LARGE DISPLACEMENT SMA ELECTRO-MORPHING PLATE FOR WIND TUNNEL EXPERIMENTS

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Summary: *This work present the experimental velocity field obtained for an electro-active plate placed in a wind tunnel. Actuators used in this study are SMA technology. In a first section, we will present studies on a single SMA wire. Next we will present Particles Images Velocimetry (PIV) results obtained in wind tunnel section.*

CONTEXT OF THE STUDY

Wing deformation studies in the aerospace area are subject of much recent interest [1]. The development of micro and nano-air vehicles conducted by the French foundation of "Sciences et Technologies pour l'Aéronautique et l'Espace" led to the launch of the RTRA-EMMAV research program (Electro-active Morphing for Micro Air Vehicles) for the period 2009-2011. This program, composed by three French laboratories (IMFT, LAPLACE, ISAE), aims at optimising micro-air-vehicle performances in realistic environments by means of electro-active morphing concepts. In this context, the team at LAPLACE developed a deformable plate which permits the study of fluids-structure coupling in wind tunnel experiments using innovative actuation technology. The aim of this work is to present the different steps studied during the construction of the EMMAV electro-active plate. Initially, our work is focused on the plate deformation by torsion characterized by large amplitude and low frequency. SMA (Shape Memory alloy) technology was choosen to realize the deformation. For the last decades SMA technology was intensively studied and is now well understood. This material commonly used to an alternative actuator has many applications in industry including medical and aerospace. SMA is defined by a thermo-mechanical coupling that is to say that it could be used as actuator by controlling the temperature of the material. The EMMAV project conduced LAPLACE laboratory to define two different objectives [2]. Firstly, the control of the displacement deformable plate appears as the most important problem to resolve. This problem motivated a study in order to find a physical parameter which could be considered as a displacement image. This parameter is intended to be implanted in a computational program. Secondly, the dynamics of deformation has to be optimized. At this step, the problem consists in minimizing the time necessary to change the plate position.
This work is divided in two parts. In the first section, we will study a unique SMA wire. A theoretical model is developed and experiments on unique SMA wire are suited. This work permits the creation of an SMA electro-active plate (called EMMAV plate). In the second section, we will describe velocity field measurement realized in a wind section tunnel with the EMMAV plate.

SMA CARACTERIZATION

Theoretical model

In a first approach, we decided to study a single SMA wire. The studied SMA could be considered as a metal binary mixture of Titanium (Ti) and Nickel (Ni). This kind of SMA mixture is largely described in the literature [3]. We develop a theoretical model in order to predict the thermal distribution in the SMA wire. The chosen method to control the SMA temperature was to electrify the wire by a continuous electrical field. The predicted temperature could be written in function of the current intensity taking into account, at a first time, the natural conduction inside the SMA wire and secondly the natural, or forced, convection on the free surface. The goal of this model is to predict the temperature dependent crystalline phase changing (Martensite-Austenite) which is responsible of shape memory effect of the SMA.

Experimental validation

A 200 mm Ti-Ni SMA wire of 1 mm diameter was studied. The metal wire is electrified by continuous current generator which permits to control the current intensity. A thermo-sensor records the temperature at the SMA surface while SMA relative displacement and SMA electrical resistance are also measured. The data is then computed in a Matlab program. The experiment permitted to establish the steady temperature dependence with the current intensity. According to the theoretical model, the SMA surface temperature increases in time exponentially before stabilizing on a limit value temperature which depends of the metal wire properties, the current intensity and the ambient temperature. A maximum SMA relative displacement value is linked to the steady temperature. A second experimental setup was studied in which forced convection is applied. The metal wire is placed in a cylindrical tube in which a steady air flow is applied. Experiments pointed out the improvement of the cooling response. Indeed the cooling response time indicated by a forced convection is of the same order as the heating response while there is a ten order difference between heating and cooling response with natural convection only. The SMA wire experiments permits to optimize the shape memory cycle.

Displacement control and dynamical optimization

The SMA electrical measurement permitted us to compute the electrical resistivity of the metallic wire. The previous experiment confirmed that the SMA resistivity could be considered as an image of the crystalline phase. SMA resistivity seems to be independent of the current intensity and the decreasing of the resistivity with the augmentation of the temperature could be interpreted as the progressive evolution of the Martensite phase to the Austenite phase. Electrical resistivity remains the better parameter to control the relative displacement of the SMA wire while the electrical intensity is chosen as the control parameter of the temporal dynamics of the SMA relative displacement.

Electro-active plate

EMMAV plate is a PEEK plate of 15×300×600 mm. the SMA wire are implanted on the surface of the plate and maintained at the plate by fasteners polymer (Fig 1.b). Indeed the longitudinal SMA displacement constrained the polymer plate and this configuration permits a maximal bending displacement of the trailing edge about 36 mm. The maximal displacement is obtained for 3 s, which was a necessary condition to realize velocity measurement in a wind tunnel section (see next section). Initially the SMA wires are placed above and under the plate which permits a twisted bending movement.

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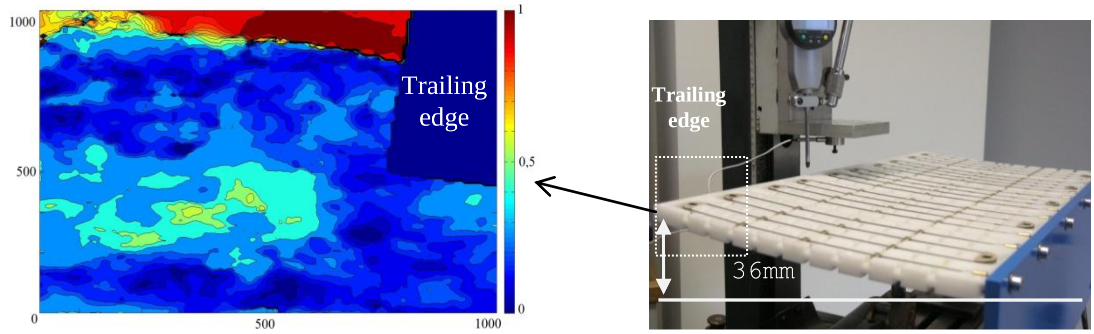

Figure 1.a) Picture of PIV measurement realized in the S4 IMFT wind tunnel. Distances are given in Pixel and the velocity is normalized. b) Picture of the EMMAV plate.

In this experiment, EMMAV plate is placed in the S4 wind tunnel section (2×0,7×0,6 m) of the IMFT. A time resolved 2D2C Particles Images Velocimetry (TRPIV) measurement was realized [4], in a little area, near the trailing edge (Fig 1.a). The PIV configuration permits a 2D velocity field measurement. Cross correlation algorithms are realized using the home software PIVis [5] develop in the IMFT. In order to obtain a good velocity map in the studied area, we needed to develop images processing composed by an image median subtraction and an Intensity capping treatment. After a velocity field treatment, a final velocity map could be obtaining (Fig 1.a). As we can see, a Von Karman vortex is clearly visible under the trailing edge and the shear layer is also clearly illustrated. Our measurements indicated that the plate deformation induced a modification of the position of the Von Karman vortices as well as the shear layer position. These modifications have the potential to reduce both the noise and the drag coefficient.

CONCLUSIONS AND OVERVIEWS

The effectuated work provided the possibility to fully characterize the SMA deformation. Furthermore the analyzed cooling method allowed a better control and thereby a higher frequency of utilization. The usage within a deformable wing and the potential benefits were demonstrated and will be further investigated. Wind tunnel experiments clearly showed that the wing deformation induced a modification of the aerodynamical behaviour. The present work will be extended to more complex movement (PIV for oscillating plate movement...). Otherwise, EMMAV program wants to implant more complex technology on the plate. Actually Piezo ceramic and Piezo polymers actuators are studied in order to realize high frequency bending movement.

References

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