EUROSENSORS 2015

Elaboration of compact synthetic micro-jets based on micro magneto-mechanical systems for aerodynamic flow control

Jean-Claude GERBEDOEN\textsuperscript{a}\textsuperscript{*}, Abdelkrim TALBI\textsuperscript{a}, Romain VIARD\textsuperscript{a,c}, Vladimir Preobrazhensky\textsuperscript{a,c}, Alain Merlen\textsuperscript{b,d}, Philippe PERNOD\textsuperscript{a}

\textsuperscript{a}Univ. Lille, CNRS, Centrale Lille, IEMN UMR 8520, Cité Scientifique, 59651 Villeneuve d’Ascq, France.
\textsuperscript{b}IEMN UMR 8520, USTL, Univ. Lille, Cité Scientifique, 59652 Villeneuve d’Ascq, France.
\textsuperscript{c}Wave Research Center of A. Prokhorov General Physics Institute RAS, Russian 119991, Moscow, Russia.
\textsuperscript{d}ONERA, chemin de la hunière 91123, Palaiseau, France.
\textsuperscript{e}Thurmelec, Aire de la Thur, 68840 Pulversheim, France.

Abstract

This paper describes an optimized and compact lateral slot synthetic jet based on magneto-electro-mechanical actuation. The main objective in designing this device is to meet the performances required for flow control applications on the square back body. First, we present the synthetic jet design and the result of numerical simulations based on finite element method showing the formation of the vortex rings. Secondly, the fabrication process and the elaborated devices were described. Finally, fluidic characterizations were performed using one component calibrated hot wire. The results show that for an operation frequency close to 330 Hz and a bias power less than 1W, the output velocity reaches 40 m/s at 2 mm from the slot exit. The design enables us to choose the range of operation frequency in the frequency range 100Hz-700Hz by varying the thickness of the elastomeric membrane between 100µm and 600µm.

Keywords: actuators; MEMS; synthetic jet;

* Corresponding author: jean-claude.gerbedoen@iemn.univ-lille1.fr ; abdelkrim.talbi@iemn.univ-lille1.fr
1. Introduction

MEMS actuators becomes more and more useful in a wide range of active flow control applications, such as boundary layer separation [1], mixing enhancement [2,3], thermal management [4,5] and turbulence [6]. The synthetic jet (SJ) devices or Zero-net mass-flux (ZNMF) consist of a vibrating diaphragm enabling momentary periodic expulsion and suction states of surrounding fluid at the exit of a slot (or an orifice). The diaphragm oscillations generate successive vortex rings (for orifice exit) or vortex sheets generation (for slot exit) that propagate away from the outlet. The main advantage of the SJ actuators compared to continuous or pulsed one is that they require no inlet fluid source, and consequently are easily implemented in network to achieve practical flow control solution. This paper deals with the design, fabrication and characterization of a compact lateral slot synthetic jet actuated by magneto-electro-mechanical method, which enables us a useful integration on square back body.

2. Design, Simulations and Fabrication

2.1. Design

In general, the design of any actuator must take into account actuation mode, bandwidth, robustness, efficiency, power, weight, size, and so on. The main objective in designing this device is to meet the performances required for flow control applications on the square back body. Then, a lateral slot was incorporated in the design of this SJ in order to achieve integration as possible near the top and bottom edges of the square back body. The design of the SJ is described on figure 1. The SJ actuator consists of a cavity, a slot and oscillatory diaphragm, which dominate the performances of ZNMF actuators [7-10]. All the components are assembled to form an enclosed cavity. The membrane vibration is achieved using a magnetic actuation optimized to provide large out of plane displacements, necessary to achieve the required performances for flow control. The compactness of optimized devices doesn’t exceed 2cm³.

![Fig. 1: Lateral slot synthetic jet with packaging](image)

2.2. Simulation

Finite Element Method (FEM) using COMSOL multiphysics software were used to optimize the design of the synthetic jet device. The model geometry is decomposed in 5 areas: a cavity, a guide for the slot, forming the SJ and 3 areas where the vortex sheet are formed as described on figure 2a. The meshes are refined in the cavity, the slot and the region around the jet axis. The cavity dimension is 10mm×670µm, the guide dimension is 200µm×4mm and the external SJ area is 52mm×25mm. The physical model uses Reynolds-Average Navier-Stokes equations and incompressible flow. For simplification, a velocity inlet boundary condition was applied to the diaphragm. The boundary velocity is chosen in order to obtain an actuation frequency and membrane displacement close to 300Hz and 500µm, respectively. Figure 2a shows the jet velocity magnitude inside and outside the cavity for one time point in expelling state. Figure 2b shows the jet velocity magnitude at different position in the middle of the guide (probe 3), at the exit (probe 2) and at 2mm of the exit (probe 1). The jet velocity profile indicates clearly that the design enables the formation of the jet in the far field with a peak velocity that reaches 40m/s.
2.3. Fabrication

The SJ devices were fabricated based on micromachining technology. The process were performed on 4 inch Silicon wafers. The cavity and diaphragm were elaborated separately. A high flexible elastomeric material is used for the diaphragm, and was spin coated to achieve desired thickness. To pattern diaphragm, cavity and slot, we use a deep Silicon etching based on Bosch process. The membrane thickness is chosen to obtain a resonance frequency of about 300Hz. The cavity was then bonded with the membrane to obtain the final device. At the end of the assembly, NdFeB magnet is added (with grade N48) and glued on the silicon pad located at the membrane center. The final devices were packaged with a polymer mold to enable us an easy integration on a model body (Figure 3a). The process enables us to elaborate 25 SJ devices per wafer. Figure 3b shows the result of two complete processes.

For actuation, a coil has been optimized in order to meet the specifications in term of compactness and to provide force enabling a membrane displacement larger than 500µm.

3. Characterization of the synthetic jet

The jet velocities are measured using a constant-temperature hot-wire anemometer (Dantec Streamline with CTA module 90C10), with 1-D probe (55P11). A current of amplitude close to 0.6A was feed in the coil of resistance close to 3.5Ω. The amplifier was set in a constant current mode. The hot-wire probe was positioned alongside of the slot and centered at a distance of about 2mm from the exit slot. The micro-jet velocity reaches a maximum at 330 Hz as shown on figure 4a, which corresponds to the membrane resonance frequency. Figures 4b shows an example of the
device response: jet velocity versus time for burst actuation signal mode. The maximum output velocity is around 43m/s. Characterizations of all devices issued from the two-batch process show dispersion on the peak velocity of around +/-5%, which is due principally to the inhomogeneous membrane thickness.

4. Conclusion

The aim of this study was to demonstrate the feasibility of compact MMEMS actuators with high performance and its potential for future application in the automotive industry thanks to its low consumption (<1W per micro jet) and easy integration (compact dimensions ~2cm³). The synthetic micro-jets used in this study, leads to significant maximum high speed outlet (43m/s) at 330Hz.

Acknowledgements

This work was supported by the French National Research Agency (ANR), in the frame of the project Limitation of the impact of vehicles on the environment by means of aerodynamic control using synthetic micro-jets (LIVE-CAMS).

References