Title of the project :
New nonlinear design for cyclic symmetric structures

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1 Context

The society is currently facing the paradox of an ever more interconnecting world and its need to decrease the pollution to protect the environment. In this context, European authorities have defined specific goals for aeronautical companies. In the short-term planning, they must decrease carbon emission and noise pollution. The proposed work is in line with the ecological goals and aims to be a pioneer for the 2050 target, which is carbon neutrality. These formidable challenges require a new vision of designing airplanes engines.

In order to reduce fuel consumption, designers aim to increase the bypass ratio of the engines. Thanks to the developments of composite materials, fan systems have become larger while maintaining a slender profile. However, the intrinsic geometrical effects become more pronounced, leading to a nonlinear dynamic behavior. One of the main features of nonlinear system is that multiple stable solutions can coexist. This project thus aims to find these new solutions and design the system to make them advantageous in term of vibration attenuation.

Complex dynamic behaviors (internal resonances, subharmonic interaction, and so on) arise in nonlinear systems. Different kinds of solution may exist : stable/unstable, periodic, quasiperiodic, and chaotic. Bringing new insights into these behaviors will enable using these nonlinearities for energy transfer between the modes, and thus aiming for a global energy reduction.

2 Description of the project

2.1 Goals

This project aims to propose new design of cyclic symmetric structures using wisely the intrinsic nonlinearities to decrease the vibration levels. To achieve this, it is mandatory to compute all periodic solutions of the systems, to characterize them and follow their evolution. The outline of the project is the following

1. Carry out an extensive literature review of the different analytical and numerical methods and evaluate their respective efficiency.
2. Apply and adapt the most promising strategy to cyclic symmetric structures
3. Low dimension system will be initially investigated before large scale systems.
4. Find, on an experimental setup, the solutions (isolas, bifurcations, etc).

2.2 State of the art

When nonlinearities are taken into account, the system exhibit numerous stable and unstable solutions [1]. Continuation strategy and bifurcation tracking [2, 3] exist to compute these underlying solutions from the linear system. However, other solutions, called isolas, also exist and are detached from the main solution curve. These solutions come from modes coupling and have been observed numerically [4] and experimentally [5]. Many strategies have been proposed throughout the years to compute these solutions: Groebner basis [6], Melnikov principle [7], and so on. Cyclic symmetric structures are found in many engineering systems: engines, nuclear power plant, windmills, and so on. The nonlinear dynamics of these structures is extremely interesting as the mathematical properties of cyclic symmetry can be combined to the nonlinear features of the system. This research topic is largely studied [8, 9, 10, 11].

3 Associated research team

The candidate will join the Complex Systems Dynamics team (DYSCO) at Ecole Centrale de Lyon. The person will be supervised by Samuel Quaegebeur (junior professor at Ecole Centrale de Lyon) and by Fabrice Thouverez (full professor at Ecole Centrale de Lyon). Depending on the results of the research, a partnership with Camille-Jordan institute might be considered.

4 Skills

- Nonlinear Dynamics
- Applied mathematics
- Programming software
- English

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Title of the project :
Rotating bladed disk vibratory reduction with piezoelectric elements

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1 Contexte

The society is currently facing the paradox of an ever more interconnecting world and its need to decrease the pollution to protect the environment. In this context, European authorities have defined specific goals for aeronautical companies. In the short-term planning, they must decrease carbon emission and noise pollution. The proposed work is in line with the ecological goals and aims to be a pioneer for the 2050 target, which is carbon neutrality. These formidable challenges require a new vision of designing airplanes engines.

Engines vibrations are one of the main cause for noise pollution and system failure. Understanding and mitigating these vibrations allows decreasing the consumption of primary resources. Several strategies have been developed throughout the years to decrease the vibration level. For bladed disk systems, a mechanical passive approach is usually employed: small mechanical parts (underplatform dampers or friction rings for instance) are inserted into the main system to decrease the energy by friction. These approaches are cheap and barely invasive. However, they may be inefficient for some mode shapes of the structure: some modes may create a relative displacement at the contact interface which is more or less prone to dissipation. Besides, predicting the vibration reduction requires complex nonlinear static and dynamic computation.

An interesting alternative approach consists in using piezoelectric patches to convert mechanical energy into electric one. By connecting the system to a well-designed electrical circuits (shunt), the vibratory energy can be dissipated. This approach is becoming widely used in the scientific community and is often used to create metamaterials whose properties can not be realized currently with standard mechanical systems.

2 Description of the project

2.1 Goals

The main purpose of this work is to reduce the vibration levels of a rotating bladed disk system through piezoelectric patches and thus to create a highly damped metarotor. Piezoelectric patches can be connected to synthetic impedances to virtually realize any electrical circuits or mechanical components. Three approaches will be investigated during this project. Each one of them presents orginal features and can be subject to journal publications.

1. First a shunt approach will be investigated. A synthetic impedance mimicking an electrical circuit targeting a specific mode will be implemented. This strategy is well known but has never been realized on a rotating bladed disk system.

2. A second approach consisting of virtual acoustic black hole will be investigated. While the shunt strategy targets specific modes, the acoustic black hole is efficient starting from a cut-on frequency. Its reduction capacities is thus very interesting. However, its experimental implementation remains challenging and instabilities may arise.

3. Bladed disk structures are usually modeled as cyclic symmetric systems. However, this mathematical property breaks when mistuning (blades may be slightly different from one another due to manufacture tolerance or wear) is taken into account. Mistuning usually has the negative impact of increasing the vibration level due to the localization phenomena. The third proposed approach consists in implementing into the piezoelectric elements a control pattern to retune the structure and thus to optimize its vibration level.

This project will use the three main components of any scientific approach: theoretical (20%), numerical (40%), and experimental (40%).

2.2 State of the art

The shunt approach was initially proposed by Hagood and Flotow [1]. Since then, it has been widely used [2, 3]. One of the main challenges of such a strategy is the high inductance values required to target low frequency modes. To remedy this issue, Flemming et al. [4] proposed the idea of a synthetic impedance: the electrodes of the piezoelectric patches are connected to a digital circuit modeling any control law. This strategy offers countless of possibilities [5, 6, 7], such as nonlinear digital vibrations absorbers [8] or rainbow trapping devices [9].

For the shunt approach, different works have managed vibration reduction for a non-rotating structure [10] numerically, and [11] experimentally. Virtual acoustic black holes have already been implemented for the beam case [12]. For these first two approaches, the strategy to define the control law has already been defined.

3 Associated research team

The candidate will join the Complex Systems Dynamics team (DYSCO) at Ecole Centrale de Lyon. The person will be supervised by Samuel Quaegebeur (junior professor at Ecole Centrale de Lyon) and by Fabrice Thouverez (full professor at Ecole Centrale de Lyon).

4 Skills

- Mechanical Engineering
- Control theory
- Matlab, Simulink software
- English

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