COMPUTATIONAL MECHANICS 2021
36th conference with international participation
Srní
November 8 - 10, 2021

Planar and spatial active absorbers for entire vibration suppression

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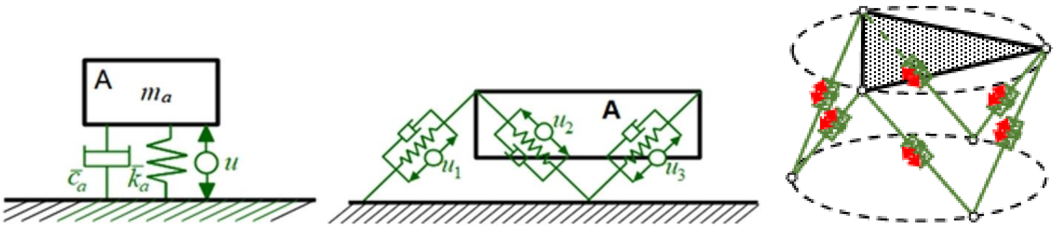
Vibration plays an important role in many engineering applications and often needs to be eliminated. These problems occur with machine tools, where vibrations can affect the workpiece surface quality, with turbine rotors for different applications, in precise instruments such as electron microscopes, deep space telescopes, particle detectors, etc. Vibration compensation is a big task also in control of flexible robots [4], considering classical serial industrial robots, micromanipulation assembly lines (e.g., in microchip production), or high precision surgery robots.

The idea of 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. The active versions of vibration absorption concept (Fig. 1) however significantly improve its efficiency. There is a lot of ways of control algorithm design. One specific alternative is a Delayed Resonator (DR) approach [2], [6], [7] – an active vibration absorber with delayed feedback from the position, velocity or acceleration measurements. Subsequently, applying delayed feedbacks, the physical absorber is turned to the ideal absorber at the given frequencies. For many such systems the vibration-affected parts of the structure are also the most inaccessible for a variety of reasons. For example, we cannot place an active vibration absorber at the tip of the cutting tool in machining or at the end-point of micro-manipulator of a surgery robot. This leads to the usage of non-collocated vibration absorption concept [3].



a) 1 DOF active absorber [5]   b) 3 DOF active planar absorber [5]   c) 6 DOF active spatial absorber

Fig. 1. Active absorbers of different dimensionality

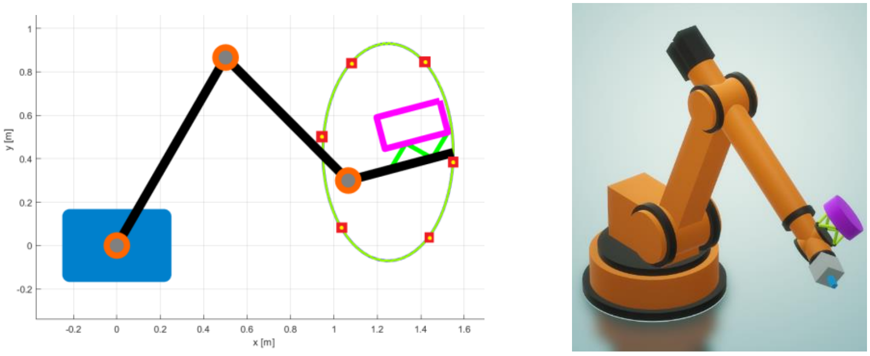
In the case of application of active absorbers to planar or spatial robots and manipulators, the basic question is whether it is more efficient to use several 1 DOF (Fig. 1 a)) absorbers, or one compact planar or spatial variant (Fig. 1 b), c)). Investigation of this question shows, that one multi-DOF absorber typically needs less mass in total to achieve the same absorption ability than multiple 1-DoF absorbers do. One multi-DOF absorber also seems more advantageous given that we have one removable compact device for various directions and modes. The multi-DOF active absorber is generally considered in the form

$$\mathbf{M}\ddot{\mathbf{X}}_a(t) + \bar{\mathbf{C}}\dot{\mathbf{X}}_a(t) + \bar{\mathbf{K}}\mathbf{X}_a(t) = \mathbf{L}\mathbf{U}(t), \tag{1}$$

where $\mathbf{U} = [u_1, u_2, \dots, u_n]^T$ is vector of action forces, and $\mathbf{L}$ provides the projection of the action forces to the absorber coordinates. By introducing the set of delayed feedback rules, the active absorber is transformed from (1) to a time delay system of retarded type with n delays

$$\mathbf{M}\ddot{\mathbf{X}}_a(t) + \bar{\mathbf{C}}\dot{\mathbf{X}}_a(t) + \bar{\mathbf{K}}\mathbf{X}_a(t) + \sum_{i=1}^{n} \mathbf{G}_i \mathbf{X}_a(t - \tau_i) = 0 \,. \tag{2}$$

For the final use on a robotic arm moving in a workspace, the basic control law must be formulated as position-dependent. This applies to delayed resonators as well other ways [7].



a) planar variant [1] b) spatial variant

Fig. 2. Compact multi-DOF active absorbers on serial robots

The position sensors (incremental encoders) parallel with voice-coils are considered for relative motion sensing in the multi-DOF absorbers cases. The main advantage over accelerometers is lower noise and direct collocation between measurement and active force. The voice-coils are considered for actuators, since they are easily capable of dozens of millimeters motion. Above all, however, compared to piezoactuators, they have zero initial stiffness between moving bodies, thus the eigenfrequencies can easily be tuned by parallel springs. A final absorber design is a multi-criteria optimization task, involving the structural, stability and implementation aspects.

Acknowledgements

The work has been supported by the Czech Science Foundation project GA21-00871S “Active non-collocated vibration absorption for robots and mechanical structures”.

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