Active Vibration Control

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The performance of passive vibration control treatments, e.g., tuned passive vibration controllers, including Helmholtz resonators, are highly system dependent. They are unable to adapt or re–tune to changing disturbance or structural characteristics, over time. This along with the technological advancements such as the availability of high–power/low–cost computing, smart materials, and advanced control techniques have led to the use of active vibration control. Moreover, active vibration control treatments do not penalize the weight sensitive structures such as the ones used in aerospace by adding excessive weight to them.

The implication of active control is that desirable performance characteristics can be achieved through active control, whereby actuators excite the structure based on the structure's response measured by sensor(s). Control of structures involves a number of disciplines, including structural dynamics, control theory, and materials engineering.

If the disturbance, or some attributes of it, could be measured, then feedforward controllers could be used very effectively, knowing the model of the process. When the process model has some time-varying parameters or it is not known to begin with, then adaptive feedforward techniques are most suitable (assuming real–time computational capabilities exist). Otherwise, when no attribute of the disturbance is measurable, feedback techniques are most suitable for lowering the effects of process noise on the closed–loop system.

The common sense approach to vibration control of structures subject to broad–band disturbances is increasing the damping (passively or actively). Depending on the sensing mechanism and the proximity of sensors and actuators in active structures a few successful active damping schemes are proposed by researchers. They are all based on the addition of around +90 degree phase shift to the open–loop system at the natural frequencies of the modes designated to be damped. For example having strain or displacement as the measured output, with collocated or nearly collocated arrangements and feeding back the rate (provided by a differentiator accompanied by a low–pass filter) has proven to be very effective in adding local damping to the structure. This controller has been employed effectively in control of flexible structures. Another active damping mechanism is based on positive feedback of the integral of displacement or strain (known as the positive position feedback, PPF). This technique mimics the attributes of a passive tuned mass damper. At low frequencies this controller adds flexibility and at high frequencies it adds stiffness to the structure. Moreover it also tends to split the modes.

Active damping would only lower the magnitude of the amplitude ratio at natural frequency(ies) of the structure. This phenomenon although very effective for broad–band and/or shock disturbance rejection, may or may not work when the disturbance is at certain frequency(ies), i.e., periodic disturbances. This is because those frequencies are not necessarily close to the natural frequencies of the damped modes. The matters become more complicated when the dynamics of the system and/or the frequencies of the disturbances are time varying, e.g. in helicopter rotor blades where the natural frequencies, as well as the disturbance frequencies, of the blade changes with the rotational speed of the rotor.

Positive position feedback controllers could be tuned such that the natural frequency of the compensator (filter) correspond to the excitation frequencies, rather than natural frequencies of the structure, and thus provide effective vibration cancellation. Another technique suitable for canceling the single or multiple frequency vibration is based on adaptive filtering schemes. In these schemes feedforward controllers with feedback adaptation are used. The adaptation speed in these schemes are very fast when the sampling frequency of the measured output is 4 times or higher even-integer multiples of the disturbance frequency(ies); this sampling technique is called synchronous sampling. The premise of this scheme is identifying the dynamics of the structure only at the frequency(ies) where excitation(s) are disturbing the system. Using synchronous sampling the plant could be represented by a low (as low as 2nd) order finite impulse response (FIR) filter, which makes the adaptation fast. Although the feedforward nature of the controller is attractive considering the stability concerns, but the adaptation is based on feedback schemes which makes the system vulnerable, like any other feedback system, to stability issues.