

## COMPENDIUM

### Principles of Halcyonics Active Vibration Isolation Technology

#### INTRODUCTION

Vibrations accompany us everywhere and, in most cases, these vibrations are undesirable. Such disturbances can be caused by traffic, motors and machine tools, oil and gas platforms, buildings and other construction in seismic zones, undesirable locations of laboratory tables and experimental setups, etc. Modern technologies, e.g. in the area of high-resolution measurements, high-precision manufacturing processes, and super lightweight constructions, require effective anti-vibration solutions to achieve maximum performance. In all these cases, objects require isolation from the sources of vibration. This is particularly true for experiments or processes where the typical amplitudes of the ambient vibration and the dimensions of investigated or manufactured structures fall in the same range.

Despite of all the constructional differences, the essence of vibration isolation systems is identical. The passive vibration isolation system consists of a spring and damper (dash-pot). The spring is intended to soften vibrations and disturbances, and the damper has to terminate the oscillation which is amplified within the system. The combination of a mass and the spring is known as a mechanical low-pass. The mechanical response of the spring-mass system decreases significantly for frequencies above the resonance frequency, and the damper reduces the vibration amplitude especially within the resonance range. Because of the low-pass characteristic, passive damping systems are designed with very low resonance frequencies. Since pneumatic springs are characterized by low stiffness and high damping, most anti-vibration mountings available are pneumatic systems. Resonance frequencies between 2 to 5 Hz are typically achieved. Due to internal resonance, pneumatic systems amplify vibrations from approximately 1 to 8 Hz instead of damping them. The solution to this problem is active vibration control (AVC). The signals, acquired by extremely sensitive vibration detectors, are analysed by electronic circuitry driving electro-dynamic actuators which instantaneously produce a counter-force to compensate for the vibration. The active damping system has no resonance and no amplification of vibrations at any frequency.

Accurion provides sophisticated vibration reduction systems based on state-of-the-art engineering methods. Continuous advances in the development of active vibration suppression, and close contact with leading research institutes, ensure systematic integration of leading-edge technology. The engineering know-how which goes into the design of these systems is also available for analysing vibration problems and creating customized solutions.

#### GENERAL INFORMATION

Within the context of mechanical vibration, the term active designates active mechanical structures which are equipped with sensors and actuators in such a manner that – governed by a controller – they can react to environmental disturbances. The link-up between sensors, controller and actuators is depicted in figure 2 and 3. The closed loop creates a feedback control architecture, whereas the open loop results in

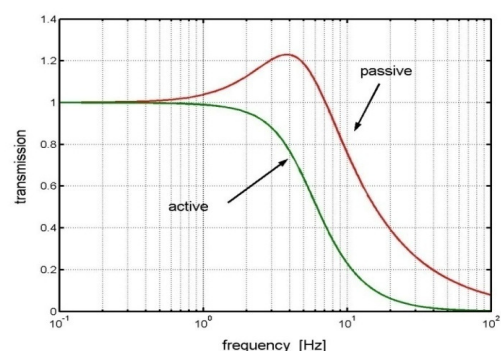


Figure 1: Comparison of passive and active damping systems. The comparison reveals the complete absence of resonance in the active damping treatment.

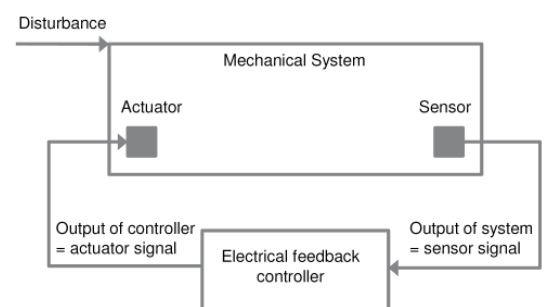


Figure 2: Mechanical system with closed loop control system

a feedforward control design. Classical proportional + integral + derivative (PID) controllers, and advanced space controllers, are often used for feedback control. Adaptive algorithms, e.g. x-filtered LMS, have been developed to implement feedforward loops.

In the case of feedback control, the vibration detection is carried out by sensors. The displacement, velocity or acceleration is measured depending on the application at hand. Since most applications demand a compact design, the sensors are frequently integrated in the mechanical structure. Piezoelectric sensors can be used for high structural integration. The sensor signals are fed to the controller, which can be implemented using analog electrical circuits or digital signal processing (DSP) boards. The controller output is connected to the actuators. The actuator converts the electric voltage into a mechanical force. The most commonly used actuators are piezoelectric and electromagnetic.

**ACTIVE VIBRATION ISOLATION (AVI) AND ACTIVE VIBRATION CONTROL (AVC)**

Active Vibration Isolation (AVI) is used to isolate a mechanical construction, e.g. a microscope, from a vibration source, e.g. a pump, and Active Vibration Control (AVC) is deployed to reduce the mechanical vibration of a structure. Figure 4 illustrates the principle of AVI and AVC for a common setup. The application is positioned on top of the table and requires that the displacement,  $u_2$ , is minimized. The table top is mounted on active elements which are coupled to the foundation. In the case of AVI, the active elements are to minimize the vibration transmissibility,  $u_2/u_1$ , between the base and the table top. This is achieved by elongation and buckling of the active element (see Figure 5). For AVC, the active element must react to the primary excitation force by generating a secondary reaction force (see Figure 6). If the reaction force of the actuator has the same magnitude as the primary excitation force, but is at a phase angle of 180 degrees, then a force cancellation can be observed.

**TECHNOLOGY OF HALCYONICS SYSTEMS**

All Halcyonics systems are designed for AVI and AVC. They comprise several active elements to control the vibration of the table top in all six degrees of freedom. Each active element consists of a piezoelectric accelerometer, an analog control circuit, an electromagnetic transducer and a spring. These components are arranged in a closed-loop (depicted in Figure 7).

The spring supports the weight of the table top and the device which is mounted on the table. The low-pass characteristic of the spring-mass combination dominates the dynamic behavior of the structure for frequencies above 200 Hz. The active part of the system becomes more important for lower frequencies. The motion of the table top is detected by a highly sensitive piezoelectric accelerometer consisting of a mass resting on a piezoelectric disc and a covered housing. The acceleration signal generated is fed to an analog control circuit.

The pre-amplifier performs time integration, and some low and high frequency attenuation, thereby converting the acceleration signal into a frequency-filtered velocity signal. The controller defines the feedback gain and smoothes the signal near the saturation by some nonlinear operations. Finally the signal passes the power-amplifier which generates the current to drive the coil of the force transducer. Due to electromagnetic interaction, the current produces a variable force between the foundation and the underside of the bracket. The coaxial construction of the acceleration sensor and the electromagnetic actuator provides a collinear relation between the force and the measured component of the acceleration.

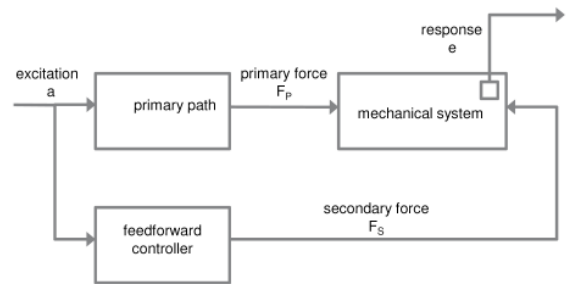


Figure 3: Mechanical system with open loop control system

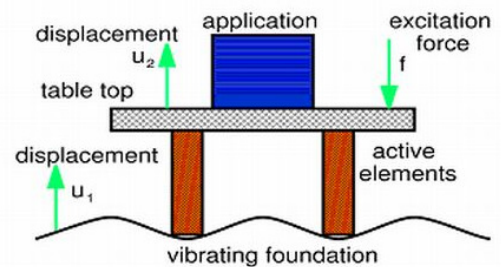


Figure 4: AVI and AVC for an application positioned on a table top

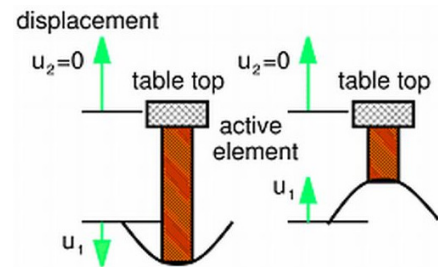


Figure 5: Active Vibration Isolation

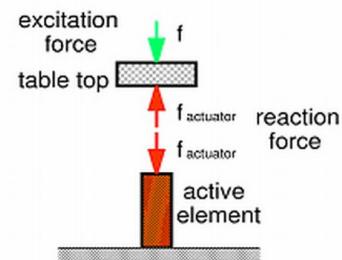


Figure 6: Active Vibration Control

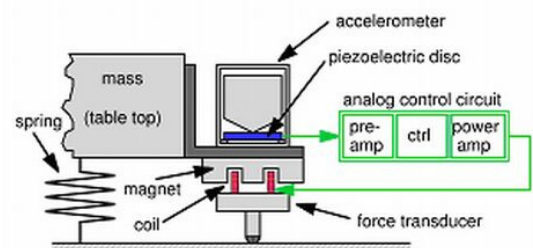


Figure 7: Active Vibration Control