Passive and active vibrations allow self-organization in large-scale electromechanical systems

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I. EXTENDED ABSTRACT

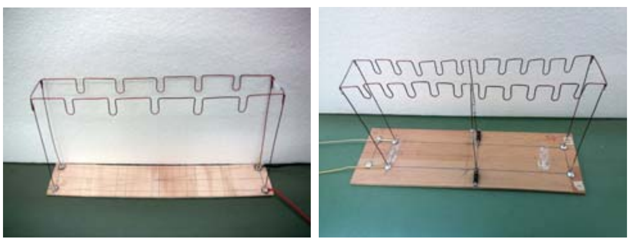
In this contribution our attention is devoted to the fundamental role of mechanical noise[1] to favor the working of a complex electromechanical system. In the literature it has been studied how uncertainty allows self-organization of pendulums arrays[2]. The idea of our contribution is to show that mechanical noise can play a fundamental role in the self-organization of complex electromechanical systems.

The considered system is essentially based on a low weight mechanical structure that supports very simple rotating coils. With this term we indicate coils realized with few turns of a copper wire. The $i-$th coil can be described with a nonlinear dynamical model:

$$\begin{cases} \dot{X}_i = Y_i \\ \dot{Y}_i = \frac{1}{J}(I_a SB \sin(X_i) - K_1 Y_i) \end{cases} \tag{1}$$

where X_i ($i = 1, \dots, N$ with N indicating the number of coils) represents the phase of the coil, Y_i the angular velocity, J the angular momentum, K_1 the damping factor, I_a is the current flowing into the coil and is given by $I_a = \frac{V_a - YSB\sin(X_i)}{R_a}$ with V_a the voltage supplied to the coil, S the coil area, B the magnetic field and R_a the contact resistance, which, due to the coil construction constraint, is nonlinear: $R_a = \begin{cases} 0.4\Omega & if X < \pi \\ 10k\Omega & if X \geq \pi \end{cases}$.

The structures that are considered are of the type shown in Fig. 1, where the coils are hosted in the various slots and powered by a unique voltage source.



(a) (b)

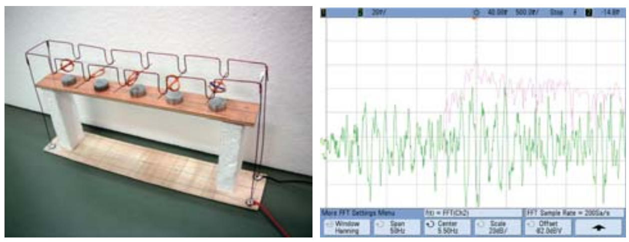
FIG. 1. Structures used to host the coils: (a) rectangular structure with 5 slots; (b) rectangular structure with 10 slots.

The investigated structures are classified in the family of large scale dynamical systems, in the sense that the low weight of the structure, including the coils, is negligible with respect to the volume. The task that we want to achieve is, at the first step, to have the complete start up of the various coils and, then, to get a complete synchronization of the coils, both as regards their angular speed and phase.

The mechanical structure is a flexible structure[3] where the natural modes have the main frequency between 10Hz and 30Hz. The coils, even if they are easy represented by the model in equation (1), globally should be considered nonlinear uncertain systems, due to the practical difficulties in building identical coils. Another source of uncertainty derives from the fact that the coils are located in the mechanical structure free of moving in the three directions. Moreover, the structure and the slots, where the coils are located, are different each other. Therefore, there are tremendous negative conditions to get a regular behavior of the system.

Depending on the initial conditions, when the power is switched on, typically it occurs that some coils start rotating, while others do not. The idea is to design flexible structures that, mechanically excited by their self-oscillations, allow the coils which are not working to receive solicitations in order to win the off condition and to start working. This should occur globally and due to the mechanical vibrations that couple each coil with the other. Therefore, the mechanical vibrations should allow the self-organization of the system in order to win the uncertainties.

In the structure of Fig. 2(a) the mechanical vibrations elicited by those coils, which do start when the power supply is switched on, are enough large to let the other coils to also start. So, in the structure of Fig. 2(a), over a relevant number of trials under the same power supply conditions, the various coils work. In Fig. 3 the trends of the angular velocities of the five coils are reported and in Fig. 2(b) the horizontal mechanical displacement that allows the self-organization of the coils is shown.



(a) (b)

FIG. 2. (a) Structure of Fig. 1(a) with the coils. (b) Horizontal displacement of the structure.

Coupling more structures of this type, as shown in Fig. 4, by using mechanical springs a global start up of a

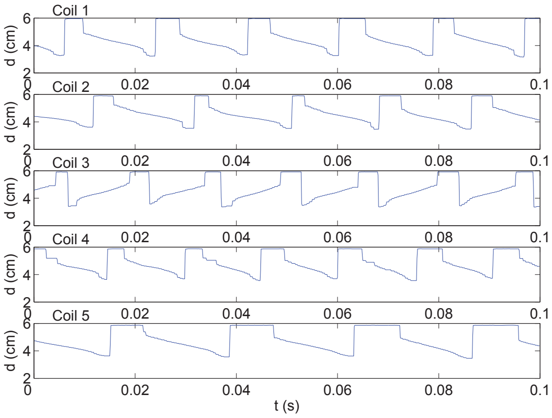


FIG. 3. Angular velocity for the 5 different coils.

system with 10 coils can be achieved, while for the structure of Fig. 1(b) an active solution has to be envisaged.

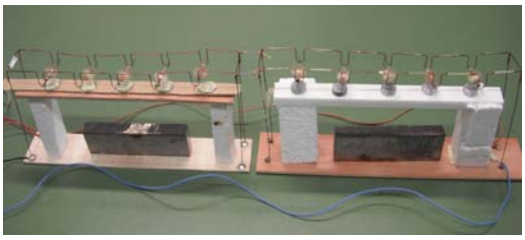
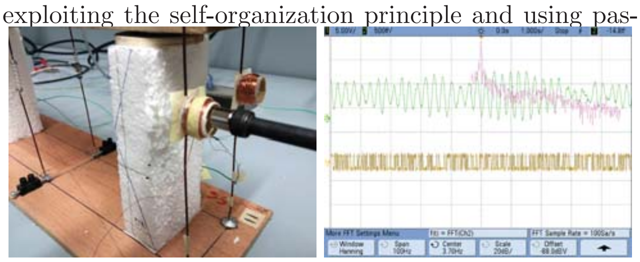


FIG. 4. Two structures with 5 coils coupled through two springs.

The resulting structure is more rigid, and, therefore, the self-generated vibrations of the coils cannot allow the complete start up of all the coils of the system. In order to overcome this drawback, a shock system actuated with low power electromechanical transducer has been conceived to excite the mechanical structure to favor active vibrations helping the start up of coils. The electromagnetic actuator is driven by a chaotic signal generated by a Chua's circuit[4]. This signal works in the range of the natural frequencies of the mechanical system, to give suitable electrical signal in order to stimulate in an active way the system to start. In Fig. 5(a) the proposed structure is reported. In Fig. 6 the trends of the angular velocities of the various coils are reported and in Fig. 5(b) the induced mechanical vibrations. After the start up of the system, the actuator is switched off.

The project will consist of coupling a great number of coils and study the possibility to favor the self-organization of the coils by using different ways such as: self-elicited oscillation of the structure, passive coupling and active generation of mechanical vibrations. The project is conceived in order to design and realize experimentally a system with hundreds of coils. The main idea is to establish the conditions under which a global behavior can be obtained in high order structures of coils by exploiting the self-organization principle and using passive low level power induced fluctuations or external powered devices; this latter solution is needed only during the complete start up of the system.



(a) (b)

FIG. 5. (a) Structure of Fig. 1(b) including the coils and the active shock system. (b) Horizontal displacement of the structure.

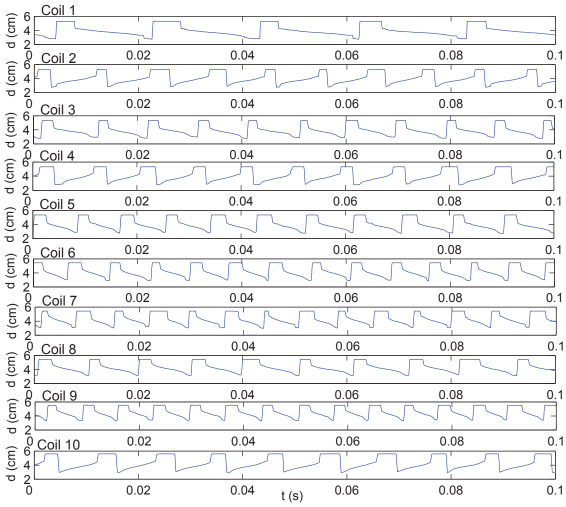


FIG. 6. Angular velocity for the 10 different coils.

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