EMF generation from a fluttering magnetic flag

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***Abstract*—An EMF generation system based on electromagnetic induction is considered. It consists of a fluttering articulated magnetic flag in axial water flow which induces an electromotive force in a circular coil. The kinematics of the fluttering flag is tracked experimentally by image processing. This alows to compute the induced EMF across a loop of the coil. The position and radius of the loop that maximizes the EMF are finally sought for.**

I. Introduction

Electromagnetic induction is the generation of an electromotive force (EMF) by a conductor subject to a time varying magnetic flux. This is involved in several power generations applications using permanent magnets. For example, they are used in Permanent-magnet AC generators [1], in power generation from low frequency vibrations **(?)** [2] and using renewable energy resources **(?)** [3]. **(faudrait être un peu plus précis sur les deux dernières refs)** Harvesting energy from classical fluid-solid instabilities has received a considerable amount of attention during the last decade. In particular, the case of a fluttering plate in an axial flow has been consisdered both using piezoelectric coupling [4], [**?**] and induction [**?**]. In the latter case, the system consisted of an oscillating steel plate that perturbates a surrounding magnetic field. In the case presented here, the system consists of an articulated plate made of permanent magnets. When the plate enters in self-oscillation the oscillating magnetic field is hence produced by the plate itself. The present work focuses on finding the position and geometry of the induction loop that maximizes the generated EMF.

II. EMF generation system

We consider the EMF generation system in a water flow sketched in Fig. 1. It consists of an articulated magnetic flag in an axial flow in proximity with a coil. Experimentally, a water tunnel of rectangular section 7.5 cm $\times$ 15 cm is used. As is represented in the Fig. 1, the flag consists of 3 rectangular neodymium magnets having the same length and width L, a small thickness $h \ll L$ and a uniform magnetization along the thickness. These magnets are linked by articulations, the first being clamped to hold the fluttering flag. Below this system, a coil of N turns of spiral wire is placed. Once the flow velocity reaches a critical value, spontaneous oscillations occur and time varying magnetic flux is generated through the coil. The estimation of the induced EMF is performed in two stages.

First, using an high speed camera we produce an image sequence of the flag fluttering for different flow velocities U_f without the coil. For each frame of the videos, the positions of the 3 plates are tracked in the coordinate system (x, y, z)

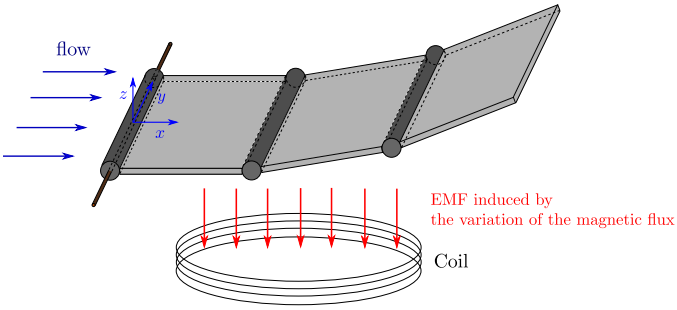

Figure 1. Sketch of the EMF generation system. The articulated flag of 3 magnetized plates is fluttering in a water flow. A coil is placed below to induce the EMF from the time variation of the magnetic flux.

whose origin is at the center of the clamped articulation (Fig. 1). The magnetic field is then computed from these data. The time varying magnetic flux and also the induced EMF for a period of oscillation are next computed for a coil of a given geometry. Figure. 2 represents one of the results obtained at $U_f = 6$ m/s for a circular loop of 2 cm of radius whose center **of gravity???** is at $(0.05, 0, -0.06)$.

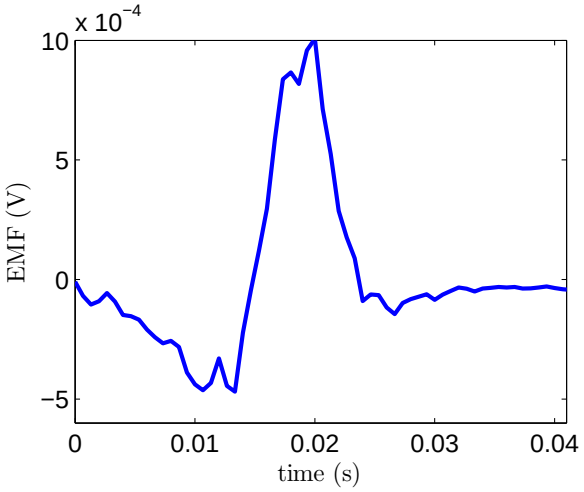

Figure 2. EMF induced from the flag fluttering at $U_f = 6$ m/s in a circular loop of 2 cm of radius whose center of gravity is placed at $(0.05, 0, -0.06)$ during one period of oscillation.

III. Optimization of the system

The EMF induced in a circular loop depends on its radius and its center of gravity position (x_0, y_0, z_0). Fixing z_0, we sought the optimum position and radius of a loop for which we

have the maximum of root mean square (RMS) of EMF. This maximization problem is solved using Nelder-Mead method [5] for different values of z_0.

Currently, instead of imagining a circular coil, we are performing the experiments of fluttering flag with real circular coils to validate the numerical estimation of the induced EMF. After the validation phase, we plan to assemble an electric circuit to develop an energy harvesting system.

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