Active Multidimensional Vibration Absorbers for Light Robots

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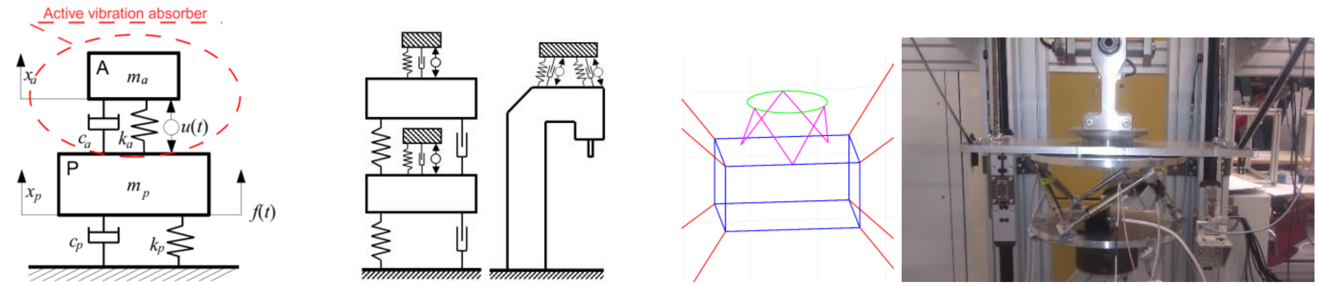
The idea of the passive vibration absorber connected to the primary mechanical structure to suppress its vibrations is known and patented for approximately one hundred years. The main benefit of this passive approach is that no (or minimal) energy needs to be exerted to damp the oscillations. On the other hand, the frequency band where the absorber suppresses the vibrations efficiently is relatively narrow, being centered at the natural frequency of the absorber. This inefficiency can partly be mitigated by tuning the mechanical parameters of the absorber, particularly the stiffness and mass of the absorbers, e.g. [1] with method to achieve more broad-band suppression. Substantially better results can be achieved by an active approach, i.e. utilizing the controlled active actuators. The active vibration absorbers are usually designed as single DOF mechanisms (Fig. 1 a)) even in the multi DOF case where several SDOF absorbers are used (Fig. 1 b)). On the other hand, the multi DOF active platforms (e.g. of the Stewart parallel mechanism type) are often used as active vibration isolators. This concept is inspiration of the primary demonstrator of the multidimensional 6DOF vibration absorber (Fig. 1 c)) using regular cubic truss created from six piezoelectric stack actuators. The control of the active absorber can be designed using different strategies including LQG, H_∞/H_2, model predictive control and others. The interesting alternative is a so called “Delayed Resonator” concept. In this method, the passive absorber is supplemented by an active feedback with the objective to turn the physical absorber to an ideal (undamped) absorber with natural frequency equal to the frequency to be suppressed. As a consequence, the vibrations at the given frequency are suppressed entirely, which is the key benefit. Several variants of this method have been developed and successfully tested [2], however many questions are open, especially non-collocated examples and usage for more complex structures.

The concept of multi-level mechanisms brings the potential to improve dynamical properties of the diverse lightweight robots and manipulators with large workspace. The primary end-effector should cover the full workspace while the superimposed secondary platform is capable to perform smaller but highly dynamic manoeuvres [3], [4]. The cable driven robots and manipulators are an important but not the only representatives of such promising light machines. The usage of the secondary platform as the true end-effector [4] requires measurement of its absolute position e.g. by laser tracker. Unfortunately such operation is often very difficult to implement especially for the large workspaces in the complex industrial environment. The usage of the secondary platform as an inertial base of the active multidimensional vibration absorber (Fig. 1 c)) presents an alternative idea which needs less demanding and more robust local sensing e.g. by accelerometers or geophones. The necessity of usage of active version of MDOF absorber is emphasized by typically strong variability of eigenfrequencies and eigenmodes of such flexible robots and manipulators within their workspace.

The optimization of mechanical properties and control algorithms of active absorber(s) mounted on the end-effector has been realized by several strategies. The absorbing device should be as efficient as possible already in its passive form, without usage of the feedback control of actuators. Such request leads to the **primary optimization** of stiffness and mass properties and geometric configuration. The important design constraints of absorber come from the properties of realistically available actuators (piezoactuators, voice-coil actuators, etc.).

The **second phase** of active absorber **design** has been realized by several control design methods. The tested strategy follows up the primary optimization of mechanical structure. It has been also optimization based strategy, namely the **fixed order** H_∞/H_2 controller optimization.



a) SDOF active absorber b) multi SDOF and multi DOF version c) demonstrator of 6 DOF absorber on cable driven platform

Fig. 1: Active vibration absorber concepts and demonstrator

The local optimization of the controller is combined with the global optimization by the genetic algorithm and particle swarm method. The global algorithm optimizes the starting values of the fixed-order controller parameters of their local optimization together with further direct optimization of mechanical parameters starting from end values of primary (passive absorber) optimization. The second control method of interest is generalization of the above mentioned **delayed resonator** principle [2].

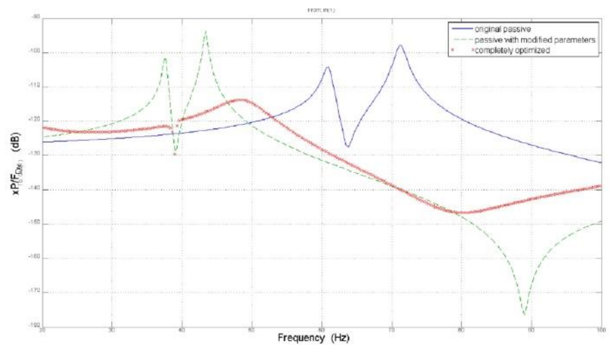


Fig. 2: Example of optimization results with simulation model (red curve is the optimized).

The primary absorber demonstrator (Fig. 1 c)) has been experimentally identified and serves as the source of the basic parameters for the simulation model and its optimization. The example of optimization results for the transfer function from the platform disturbing force to the platform point position is in Fig. 2.

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References

[1] C.A.M.Verbaan, P.C.J.N. Rosielle, M. Steinbuch, "Broadband damping of non-rigid-body resonances of planar positioning stages by tuned mass dampers", *Mechatronics*, vol. 24, no. 6, pp. 712-723, 2014.

[2] T. Vyhlídal, N. Olgac, V. Kučera, "Delayed resonator with acceleration feedback – Complete stability analysis by spectral methods and vibration absorber design", *Journal of Sound and Vibration*, vol. 333, Issue 25, pp. 6781–6795, 2014.

[3] X. Duan, Y. Qiu, J. Du, Z. Zhao and Q. Duan, "Real-time motion planning for the macro-micro parallel manipulator system", *Proceedings of the IEEE International Conference on Robotics and Automation 2011,* pp. 4214-4219, Shanghai, China, 2011.

[4] Z. Šika, P. Beneš, M. Valášek, J. Volech and K. Kraus, "Cable Driven Spherical Mechanism Quadrosphere Enhanced by 3 DOF Piezo-actuated Platform", *Proceedings of the 8th ECCOMAS Thematic Conference on MULTIBODY DYNAMICS 2017*, pp. 511-514, June 19 – 22, Prague, Czech republic, 2017.