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A non-invasive capacitive sensor strip for aerodynamic pressure measurement

M. Zagnoni[a]*, A. Golfarelli[a], S. Callegari[a], A. Talamelli[b], V. Bonora[c], E. Sangiorgi[a], M. Tartagni[a]

[a] ARCES, University of Bologna, Via Fontanelle 40, 47100 Forlí, Italy
[b] DIEM, University of Bologna, Via Fontanelle 40, 47100 Forlí, Italy
[c] DICASM, University of Bologna, Via Fontanelle 40, 47100 Forlí, Italy

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Abstract

This paper presents a capacitive pressure sensor strip implemented in general purpose printed circuit board (PCB) technology based on a thin 3D structure composed of polyimide, woven glass reinforced epoxy resin (FR4) and metal layers. Multiphysics finite elements method (FEM) simulations have been performed over the proposed structure in order to develop a time-dependent electrical and mechanical model that can be easily used to tailor the characteristics to the application. The device targets a wide class of fluid dynamics applications, being non-invasive, comformable and smart for placement. The device simulations are herein validated by experimental wind tunnel measurements and compared with figures obtained on a wing profile by conventional electromechanical pressure transducers. This approach is one of the first example of fully embedding and electronically controlled fluid flow monitoring apparatus that could be used in replacement of state of the art mechanical systems.

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1. Introduction

Pressure measurements are of great importance in almost all field of engineering and industrial application. The recent development of numerical codes to calculate fluid flow has not diminished the need of detailed space and time resolved measurements, both to provide boundary condition and to validate the results. Despite the large amount of literature on the subject [1], whenever sensors are used in situ to monitor pressures on large domains in highly unsteady flows, there are still problems in using classical techniques due, for instance, to the cost of each single transducer, their intrusiveness or their time response.

In transport related industry, sensors are essential for monitoring the fluid dynamic environment, required for instance in aerospace, ground vehicle and nautical applications, and for the aerodynamic body optimization during the design phase. Although similar, the above mentioned applications are characterized by very different environments, requiring sensor features and specifications that are very different from each others. For instance, sensors for aircraft design need high accuracy and precision, working in ranges up to 2 kPa. Conversely, sensors for internal airflow for automotive applications require a reduced sensitivity with respect to the previous ones, operating in a range of pressure from 10 to about 30 kPa and requiring fast dynamic response with regard to the fluid to be monitored. Finally, sensors for nautical applications must be able to resist to wet environments and they must detect pressure ranges up to 300 Pa.

A common specification in most of the above applications is related to the large size of the surfaces that has to be monitored, leading to the use of a large number of sensors in order to achieve the required spatial resolution. In this scenario, a

* Corresponding author. Tel.: +39 0543 786924; fax: +39 0543 786926.
E-mail address: mzagnoni@deis.unibo.it (M. Zagnoni).

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real-time pressure distribution represents an important mean for the analysis of the aerodynamic behavior of the body and for its correct trim.

Modern pressure sensors that are used in this environment are silicon based capacitive sensor [2–4]. Silicon sensors can reach high sensitivity and accuracy, however they scarcely address all the requirements of the above industrial applications, such as high robustness and low manufacturing costs. On the other hand, standard fluid dynamics techniques, as Pitot tube, Prandtl tube or other optic techniques [5,6], are not able to satisfy, in many cases, either the low invasiveness (due to the presence of the pressure tubes) or the required accuracy, reducing their range of applications.

2. Aims and sensor structure

In the last few years printed circuit board (PCB) technology has greatly improved, achieving the photolithographic resolutions of silicon planar technology in the earlier 1970s, thus allowing the design of low cost precision transducers [7,8]. Materials such as polyimides and polyesters are now available in thin films of tens of μm, allowing PCB devices to be used other than connecting electronic components but also as means for mechanical transduction. By using PCB technology it is possible to build up devices achieving most of the specifications required by fluid dynamic applications at low cost. Herein the sensors structure is presented together with the simulation methodology by which these devices can be optimally designed for the targeted application. Furthermore, the use of PCB technology has advantages over other approaches: it allows to naturally host electronic sensing and signal processing components by means of smart packaging such as the chip on board (COB) technology.

The sensor presented in this paper is a capacitive differential pressure transducer built in PCB technology as shown in Fig. 1. The sensitive unit consists of a three layer structure in a stack (Fig. 2): a rigid copper-clad glass-fiber base, a rigid glass-fiber spacer and a 25 μm thick deformable copper-clad Kapton® polyimide layer. Layers are attached to each other by means of a 50 μm thick biadhesive tape, patterned in the same shape as the spacing layer. The device length and width can be set according to the application: the measurements and simulations of this paper are related to devices that are from 13 to 16 cm long and from 1.5 to 3 cm large. The total thickness is below 1 mm. Each unit can be electronically readout in a multiplexed fashion in order to collect a set of surface pressure points, depending upon the application (Fig. 3). All chambers are connected by miniaturized pipes, patterned in the spacing layers, in order to share the same internal pressure. Small holes, drilled on the sides of

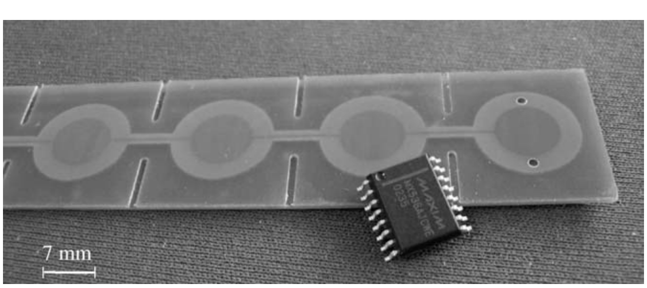

Fig. 1. PCB pressure sensor strip.

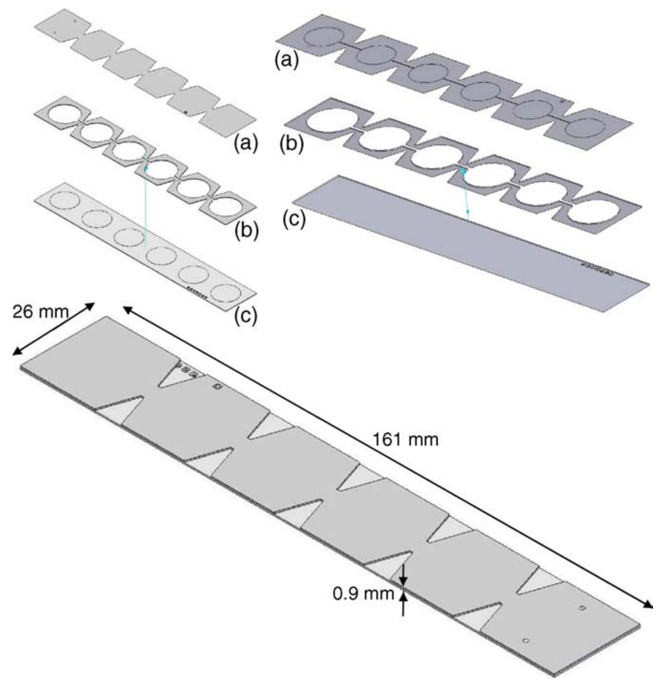

Fig. 2. PCB pressure sensor strip structure: (a) deformable copper-clad polyimide layer, (b) rigid glass-fiber spacer, (c) rigid copper-clad glass-fiber base. Exploded top view (up left side). Exploded bottom view (up right side). Assembled view (bottom).

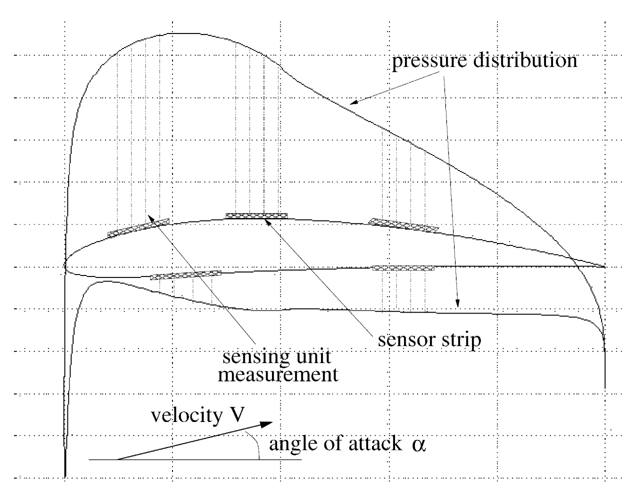

Fig. 3. Application example: monitoring pressure distribution over a wing profile. The pressure distribution over the profile depends by free stream velocity V and angle of attack α: a changing in the (α, V) field leads to a different pressure pattern.