Theoretical Analysis of Semi-active Noise Control and First Experiments

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Introduction

A significant reduction of disturbing noise can be achieved by passive, semi-active and fully active control approaches. Passive noise treatments such as dynamic vibration absorber are very robust and can be applied to obtain a broadband performance. Active noise control systems are designed to control harmonic or broadband noise. They are very effective, if the control volume is small as known from single-input/single-output systems used in active headphones.

However, if distributed control is required, the control profit is not scalable, because the required multiple-input/multiple-output systems must be adjusted to specific acoustic modes as known from the active control of propeller-aircraft interior noise. Semi-active control that is based on the principle of dissipation allows to combine several single-input/single-output systems without cross-coupling. Thus semi-active approaches are capable to solve the problem of scalability.

The paper reports on a specific approach that is based on a dynamic absorber attached to a vibrating structure and coupled with a dissipating electrical network. The electrical components of this network can be adjusted to the mechanical impedance to realize dissipation. The theoretical investigations as well as results of first experiments will be presented.

Theoretical Investigations

As reported in [1] the working principle of semi-active vibration control can be analysed using a linear and time-invariant discrete electro- mechanical model, as shown in figure **1**. The response to the excitation force F_S is described by 3 degrees of freedom (x_S, x_E, i). As further shown in [1] it is possible to reduce the complexity of the problem, if the equations of motion are analysed in a non-dimensional representation. Considering time-harmonic fluctuations of all quantities, the transfer behaviour of the discrete system is therefore described by the complex compliance matrix

$$\{\mathrm{N}\} = \mathrm{inv}(-f^2\{\mathrm{M}\} + \mathrm{i}f\{\mathrm{B}\} + \{\mathrm{K}\}) \qquad (1)$$

with mass normalized matrix {M}, normalized damping matrix {B} and normalized stiffness matric {K} such as

$$\{M\} = [[1,\ 0,\ 0];[0,\ m,\ 0];[0,\ 0,\ 1]] \qquad (2)$$

$$\{B\} = [[2D(1 + b),\ -\ 2Db,\ 2D];[-\ 2Db,\ 2Db,\ -2D];[-2Ew\gamma,\ Ew\gamma,\ 2Ew]] \qquad (3)$$

$$\{K\} = [[1+n,\ -n,\ 0];[-n,\ n,\ 0];[0,\ 0,\ 0]]. \qquad (4)$$

The model parameter introduced in equation (**2**), (**3**), and (**4**) are the relative mass m = 0.1, the normalized structural damping D = 0.005, the relative viscosity b = 0.1, the relative stiffness n = 0.1, the normalized decay constant of the electrical circuit Ew = 456.9, and the normalized force factor γ = [0.0, 0.5, 1.5, 2.5, 3.5, 4.5].

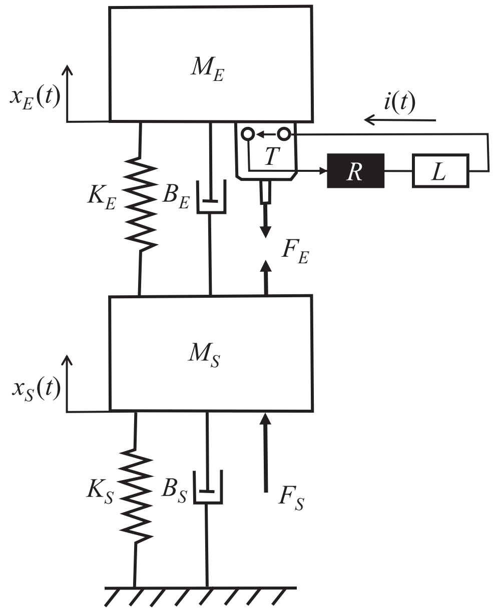

Figure 1: Discrete electro-mechanical model with M_S – mass of structure, B_S – viscosity of structure, K_S – stiffness of structure, F_S – excitation force, x_S – displacement of structure, M_E – mass of exciter, B_E – viscosity of exciter, K_E – stiffness of exciter, F_E – electro-dynamic force, x_E – displacement of exciter, i – electric current, R – electric resistance, T – force factor, L – inductance, see [1].

The dynamic behaviour is finally described by nine complex and dimensionless frequency response functions N_{ij}. In order to study the system response it is possible to introduce a logarithmic measure as defined in equation (**5**)

$$H_{\mathrm{ij}} = 20\log_{10}[\mathrm{abs}(N_{\mathrm{ij}})]. \qquad (5)$$

In order to analyse the noise control potential, the model response has been analysed using the following transfer functions: H_{11} (representing the magnitude response of the structure due to an excitation acting on the structure), H_{12} (representing the magnitude response of the exciter due to an excitation acting on the structure), and H_{13} (representing the magnitude response of the electrical network due to an excitation acting on the structure). The simulation results are shown in figure **2**.

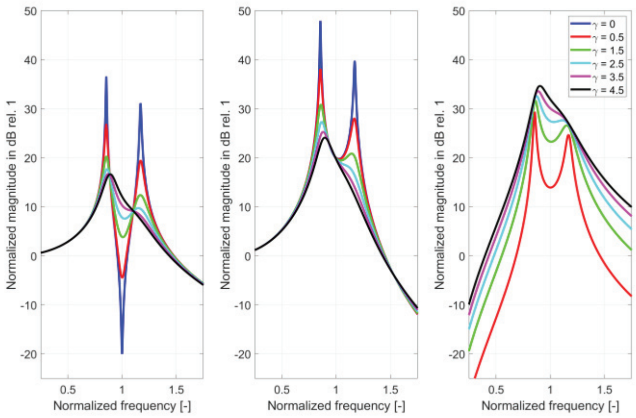

Figure 2: Results of numerical investigations, see [1].

The results shown in figure **2** proof that the situation without electrical network corresponds to the value $\gamma = 0$. The resonances are to be found at $f = 0.86$ and $f = 1.17$. The anti-resonance is (in agreement the theory of dynamic absorbers) to be found at $f = 1.00$. The control profit at the resonance frequencies increases with an increase of γ, compare figure **2** (left) and figure **2** (middle). At the same time the normalized electric charge in the electrical network increases too as shown in figure **2** (right). Furthermore, the effect of neutralizing the excitation decreases, if γ increases. The results proof that a proper adjusted electrical network can effectively dissipate the kinetic energy of the excited structure.

Experimental Investigations

As reported in [2] experimental investigations based on a hardware produced by the ZAL GmbH have been performed at the Hamburg University of Applied Sciences. The experimental setup is shown in figure **3**.

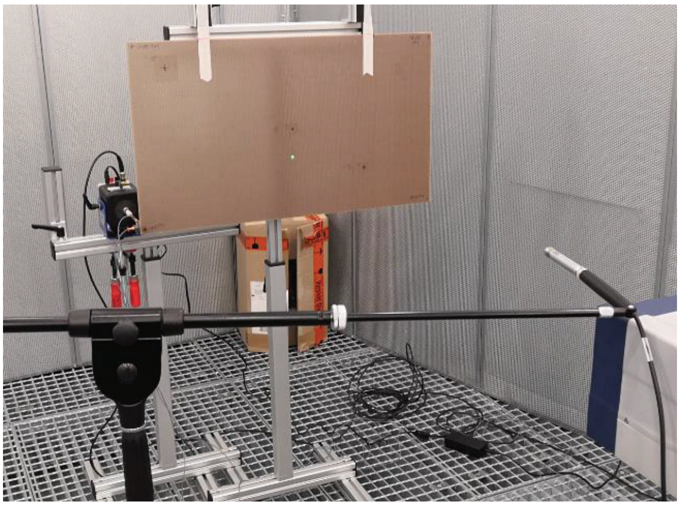

Figure 3: Setup for experimental investigation.

A lightweight structure has been excited using a modal shaker and both acceleration and radiated sound pressure have been recorded. The dynamic absorber (including the electrical network) has been attached to the back side of the structure, close to the centre point of the plate. The experimental results are shown in figure **4** and figure **5**.

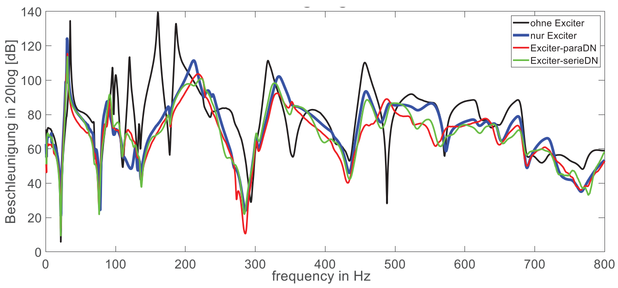

Figure 4: Acceleration on structure (black: without exciter, blue: with exciter, but without electric network, red: with exciter and electrical network (resistance and inductance in parallel connection), green: with exciter and electrical network (resistance and inductance in serial connection)).

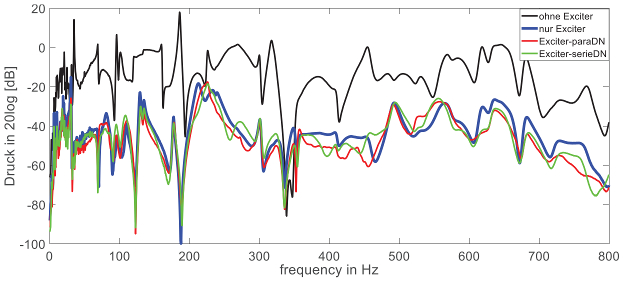

Figure 5: Sound pressure level (colours as in figure **4**).

Summary

The presented numerical and experimental results proof that the suppression of structural vibrations can effectively be improved, if not only a dynamic absorber, but an exciter coupled to a dissipative electrical network is coupled to a vibrating structure. This approach works successful, especially at the resonance frequencies. Furthermore, it turned out that this approach can also reduce the sound pressure that is radiated from a vibrating structure. The electrical impedance of the network can be used to match the mechanical impedance of the structure. Both parallel and serial realizations of the electrical network can be applied.

Acknowledgements

The support of the Zentrum für Angewandte Luftfahrtforschung GmbH (ZAL) by manufacturing of the RL-shunt box is gratefully acknowledged. Also the financial support of the Behörde für Wissenschaft, Forschung, Gleichstellung und Bezirke (BWFG) of the city of Hamburg is gratefully acknowledged. The same holds for the contributions of Ms. Yi Wang, scientific assistant in the one-year-project financed by the BWFG.

References

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[2] Wang, Y. and Kletschkowski, T.: Semi-active vibration control based on smart exciter with optimized electrical shunt circuit. Submitted to Applied Science (MDPI), under review (2021)