the frequency drop of the capacitance controlled oscillator was poorly correlated with mass flow rate ($R^2 = 0.486$). Described device was better correlated with water flow rate ($R^2 = 0.624$).

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On the basis of those findings previously published, the main aim of our research was to find a non-contacting method for forage material mass determination. Because of its relatively low purchase cost and quite promising results obtained and described before, the capacitance type sensor appears to be suitable for that purpose. The measurements described in this paper were realized in order to find out whether there is some relationship between the weight of wet plant material placed into the capacitance sensor and its capacity. This possibility of mass determination could be useful for the aim of forage maps creation.

MATERIAL AND METHOD

A parallel plate capacitance sensor was designed for our measurement. The connection of electronic measured circuit was relatively simple. The parallel plate capacitance sensor consists of two metal sheets 2 mm thick and with the dimensions 500 mm in length and 150 mm in width. The distance between the plates is 100 mm. In series with the plate capacitance sensor another capacitor of known capacitance of 2 µF was connected for elimination of conductance influence. Described apparatus was connected with capacitance meter MESTECH my-6013, which is working at 800 Hz frequency. In comparison with the frequencies used by the authors cited before (Osman et al., 2003; Stafford et al., 1999; Martel, Savoie, 1999; Savoie et al., 2002) that frequency used by us was relatively low. The connection of electronic measured circuit is in Fig. 1.

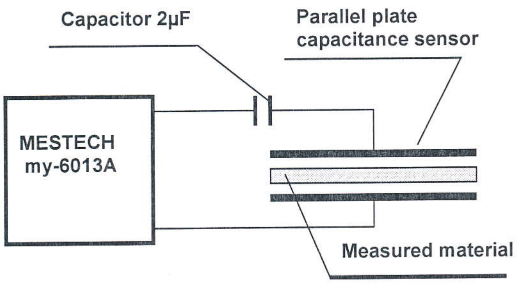

Fig. 1. The connection of electronic measured circuit

The static laboratory measurements were carried out in May 2005 with the fresh grass from natural meadow at different sample weights and at almost optimal harvesting crop maturity. Each sample was spread and placed between two capacitor plates. The capacity of measuring circuit with the different amount of plant material between the plates was showed on the capacitance meter display and registered. Firstly, the freshly mowed material was measured in the capacitor and then the moisture content was determined by the standardised method. The sample of wet material was weighed and after that placed into a drying room and dried for 24 hours at 105 °C. The sample of material was weighed again after drying and from the values of wet and dry material weight the material moisture content in % of wet basis for each measured sample was calculated. The average of all samples was done for each day of measurement.

The measurements were carried out during five days, from 18th till 27th May 2005. First two days of the measurement was relatively low outside air temperature and that is why the temperature of material tested was 18 °C only. After one week the outside temperature was considerably higher and that was the reason that the temperature of measured material was 21 °C on 24th May and 25 °C on two last days of the measurement. As it was just discussed above, the material was freshly mowed grass from natural meadow located in the University Campus in all cases. Statistical processing of all obtained data was performed using Microsoft Excel. The graphs were built from the data obtained during each day of the measurement and the regression analysis was used for the statistical data evaluation. According to the resulting graphs obtained it is possible to divide them into three groups.

First group are the data which came from the first three days of the measurement. The sensor output signal ranged from 0 to 70 nF. Material moisture content ranged between 73 and 83%.

Second group are the data from 26th May which was with different values of the sensor output signal (ranged from 0 to 200 nF). Material moisture content was 81% on average.

Third group are the data from 27th May after insulation of the sensor plates. The sensor output signal ranged from 0 to 40 nF. Material moisture content was 82% on average in that case.

RESULTS AND DISCUSSION

First data group evaluation

According to the chart (Fig. 2) it could be said that the measured capacity of parallel plate capacitance sensor depends linearly on the amount of the measured material between the plates. Nevertheless, the calculated coefficients of determination (R^2) are rather low, especially in the case of the measurement from 24th May, when the value of that coefficient was 0.17 only. In both following cases that coefficient was meaningfully higher ($R^2 = 0.68$ or 0.76, respectively) but that values are still not sufficient for the purpose of material weight determination with the adequate accuracy. The reason why the worst coefficient of determination 0.17 from 24th May was achieved could be that the material moisture content was higher for that measurement (86%) in comparison with previous two days (73% and 76%).

Although the dependence of the circuit capacity on the sample weight was not satisfactory it is also clear from Fig. 2 that the values obtained were within the same range from 0 to 70 nF for all three measurements evaluated. On the other hand, the slope of the curves was always different. This fact probably underlines the idea that the measurement arrangement was not chosen very well because of

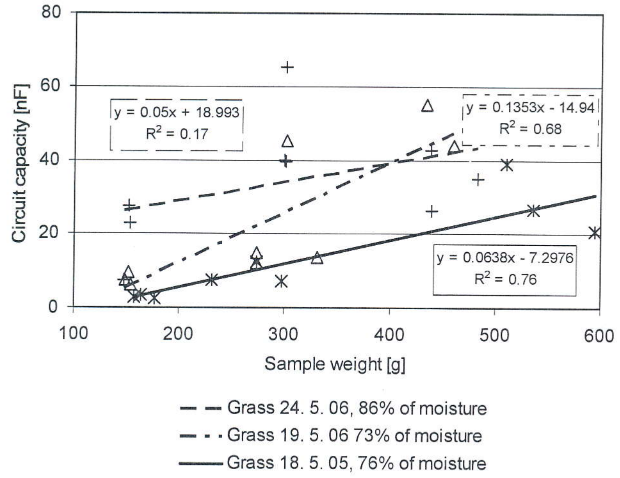

Fig. 2. The dependence of measured circuit capacity on plant material sample weight for first data group (18th, 19th and 24th May 2005)

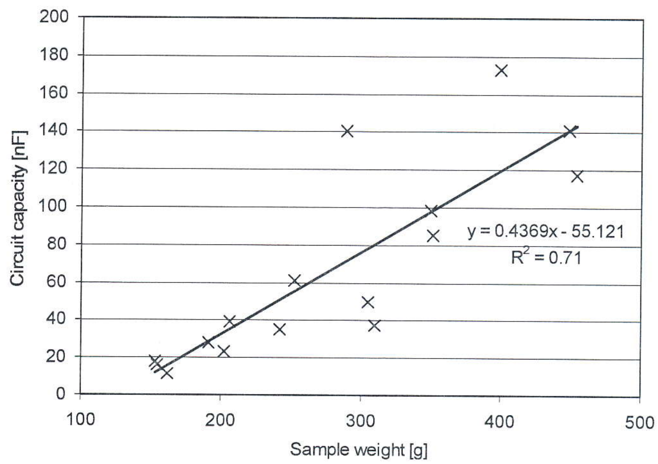

Fig. 3. The dependence of measured circuit capacity on plant material sample weight for second data group (26th May 2005)

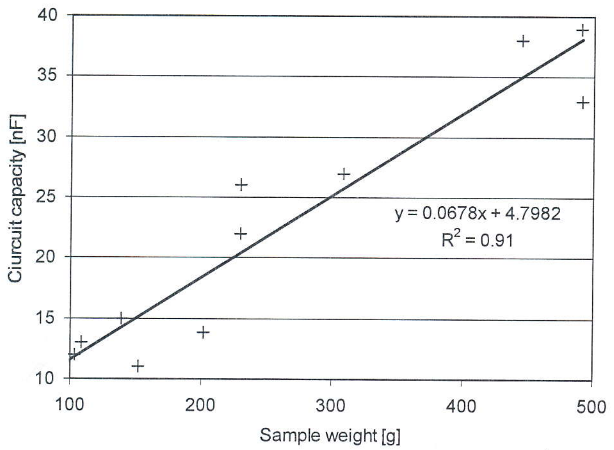

Fig. 4. The dependence of measured circuit capacity on plant material sample weight for third data group (27th May 2005, insulated plates).

the insufficient accuracy. At the low driving frequencies (800 Hz as it was used) the electric conductance of the material between the plates can play an important role and their influence on measured capacity is very difficult to estimate.

Second data group evaluation

Fig. 3 shows the graph of measured values from 26th May. Fig. 3 agrees with Fig. 2 concerning the coefficient of determination which is almost similar ($R^2 = 0.71$) to two better ones from the last chart. The difference is in the curve's slope, which is considerably higher in this case in comparison with the slopes of regression curves in the chart in Fig. 2. Nevertheless the most important difference between the values in Fig. 2 and the values in Fig. 3 is in their range. While the values 0–70 nF were obtained for the first data group (Fig. 2), the range was increased for second group to 0–200 nF (Fig. 3), which is a significant difference. Despite the connection of the measuring circuit was still the same, the measured values were fairly higher for second group, mainly if the samples of higher weight were measured. This could be explained by a high influence of the electric conductance of the measured material as well. The material moisture content was 81% on wet basis on average and the material temperature was 25 °C on that measuring day.

Third data group evaluation

The results from the previous measurements inspired us to insulate the place for inserting the material between the metal sheets by two plastic sheets. The sheets were stuck on the internal side of metal sheets. The measurements with insulated plates were done on 27th May. The obtained data (Fig. 4) led to higher coefficient of determination ($R^2 = 0.91$) and decrease of sensor output data range (from 0 to 40 nF). The slope of correlation curve almost agrees with the slope of curves in the chart in Fig. 2 as well as the range of measured values. It is possible to conclude from this measurement that insulation of inside part of the parallel plate capacitance sensor can positively influence the measurement accuracy. On the contrary, the coefficient's of determination value is still too low for the recommendation of described connection for the future research. Future improvement can be reached by increasing of the oscillating frequency from present 800 Hz to much higher values (Eubanks, Birrell, 2001; Stafford et al., 1996), preferably in the range of kHz or MHz, which could help to eliminate the material conductivity influence as well as the capacitor plate's insulation.

CONCLUSIONS

The determination of wet plant material weight by means of a parallel plate capacitance sensor driven at 800 Hz frequency capacity measurement is influenced by a relatively high error and should not be recommended for the future research of this type. Nevertheless, the insulation of parallel plates, their inside parts, did improve that kind of measurements and can be recommended. Oscillating frequency of measured circuit should be considerably higher value.

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Jednou z důležitých vlastností rostlinných materiálů je z hlediska precizního zemědělství také jejich hmotnost v okamžiku sklizně. Levnou a z provozního hlediska zajímavou variantou sloužící k zjišťování okamžité hmotnosti při sklizni může být využití kapacitního měření. Za tímto účelem byla sestavena měřicí aparatura sestávající z deskového kapacitního čidla, ke kterému byl sériově připojen další kondenzátor o známé kapacitě. Mezi desky námi vyrobeného kapacitního čidla bylo vkládáno různé množství sklízeného materiálu a kapacita celého obvodu byla následně měřena prostřednictvím měřicího přístroje pro zjišťování kapacity od firmy MESTECH my-6013, který pracuje na frekvenci 800 Hz. Následně byla laboratorně určována rovněž vlhkost měřeného materiálu. Pak bylo vyhodnocováno, zda lze z údajů o kapacitě měřicího obvodu usuzovat na hmotnost materiálu mezi deskami kapacitního čidla. Měření ukázala, že použití takto zapojené měřicí aparatury není pro dané účely vhodné, protože zjištěné koeficienty determinace nabývaly nízkých hodnot. Bylo nicméně zjištěno, že odizolování vnitřního prostoru kapacitního čidla plastovými deskami může výsledky měření pozitivně ovlivnit. Protože při námi popsaném měření měla pravděpodobně velký vliv vodivost materiálu, která je těžko definovatelná a je lepší její vliv na měření vyloučit, je možné doporučit postavení nové měřicí aparatury pracující s frekvencemi v řádu kHz nebo MHz.

precizní zemědělství; kapacitní senzor; hmotnost; pícniny

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