INFLUENCE OF CONVEYOR POCKETS ON MATERIAL THROUGHPUT MEASUREMENT BY CAPACITIVE SENSOR

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Abstract. Many various methods of material throughput measurement in agriculture and other branches were tested during the last 20 years. The current trends indicate that the non-contact methods of material throughput measurement can be more perspective than the contact methods. One of the possibilities is the capacitive throughput measurement method. In the Biosystems Engineering journal the theory of sensor filling was introduced. This theory considers material transporting on the conveyor belt. However, many conveyors are equipped with pockets. The pockets can influence the electric field of the sensor, i.e., the dependence between a filling of the sensor by material and its electrical capacitance is significantly changed. This fact can produce significant errors of throughput measurements. In this paper the influence of the conveyor pockets during material throughput measurement by a capacitive sensor was assessed. Two mathematical models of capacitance throughput sensors with plastic and metal pocket conveyors were created. The comparison of the electric field intensity showed that conveyor pockets significantly influenced the electric field. This influence was much more significant for metal pockets. The electric field in the area influenced by the pockets was inhomogeneous and this fact should be taken into account during sensor calibration.

Keywords: capacitive throughput sensor, pocket conveyor, finite element method.

Introduction

The information about instantaneous material throughput can be used for online optimization of the harvesting machine technological process or for instantaneous yield measurement. A number of sensors working on different principles were developed and tested for those purposes [1-3]. Even though these sensors are commercially available for combine and forage harvesters, for other crops the situation is different. This issue is still the subject of the research [4-6].

One of the promising methods may be capacitive throughput measurement. The first experiments were done and published by [7] on grain yield monitoring. The next research was oriented to forage throughput measurement [8-10]. The capacitive method was then successfully tested for potato, sugar beet, chopped maize and hop throughput measurement [10-12].

The capacitive sensor for throughput measurement can be described as a parallel plate capacitor where the dielectric is the mixture of air and the measured material. Equivalent dielectric constant increases with increasing of the material amount between the plates and the electric capacity of the capacitor is increasing as well. The amount of the material between the plates can be then determined via electrical capacitance measurement.

The design of capacitive sensors can be based on the models assuming a homogeneous electrical field inside the sensor [11], which means that the sensitivity of the sensor is constant at all locations between its plates. However, in many cases, this simplification is not possible to be used as it was described by [13]. The authors described the behavior of a capacitive sensor located on the pocket conveyor. The pockets of this conveyor were made from metal sheets which significantly influenced capacitor electrical field forming. In order to optimize THE capacitive sensor design the knowledge of sensitivity distribution is crucial in this case. That is why the main aim of this paper is a detailed description of the conveyor pocket influence on capacitive throughput measurement, comparison of the influence of metal and plastic pockets of the conveyor and the simulation of electrical impedance changes during throughput sensor filling.

Materials and methods

For the purpose of this research two mathematical models of capacitance throughput sensors with a pocket conveyor were created. The first model contained a pocket conveyor with metal pockets and the second model contained a pocket conveyor with plastic pockets.

A simple scheme of the capacitance throughput sensor and the pocket conveyor is in Fig. 1. The sensor consisted of two plates. Both plates were 890 mm in length, 300 mm in width and they were made from 1.5 mm thick metal sheet. The bottom plate was grounded and the upper plate was connected to the measuring circuit. The distance between the plates was 200 mm. The height of the conveyor including the pockets was 85 mm, the distance between the pockets was 100 mm and the distance between the conveyor and the bottom plate was 30 mm.

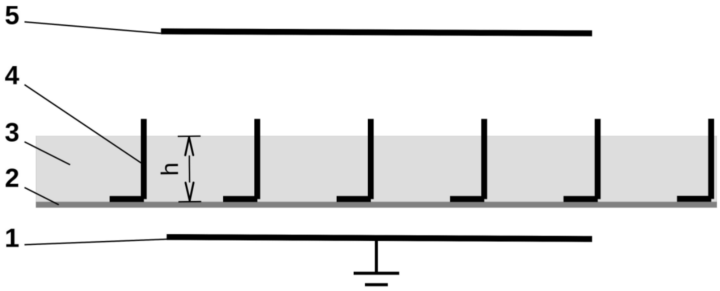

Fig. 1. **Scheme of the capacitance throughput sensor and the pocket conveyor:** 1 – sensor bottom plate; 2 – conveyor belt; 3 – thickness of the material; 4 – pocket; 5 – sensor upper plate

The electric field in the sensor sensing area is alternating and its frequency is typically 1-10 MHz. However, according to many authors [14-18] this field is commonly simplified to an electrostatic field and the following equation can be used:

$$\nabla \cdot (\varepsilon_0 \varepsilon_r \nabla \varphi) = 0 \tag{1}$$

where ε_0 – permittivity of vacuum ε_0 = 8.854×10^{-12} Fm^{-1};
ε_r – relatively permittivity, –;
φ – scalar electric potential, V.

In the mathematical models five types of the material were used: air ε_r = 1, measured material ε_r = 4 (the value is approximately according to wheat [19]), belt of conveyor ε_r = 8, pockets made of metal sheet ε_r = 10^6 and pockets made of plastic material ε_r = 5.

The boundary conditions on electrodes where defined as Dirichlet conditions, i.e., for the bottom plate φ_Γ = 0 V and for the upper plate φ_Γ = 1 V. The boundary conditions along the solved area were defined as Neumann boundary conditions.

The equation (1) was solved by the finite element method using the program Agros2D. This software is able to work with a higher-order finite element method with h, p, and hp adaptivity based on a reference solution and local projections [20].

In the first step distribution of the electric field intensity was calculated for both cases, because it can be used for sensitivity analysis of the sensor sensing area. The electric field intensity can be defined as E = -*grad* φ in this case. A situation when the sensor was gradually filled by a material was simulated in the second step. The material thickness was gradually increasing by 10 mm increment to 170 mm. The thickness of the material is labeled in Fig. 1 as *h*. This simulation was performed for both cases. For each 10 mm the impedance of the sensor was calculated using the following equations:

$$W_E = \frac{1}{2}\int_\Omega E \cdot D \, d\Omega \tag{2}$$

$$Z = \frac{U^2}{4\pi f W_E} \tag{3}$$

where W_E – energy of electric field, J;
D– electric displacement, C.m-2;
Ω – solved area, m2;
Z – impedance, Ω;
U – voltage on the upper plate, V;
f – frequency, Hz.

Results and discussion

Two variants of pocket conveyors (with metal and plastic pockets) were evaluated for the purpose of capacitive throughput measurement. A comparison of electric field intensity is in Fig. 2 for both cases. In the part (a) there is a simulation result with the pocket conveyor with pockets made from a plastic material and in the part (b) there is a simulation result for the pockets made from a metal sheet. It is evident that the pockets on the conveyor significantly influence the electric field in both cases. Nevertheless, this influence is much more significant for metal pockets. The sensing area of the sensor is approximately divided in two parts: a part influenced by the pockets and a part above the pockets. The intensity of the electric field is smaller in the area influenced by the pockets in both cases.

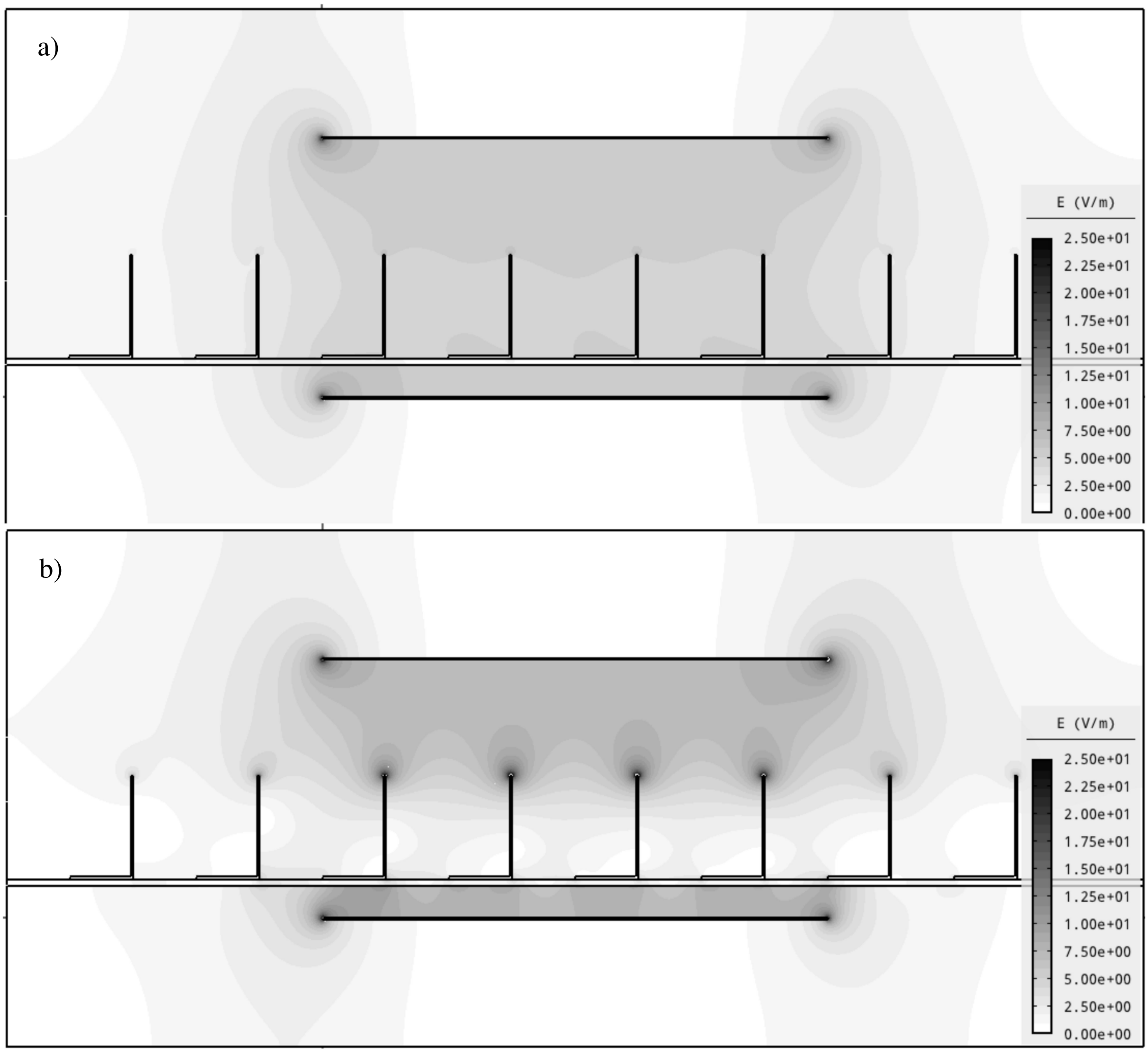

Fig. 2. **Comparison of electric field intensity:** a – pocket conveyor with plastic pockets; b – pocket conveyor with metal pockets

In Fig. 3 there are calculated values of impedance depending on the height of the material layer. The grey curve shows dependence between the impedance and height of the material layer in the case when the pockets are made from a plastic material. The black curve shows another variant which is for the pockets made from a metal sheet. In the first case the dependence between the impedance and height of the material layer is approximately linear. For the purpose of confirmation of this consideration, these data were fitted with a straight line. The resulted coefficient of determination was R^2 = 0.997. It means that the influence of plastic conveyor pockets on electric field forming is quite small in this case.

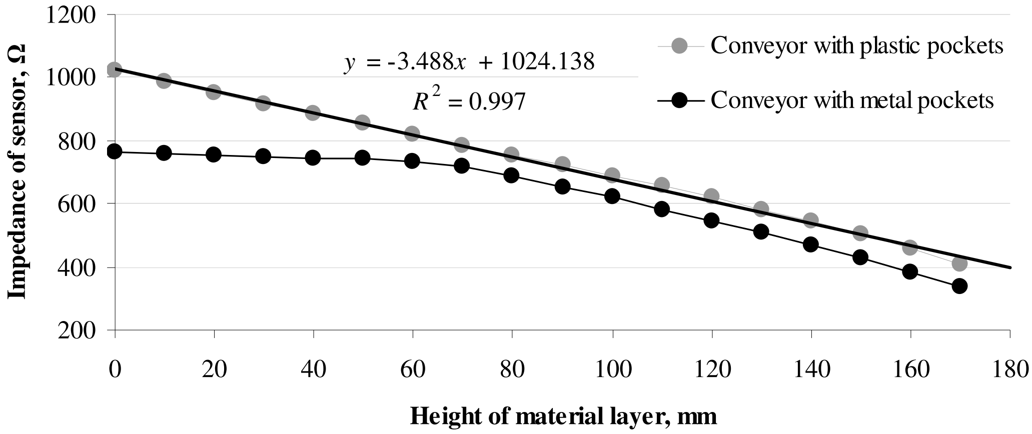

Fig. 3. **Calculated values of impedance depending on the height of the material layer**

The results were quite different in the second case. When the material was in the area influenced by the pockets, then the impedance change was quite small. When the height of the material layer is about 80 mm and more, then the impedance is decreasing similarly as in the case with the plastic pockets. It is evident that metal pockets influenced significantly the sensor sensitivity. Also the fact is important that if the area influenced by the pockets is almost full then the dependence between the height of the material layer and the sensor impedance is nonlinear. This fact should be taken into account during sensor calibration.

Conclusions

In this paper the influence of the conveyor pockets during material throughput measurement by a capacitive sensor was assessed. Two mathematical models of capacitance throughput sensors with plastic and metal pocket conveyors were created. The comparison of the electric field intensity showed that the conveyor pockets significantly influenced the electric field in both cases and this influence was much more significant for the metal pockets. The sensing area of the sensor was divided approximately in two parts: area influenced with the pockets and area above the pockets. The second area was with approximately homogeneous electric field and there was always higher sensitivity of the sensor. The electric field in the area influenced by the pockets was inhomogeneous. This sensor behavior was confirmed with another simulation where the sensor was gradually filled by a material.

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