ISSN 1726-5749

SENSORS & TRANSDUCERS

1 /08
vol. 87

Sensor Instrumentation, DAQ and Virtual Instruments

International Frequency Sensor Association Publishing

Sensors & Transducers

Volume 87
Issue 1
January 2008

www.sensorsportal.com

ISSN 1726-5479

Sensors & Transducers Journal (ISSN 1726-5479) is a peer review international journal published monthly online by International Frequency Sensor Association (IFSA). Available in electronic and CD-ROM.

Sensors & Transducers Journal

Contents

Volume 87
Issue 1
January 2008

www.sensorsportal.com

ISSN 1726-5479

Editorial

Research Articles

Authors are encouraged to submit article in MS Word (doc) and Acrobat (pdf) formats by e-mail: editor@sensorsportal.com
Please visit journal's webpage with preparation instructions: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm

Sensors & Transducers Journal, Vol. 87, Issue 1, January 2008, pp. 31-38

Sensors & Transducers

ISSN 1726-5479

http://www.sensorsportal.com

Pharmaceutical Pill Counting and Inspection Using a Capacitive Sensor

Ganesan LETCHUMANAN[1], Simon HAWKINS[1], Peter ROCKETT[1], Steve SHEARD[1], Conrad SHAIL[2], Kenneth SHAIL[2], Peter DOBSON[3]

[1]Department of Engineering Science, Oxford University, Parks Road, Oxford OX1 3PJ, UK

[2]Sparc Systems Ltd, Merebrook Industrial Estate, Hanley Road, Malvern, Worcs WR13 6NP, UK

[3]Oxford University Begbroke Science Park, Sandy Lane, Kidlington, Oxon OX5 1PF, UK

Tel.: +441865 273929, E-mail: steve.sheard@eng.ox.ac.uk

Received: 8 November 2007 /Accepted: 21 January 2008 /Published: 28 January 2008

Abstract: A capacitive sensor for high-speed counting and inspection of pharmaceutical products is proposed and evaluated. The sensor is based on a patented Electrostatic Field Sensor (EFS) device, previously developed by Sparc Systems Limited. However, the sensor head proposed in this work has a significantly different geometry and has been designed with a rectangular inspection aperture of 160mm × 21mm, which best meets applications where a larger count throughput is required with a single sensor. Finite element modelling has been used to simulate the electrostatic fields generated within the sensor, and as a design tool for optimising the sensor head configuration. The actual and simulated performance of the sensor is compared and analysed in terms of the sensor performance at discriminating between damaged products or detection of miscount errors. *Copyright © 2008 IFSA.*

Keywords: Capacitive sensor, Pharmaceutical pill dispensing, Counting and checking, EFS

1. Introduction

Companies that distribute pharmaceutical products need to package pills and capsules in a time-efficient and cost-effective manner. In practice this will require an automated system comprising conveyor belts, mechanical dispensing equipment and methods for online counting and inspection of the product being packaged. Patented technology for pharmaceutical pill inspection is held by Sparc Systems Limited [1], based on a capacitive sensor design. There are significant advantages in capacitive sensing compared to optical sensing methods in terms of reliability, complexity and suitability for operating in an industrial environment. Indeed, capacitive position (or proximity) detectors [2, 3] and moisture detectors [4] are employed in many industrial applications. Capacitive sensors are able to provide information relating to an object's position, size and dielectric properties, and as such offer an excellent tool for quality inspection. In this paper we discuss the development of a new configuration of capacitive sensor, which can be described as *longitudinal* in order to distinguish it from the previously patented technology of Sparc Systems. This sensor has been designed for applications where pharmaceutical products free-fall through an aperture in the sensor head of rectangular dimension 160mm × 21mm, and is suited to inspection scenarios where a single sensing head is required to count pills at a high throughput (i.e. greater than 1000 pills per minute). Furthermore, the relatively extensive longitudinal dimension allows for a broad range of pill injection trajectories. A key objective in the design exercise is to maintain stringent quality control constraints; such as the detection of damaged or rogue pills with high reliability, the detection of miscounts and the identification of pills compromised due to humidity.

In order to present this work in a suitable context, it is necessary to first describe the operating mode of a parallel-plate capacitive sensor in its simplest configuration, but readers are directed to reference [1] for a more practical configuration. In normal operation, pills are allowed to fall between the capacitor plates under gravity in such a way as to momentarily change the volume-averaged dielectric constant that determines the capacitance. Electronic measurement of the change in capacitance provides a signal that varies in time as the pill passes between and then out of the capacitor plates; typically lasting a few milliseconds. The signal parameter measured can be in the form of a time-varying voltage, current or charge, depending on the electrical set-up employed. In this respect a single pill trajectory passing, through the sensor produces a characteristic signal variation in terms of its peak value, duration and area. This can be regarded as a typical "signature" for a "good" pill and in its crudest sense can be used to register a "pill count" or in a more elaborate signal processing mode can be used to determine the dielectric constant or volume of the pill. For a continuous stream of pills passing through the sensor any change in this signature is interpreted as either a miscount in the pill dispensing process and/or detection of a broken or rogue pill passing through the sensor aperture.

However, most pills are not spherical but closer to a cylindrical form and this leads to a different signature for pills falling through the capacitor plates with either a vertical or horizontal orientation. These different voltage profiles can lead to a misinterpretation of the pill's integrity or its count. This problem is illustrated for a simple 2-D case in Fig. 1 below, which shows the moment when a tertagonal shaped pill is falling through the centre of the capacitor plates. The effect of orientation can be seen by considering the pill in the two different orientations (scenario *a* and *b*), with the pill rotated by 90°. As the intention of this example is simply to illustrate the effect of pill orientation, the thickness of the pill is chosen to be the same as the depth (into the page) of the capacitor plates to simplify the algebra.

The total capacitances can be approximated by considering the pill and air regions in the capacitors as lumped blocks of equivalent capacitance. By treating these blocks as either series or parallel capacitance the total capacitance can be approximated for scenario *a* and *b* respectively.

$$C_a = C_{1a} + C_{4a} + \left(\frac{1}{C_{2a}} + \frac{1}{C_{Pa}} + \frac{1}{C_{3a}} \right)^{-1} = \varepsilon_0 t \left[\frac{H-L}{d} + \frac{\varepsilon_P L}{\varepsilon_P (d-w) + w} \right] \tag{1}$$

$$C_b = C_{1b} + C_{4b} + \left(\frac{1}{C_{2b}} + \frac{1}{C_{Pb}} + \frac{1}{C_{3b}} \right)^{-1} = \varepsilon_0 t \left[\frac{H-w}{d} + \frac{\varepsilon_P w}{\varepsilon_P (d-L) + L} \right], \tag{2}$$

where t and ε_P are the width and relative dielectric constant of the pill respectively. Although these equations seem very similar it can be seen that the total capacitance given by (1) and (2) may differ significantly due to the rotation of the pill. This difference in capacitance is illustrated numerically in Table 1 for a typical pill-like geometry in a parallel plate capacitor.

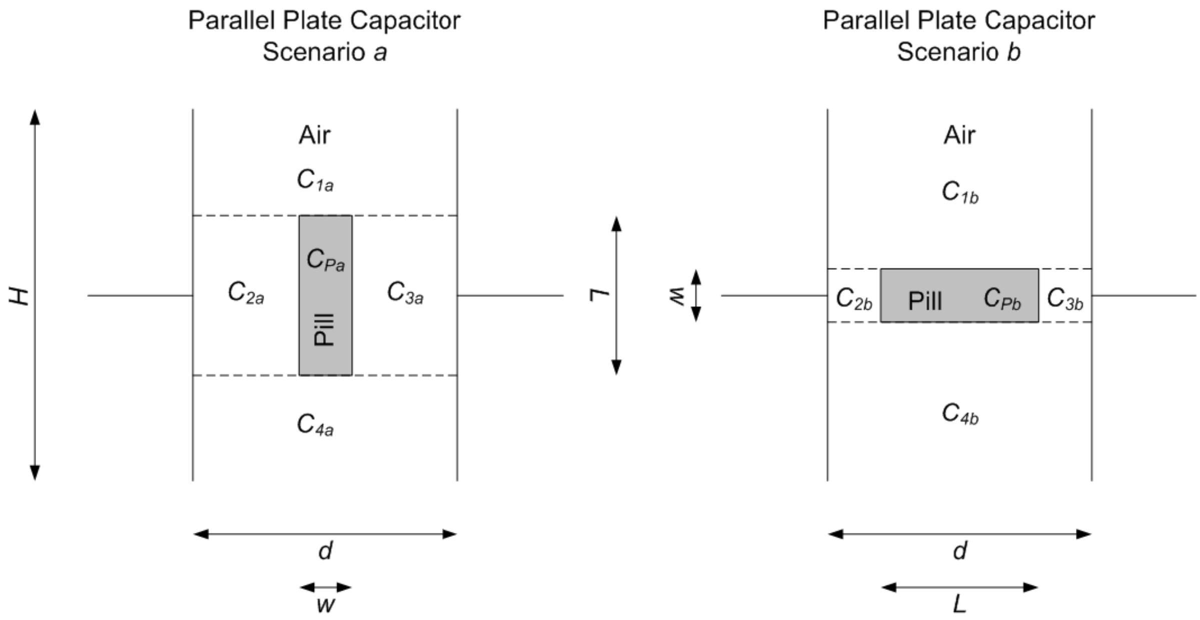

Fig. 1. Series and parallel equivalent capacitances for pills in different orientations in a parallel plate capacitor.

The values in Table 1 show that rotation of the pill by 90° can increase the capacitance of a parallel plate sensor by a significant proportion. In this case, a standard size pill passing through a parallel plate geometry shows an increase in capacitance of 11.3% when the pill rotates 90°. This simple model clearly illustrates that a pill free-falling through the plates with different orientation will lead to different capacitance signatures, and this will reduce the reliability of the inspection process. For example, a rogue pill of larger dimension falling with its long axis horizontal (as in case *b*) may produce the same peak capacitance change as a correct pill falling with vertical orientation (as in case *a*). For robust inspection it is therefore desirable to design a capacitive sensor that has reduced sensitivity to pill orientation, but still able to reliably discriminate between damaged or defective pills.

Table 1. Comparison of capacitances in parallel plate scenarios *a* and *b* with plate dimensions H = 20mm and d = 20 mm, and pill dimensions $w = t$ = 5.5 mm and pill permittivity $\varepsilon_P = 3.5$.

	Capacitance in scenario *a*, Ca/fF	**Capacitance in scenario *b*, Cb/fF**	**% Change in capacitance from scenario *a* to *b***
15mm long pill	57.6	64.1	11.3

This simple model illustrates how the capacitance of a parallel plate capacitor might vary due to pill orientation. The analysis incorrectly assumes that the electric field between the two plates is perfectly uniform. In practice, of course, there are fringing effects seen in the electric field towards the edges of the plates, with electrostatic field spilling outside the region between the two parallel plates. These fringing effects introduce further difficulties when attempting to inspect pills as they free-fall through the capacitive sensor, making the time-varying signatures also dependent on the exact path the pill takes through the plates. Furthermore, the presence of the pill itself distorts the local electric field lines, and even the velocity of the pill influences the perturbation in capacitance. In essence, the non-uniform E-field within the plates gives raise to an effective change in capacitance for different pill trajectories creating ambiguities when inspecting and/or counting pills. These issues are mitigated in the patented Sparc Systems sensor by having a set of orthogonal sensors, with each sensor offering different measurements of the pill transit for the electronics to interpret [1].

Due to the need to inspect pills with high throughput it is not seen as an attractive strategy to strictly control the trajectory of the pills dropping through the inspection region, instead careful design of the longitudinal sensor has been made to ensure that the E-field between the plates is as uniform as possible to mitigate against the effect of statistical variations in the pill trajectory and orientation.

2. Longitudinal Electrostatic Field Sensor Design

The capacitive sensor electrode configuration was designed using finite element analysis packages (Ansoft: Maxwell and Vector Fields). The primary objective of the design, for our target application, is to reduce the variation in sensor signal caused by pills not passing through the centre of the space between the sensor electrodes, and to reduce as much as possible the signal variation due to unavoidable rotation of the pills as they free-fall through the inspection area. The sensor geometry is illustrated in Fig. 2 below.

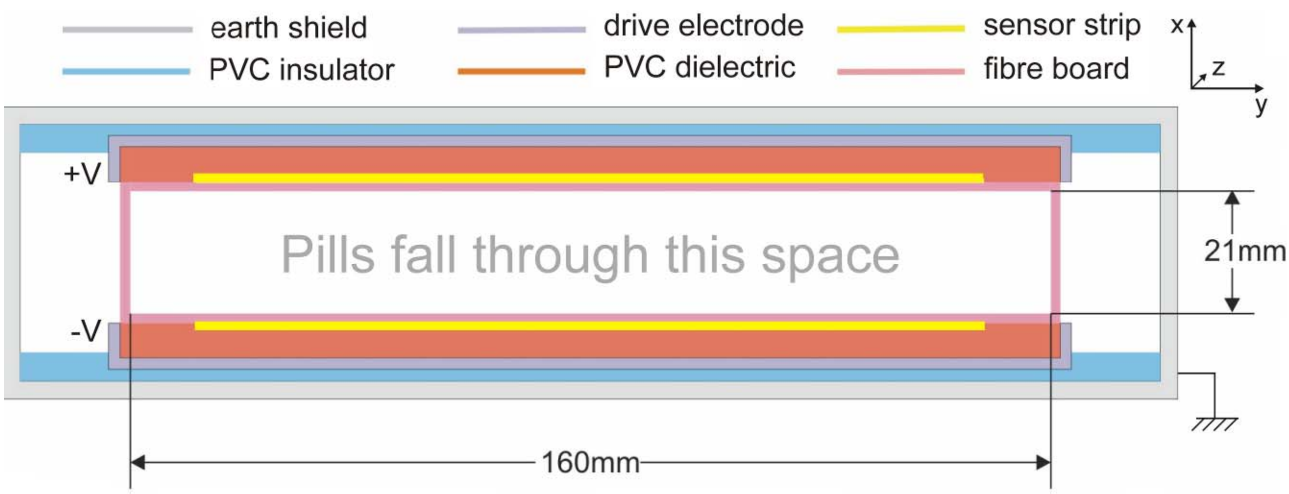

Fig. 2. Plan view drawing of a cross-section of the prototype sensor; x-y plane is horizontal in space, z vertical.

The sensor frame was constructed from dural – an aluminium (95 %), copper (4 %) and magnesium (1%) alloy – and is grounded to act as an Earth shield. The electrostatic shielding effectively surrounds the whole of the structure apart from the entrance aperture of the sensor (160 mm × 21 mm). Polyvinylchloride (PVC, relative permittivity, $\varepsilon_r = 2.9$) is used as an insulator between the outside of the frame and the two drive electrodes, which have been machined out of brass and are U-shaped in the y and z directions to improve the electric field distribution. PVC is also used as the dielectric spacer between the drive electrodes and the fibre board (PCB material FR4) which contains the patterned sensor strips. The sensor strips are PCB copper and have smaller area than the drive electrodes (140mm × 15mm). The complete sensor head is 60mm in the z direction. Voltages are applied to the drive electrodes via BNC sockets which are built into the frame to provide an earth shielding. Similarly, voltages induced on the two sensor strips (sensor electrodes) are taken out through the frame via BNC sockets.

The sensor can be driven in a pulsed or a.c. mode. In the measurements reported in this paper the drive electrodes are driven with an a.c. voltage and are always in anti-phase with each other. When an instantaneous voltage +V and –V is applied to the two drive electrodes respectively simulations confirm that the E-field within the sensing volume is nearly uniform, and across the central axis of the sensor along the y direction the potential is at zero volts. These two conditions are important in obtaining a performance that minimises sensitivity to pill position and orientation. The dielectric between each drive electrode and sensor strip increases the voltages induced on the sensor strips and leads to an improvement in signal-to-noise ratio.

3. Measurement and Discussion of Results

This section will consider results obtained by moving a solid pill-shaped object within the space between the sensor strips. The pill-shaped object was machined from acetal ($\varepsilon_r = 3.5$) and is in the form of a standard capsule-shaped pill (diameter: 5.5mm, length: 15mm). The simulations are carried out using finite element analysis and the experimental results have been obtained by moving the acetal pill inside the sensor and recording the induced voltage on the sensor strips. Measurements are therefore taken with the pills in stationary positions, rather than free-falling through the sensor, which simplifies the experimental set-up. The pill is suspended on a fine nylon thread to minimise any unwanted distortion of the E-field. The pills are translated using DC motor driven XYZ positioners. Data collection is synchronised to the exact pill location using LVDT position sensors, servo-loop and computer control running LabView software for automation. Due to our current experimental set-up the acetal pill cannot be translated in the z direction sufficiently to pass completely through the sensor, but instead can be moved from outside the sensor to just over halfway past the centre. Although not ideal this arrangement was considered acceptable due to the symmetrical nature of the sensor. The data presented in this paper corresponds to a pill signature which is a function of the z direction, rather than with respect to time as would be the normal operation of the sensor when used for pill inspection. The differences in performance are not significantly different and have been explored in subsequent trials, but not reported here.

For the purposes of this laboratory-based investigation the drive electrodes were operated at relatively low voltages (<±20 volts) to allow measurements to be taken using standard lock-in detection methods. In a factory environment, however, a few hundred volts can safely be applied to the electrodes providing a significant increase in signal-to-noise at the sensing electrodes. We applied a 19V peak-to-peak sine wave of frequency 10 kHz to the drive electrodes, with the electrodes in opposite phase such that the peak voltage between the electrodes was 38V. The voltage induced on the sensor strips was buffered using high impedance (10 MΩ) JFET amplifiers before lock-in detection. Care was taken to minimise the effects of stray capacitance as much as possible. The operating frequency is above all the inverse time constants in the circuit. Pill signatures can be obtained from a single sensor strip or by sum/difference of the two; all of which can be set by the operator using the LabView program as part of the automated system.

As anticipated, investigations showed that there was little variation in sensor voltage when translating the acetal pill in the y direction only, which confirmed that the longitudinal field was suitably uniform. The following results therefore concentrate on translating the pill in the z direction, and examining the effects of orientation and translation in the x direction. Fig. 3 shows both simulated (smooth line) and measured results (points) for a single acetal pill moving in the z direction. The x and y positions locate the pill in the exact centre of the inspection aperture. The pill's long axis is oriented in the z direction, and is similar to scenario *a* in Fig. 1. With no objects in the inspection volume the sensor electrodes record a voltage which will be regarded as a background signal, and the results plotted in the figure show the voltage change only (arbitrary scale). A useful figure of merit corresponds to the peak fractional change in sensor voltage, which in this measurement was just 0.06%. Although this seems very small it must be remembered that the pill volume is only a small fraction of the total inspection region, and is only expected to perturb the capacitance by a small amount. The experimental data points also show considerable scatter due to the low signal-to-noise ratio achievable with the laboratory set-up, which can be improved significantly by increasing the drive voltages. The experimental results are in good agreement with the simulations carried out by finite element analysis.

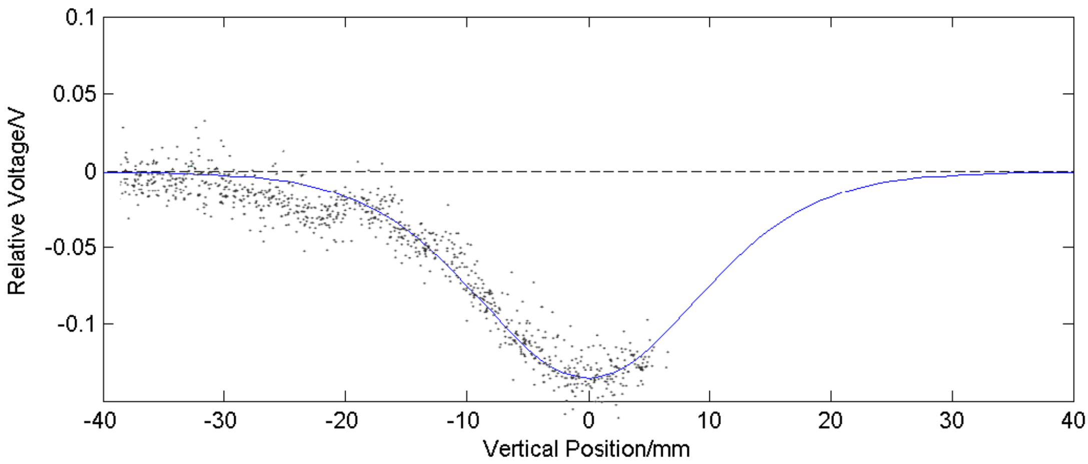

Fig. 3. Simulated (smooth line) and experiment results (points) for a 15mm long capsule-shaped acetal pill passing through the centre of the sensor in the z direction (vertical). The voltage axis is corresponds to the change in the voltage induced on a single sensor strip when both drive electrodes driven in anti-phase.

The induced voltage sensitivity to translation in the x direction was investigated by simulation and experimental verification. Both sets of results confirmed that when the pill is fully within the inspection volume movement in the x direction did not alter the induced voltage by more than 4%. These results showed that the sensor design was not strongly influenced by the exact pill trajectory. The effect of orientation was considered by rotating the pill by 90° at different positions inside the sensor volume. Measurements determined that rotating the pill when close to the centre of the sensor typically caused a 9% change in the induced voltage, but when very close to one of the sensor strips, rotation produced a worst case change of 33%. This was larger than predicted by the simulations and is attributed to the more complex field patterns produced by the pill when oriented as in Fig. 1 scenario *b*. For illustration purposes, the simulated field lines are shown in Fig. 4 for the case of a larger sensor and pill volume to help with the visualisation.

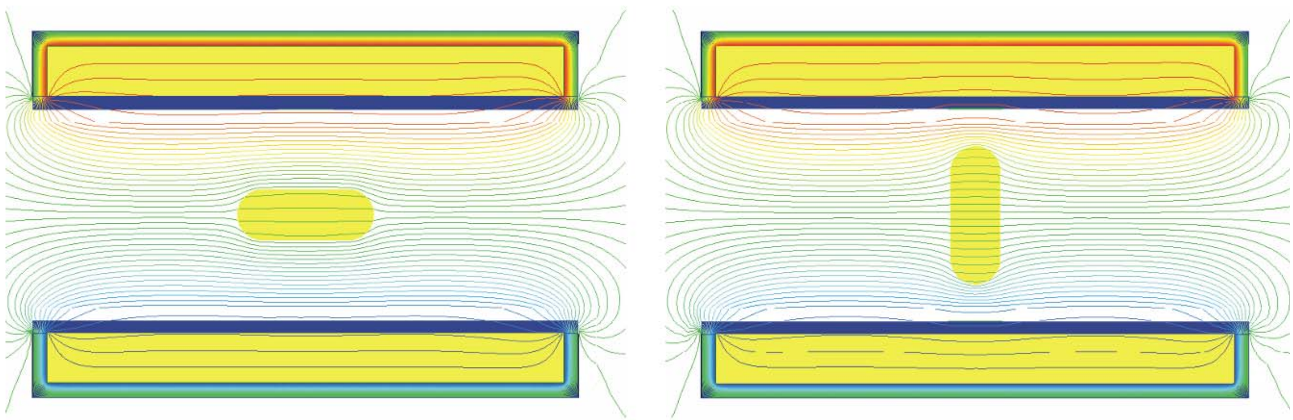

Fig. 4. Lines of equal potential for different pill orientations for an enlarged capacitive sensor, illustrating how

orientation significantly affects the induced sensor voltage.

The influence of pill orientation might be reduced in practice by constraining pills to free-fall with their long axis in the vertical direction only. However, some pills will inevitably rotate whilst free-falling leading to significant variation in sensor voltage; making it difficult to differentiate between a defective pill and the rotation of a "good" pill. Other strategies for reducing the influence of pill rotation include: preventing the pills from dropping too close (< 3mm) to the sensor electrodes by using a dielectric spacer, comparing the induced signals on each of the two sensor strips, and using an algorithm to compensate for rotation by examining the signal profile produced by the free-falling pill.

Finally, the effect of varying pill size was investigated experimentally to ensure that the prototype sensor was able to sufficiently differentiate between a "good" pill with varying pill position (or orientation) and a defective pill. Measurements were taken for a smaller 10mm long capsule-shaped acetal pill of diameter 5.5mm, representing approximately two-thirds of the dielectric volume of the pill used in the previous set of measurements. Experimental data was collected for different pill locations and orientations, and compared to corresponding data obtained using the larger (15mm long) pill. In all cases the smaller pill produced similar results, but with the expected lower peak amplitude; typically between 21% and 35% of that obtained for the larger acetal pill. This indicates that the prototype sensor is able to differentiate between a rogue pill and the variation in pill position for a "good" pill.

5. Conclusions

An innovative new electrostatic field sensor has been designed, with the aim of inspecting pharmaceutical products such as medicinal pills. The target application requires fast counting and inspection of pills free-falling through a rectangular sensing aperture with a high pill throughput. Finite element modelling tools have been used to optimise the design to achieve a near uniform E-field between the sensor plates and to predict the overall performance of the sensor for pills falling through the inspection area at different locations. For cylindrical shaped pills the effect of orientation during free-fall has been investigated and its affect on signal variation reduced by careful design. A prototype has been built and tested with an acetal pill in varying positions and orientations inside the sensor. As the sensor behaves linearly with voltage its performance was investigated at low voltage using a lock-in amplifier to observe changes in sensor output voltage. Static measurements of induced voltage on one of the sensor strips were taken by translating a single pill within the sensor space.

Measurements taken with respect to pill position have shown that the sensor is able to reliably count and inspect pills as required by the target application. The behaviour of the sensor with respect to pill orientation, however, shows significant variation in sensor signal as the pill rotates around the y-axis, which creates difficulties for a robust counting system. Methods to reduce the influence of pill rotation have been discussed that include using the signal profile (as the pill free-falls through the sensor) to interpret signal artefacts due to unfavourable pill trajectories. Also, worst case signal variations can be reduced by using a dielectric insert to prevent pills from approaching too close to the sensor strips. Trials are underway to fully evaluate the sensor and to make further improvements to its design and measurement strategies.

Acknowledgements

The work presented in this paper was supported by a Knowledge Based Partnership grant (KTP000585) and Sparc Systems Limited.

References

[1]. K. V. Shail, S. A. Tolputt, Item Detection/Inspection Arrangement, *United States Patent*, No. 6,504,387, January 2003.

[2]. F. N. Toth, G. C. M. Meijer, A Low-Cost, Smart Capacitive Position Sensor, *IEEE Trans. Instrum. Meas.* 41, 6, 1992, pp. 1041-1044.

[3]. P. W. Kolb, R. S. Decca, H. D. Drew, Capacitive sensor for micropositioning in two dimensions, *Rev. Sci. Instrum.,* 69, 1, 1998, pp. 310-312.

[4]. M. Y. Lu, P. J. Pan, J. S. Li, C. L. Chuang, Capacitive Moisture Sensor, *United States Patent*, No. 5,402,075, March 1995.

Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

Submission of papers

Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 6-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm Authors must follow the instructions strictly when submitting their manuscripts.

Advertising Information

Advertising orders and enquires may be sent to sales@sensorsportal.com Please download also our media kit: http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2008.pdf