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On the Use of Machine Learning for Vibration Control Purposes in Metastructures: Benefits and Challenges

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I. INTRODUCTION

The concept of employing distributed tuned oscillatory attachments in the metamaterials and metastructures (MSs) began to evolve at the beginning of the new millennium [1]. However, a widely accepted framework for the specific tuning of these oscillators has not been established yet. Several factors contribute to this shortcoming. Firstly, there exists a broad spectrum of mechanical models for MSs, and a comprehensive framework that integrates all these models is challenging to define. Secondly, MSs are frequently depicted as chains composed of multiple mass-in-mass units with complex forms of the corresponding governing equations. As their analytical treatments are cumbersome, researchers have resorted to utilising numerical methods. The application of data science and machine learning (ML) has open new horizons in this respect. To highlight the beneficial use of ML methodologies for MSs, this work first provides an overview of the state-of-the art regarding their mechanical models and practical realizations, focusing on the type of oscillatory attachments and the resulting responses. Then, the summary of some author's contributions to the field of the design of oscillatory attachments in MSs, achieved with co-workers [2-4] is presented related to their design, specifically targeting objectives beneficial for vibration control.

II. ON THE ORIGINAL AND RESEDIGNED METASTRUCTURES

The focus is on a base excited MS that incorporates periodically arranged external units, each containing internal oscillatory attachments. The initial design of these attachments in the MS, labelled here as MS0 (Fig. 1a), aimed to reduce vibrations around the first structural resonance was characterized by uniformity of the form and arrangement of oscillatory attachments [2]. To achieve efficient vibration control around the second or higher resonance, an analytical approach is developed first [3]. Since the values of some parameters were practically unattainable, a procedure involving ML methodology was developed [4]. The initial phase for the latter comprised the creation of a distinct numerical dataset comprising frequency-displacement amplitude diagrams within COMSOL simulation software. Secondly, two specific ML techniques (Support Vector Regression and Artificial Neural Networks) were utilized. Their efficacy and accuracy were assessed, and the surpassing one was detected. In the third phase, the optimization process was undertaken with two optimality criteria. The first one pertained to the region of vibration attenuation, which was defined as the frequency region within which the displacement amplitude of the newly designed MS is lower than that of the original one, surrounding the second modal frequency. This yielded the redesigned MS1 (Fig. 1b), featuring an innovative configuration of three types of oscillatory attachments, whose unique forms and arrangement are neither simple nor intuitively predictable. The second optimality criterion was related to the total width of the frequency ranges that demonstrate vibration reduction around both the first and second frequencies. The redesigned MS2 (Fig. 1c) was obtained to feature uniformly distributed oscillatory attachments of the same shape as those in MS0 but characterised by different dimensions. Both the original and the redesigned MSs were produced using 3D printing technology, as seen in Figure 1a)-c), and subsequently experimentally investigated to validate the benefits of the redesigns obtained by the ML technique for the sake of vibration control.

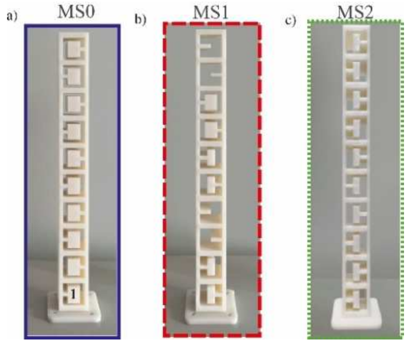

Fig. 1. The original MS0 and the redesigned MS1 and MS2

III. CONCLUSION

In addition to outlining a newly developed methodology for implementing ML techniques aimed at reaching a novel design of MSs with oscillatory attachments for the sake of effective vibration control, this study also illustrates their beneficial effects regarding originality and flexibility. Furthermore, this study also highlights specific challenges posed by system dynamics, relevant not only to this particular research but also to the broader field of vibration control.

IV ACKNOWLEDGEMENT

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