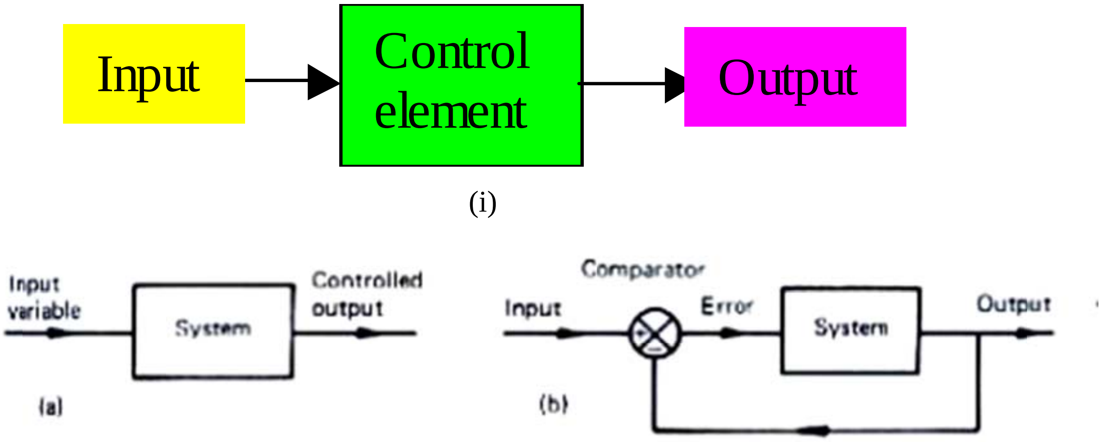
Principles of Active Vibration Control: Basics of active vibration control methods

INTRODUCTION

Vibration control is aimed at reducing or modifying the vibration level of a mechanical structure. Contrary to passive methods (dampers, shock mounts for machines, acoustic packing, various foams, etc.), active control is based on superimposing secondary noise or vibration sources on primary sources to obtain a minimum residual signal. Active vibration control is the active application of force in an equal and opposite fashion to the forces imposed by external vibration. With this application, a precision industrial process can be maintained on a platform essentially vibration-free. Many precision industrial processes cannot take place if the machinery is being affected by vibration. For example, the production of semiconductor wafers requires that the machines used for the photolithography steps be used in an essentially vibration-free environment or the sub-micrometre features will be blurred. Active vibration control is now also commercially available for reducing vibration in helicopters, offering better comfort with less weight than traditional passive technologies. In the past, only passive techniques were used. These include traditional vibration dampers, shock absorbers, and base isolation. The typical active vibration control system uses several components:

- A massive platform suspended by several active drivers (that may use voice coils, hydraulics, pneumatics, piezo-electric or other techniques)
- Three accelerometers that measure acceleration in the three degrees of freedom
- An electronic amplifier system that amplifies and inverts the signals from the accelerometers. A PID controller can be used to get better performance than a simple inverting amplifier.
- For very large systems, pneumatic or hydraulic components that provide the high drive power required.

Active methods lead to structural or parametric modifications of vibration systems using additional energy source (this is why they are called active methods). The active systems may generate local forces related to the variables assigned to other system point source external control signals. Using active methods appropriately controlled external power source can supply or absorb energy due to determined control algorithm. Then the controller consisting of converter of physical value (movement, speed, acceleration, force, pressure etc.), amplifier and actuator (electric, hydraulic, pneumatic etc.) is connected to the device. The actuator can produce a force that compensates the forces which account for vibrations. It also can change the system parameters in active way. As a result the vibration control problem may be considered as the problem of optimal control for the whole device. If the vibration is periodic, then the control system may adapt to the ongoing vibration, thereby providing better cancellation than would have been provided simply by reacting to a new acceleration without referring to past accelerations. The control system can be defined as shown in Fig. 8.1:



(i)

(ii)

Fig. 8.1 Control system

The input is the stimulus, excitation or command applied to a control system, typically from an external energy source, usually in order to produce a specified response from the control system. The output is the actual response obtained from a control system. It may or may not be equal to the specified response implied by the input. Inputs and outputs can have many different forms. Inputs, for example, may be physical variables, or more abstract quantities such as reference, setpoint, or desired values for the output of the control system. The purpose of the control system usually identifies or defines the output and input. If the output and input are given, it is possible to identify, delineate, or define the nature of the system components as shown in Fig. 8.1. Control systems may have more than one input or output. Often all inputs and outputs are well defined by the system description. But sometimes they are not. For example, an atmospheric electrical storm may intermittently interfere with radio reception, producing an unwanted output from a loudspeaker in the form of static. This “noise” output is part of the total output as defined above, but for the purpose of simply identifying a system, spurious inputs producing undesirable outputs are not normally considered as inputs and outputs in the system description.

Two examples are shown here for input-output control as: An electric switch is a manufactured control system, controlling the flow of electricity. By flipping the switch on or off may be considered as the input. That is, the input can be in one of two states on the electric switch is one of the most rudimentary control systems. A thermostatically controlled heater or furnace automatically regulating the temperature of a room or enclosure is a control system. The input to this system is a reference temperature, usually specified by appropriately setting a thermostat. The output is the actual temperature of the room or enclosure. When the thermostat detects that the output is less than the input, the furnace provides heat until the temperature of the enclosure becomes equal to the reference input. Then the furnace is automatically turned off. When the temperature falls somewhat below the reference temperature, the furnace is turned on again.

This principle was first applied to noise reduction systems, especially in air ducts acting as waveguides, where the acoustic field is simple to reduce the acoustic level in structures with a more complex geometry or free-field noise, it was attempted to reduce the noise at the source, by modifying the vibration behavior of the structures (essentially flat) where the noise originates. Here again, active solutions supplement passive ones, especially in the low frequency domain where the passive systems are not as effective. This is known as active vibro-acoustic control. When applied to a structure, instead of creating an anti-noise wave, the principle consists of locating vibration sensors on the structure or in the outside space and actuators capable of creating vibrations in the structure to achieve the minimization objective. The sensors and actuators are coupled with an electronic control system, either an analog system or a digital computer, which calculates the signal to be applied to the actuators in real time. It may also be attempted to reduce the vibration level of a structure for the structure itself, not for an acoustic purpose, to improve comfort, increase structural fatigue strength or to protect sensitive equipment. This is the fundamental area of active vibration control applied to micro-vibrations and to active isolation. Active control of structures is a multi-disciplinarian field involving the basic disciplines of structural dynamics, fluid-structure coupling, acoustics, automatic control, and materials research, since it is increasingly attempted to include the active control sensor and actuator functions in the material. This results in intelligent structures.

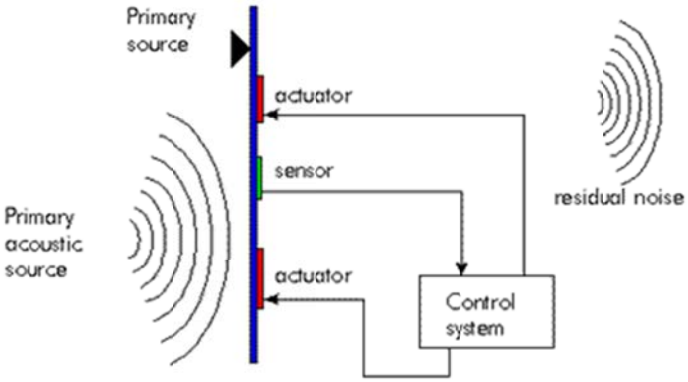


Fig. 8.2 Noise control

Areas of Applications:

- Fixed-wing aircraft
- Helicopters
- Launchers
- Satellites
- Military systems

Active Vibration Control (AVC) and Smart Materials

Every feedback control system has essential components like the hardware computing control input via the strategy of our choice, sensors to provide feedback to this controller and actuators to carry out the required changes in plant dynamics. This chapter is concerned with the latter two components, that is sensors and actuators. More specifically, here we take a closer look at some of the advanced engineering materials that can be used as actuators and in some cases as sensors in active vibration control applications (AVC).

There are many well-known traditional actuating components such as electromagnetic devices, pneumatic actuators, rotary and linear motors etc., which may be effectively utilized in vibration control as well. Unlike the previously mentioned devices, modern engineering materials which are often referred to as *intelligent* or *smart* have the advantage of being lightweight and more importantly they can be seamlessly structurally integrated. For example, a composite aeroelastic wing equipped with thin piezoelectric wafers cast directly into the structure enables us to suppress undesirable vibration without adding a considerable mass or changing the shape of the wing. On the other hand, advanced materials like the magnetorheological fluid may add unprecedented properties to already existing components, for example creating automotive dampers with automatically adjusted damping properties. Figure 2 illustrates an experimental actuator capable of providing displace-ments exceeding the usual range of simple piezoelectric materials. The robust and low-cost high displacement actuator (HDA) made of pre-stressed polymeric materials and piezoelectric ceramics is an excellent example of advanced engineering smart materials. The aim of this chapter is to introduce the reader to some of these cutting-edge materials and their use in vibration control. Actuators like the afore-mentioned electromagnetic linear motors, pneumatic devices and others will not be covered here.

Thanks to the reciprocal physical effects experienced in some of these materials, actuating elements can also be used in a sensor configuration. Just as in the case of actuators, many feedback sensing systems exist other than the ones using smart materials. Some of these are among others accelerometers,[2] strain sensors based on resistance wires, or more advanced devices like industrial laser triangulation heads or laser Doppler vibrometers (LDV). There are several engineering materials available nowadays, which exhibit some very desirable properties for use in AVC. So what is the criterion of classifying a material to be *smart?* The keyword here is coupling. From the structural point of view, the behavior of classical materials can be sufficiently described by their elastic constants: the elastic constant relates stress and strain, the thermal constant relates temperature and strain. In smart materials, coupling also exists between the either two (or even more) of the following fields: electric charge, strain, magnetic, temperature, chemical and light. This coupling is also obvious between the constitutive equations describing the behavior of these materials. The most common smart materials which are used in active structures are shape memory alloys, magneto- and electro-strictive materials, semi-smart magneto- and electro-rheological fluids where the coupling is one directional, electrochemical materials and of course piezoelectrics. The chapter begins with a discussion on the shape memory effect and shape memory alloy materials. In addition to the shape memory effect, the passive albeit still very interesting super-elastic nature of these materials is also introduced. After characterizing the interactions between the applied temperature, stress and strain; the utilization of shape memory alloys in vibration control is reviewed.

Smart materials are materials that have one or more properties that can be significantly changed in a controlled fashion by external stimuli, such as stress, temperature, moisture, pH, electric or magnetic fields. There are a number of types of smart material, some of which are already common. Some examples are as following:

- **Piezoelectric materials** are materials that produce a voltage when stress is applied. Since this effect also applies in the reverse manner, a voltage across the sample will produce stress within the sample. Suitably designed structures made from these materials can therefore be made that bend, expand or contract when a voltage is applied.
- **Shape memory alloys and shape memory polymers** are materials in which large deformation can be induced and recovered through temperature changes or stress changes (pseudoelasticity). The large deformation results due to martensitic phase change.
- **Magnetostrictive materials** exhibit change in shape under the influence of magnetic field and also exhibit change in their magnetization under the influence of mechanical stress.
- **Magnetic shape memory alloys are materials** that change their shape in response to a significant change in the magnetic field.

- **pH-sensitive polymers are materials** which swell/collapse when the pH of the surrounding media changes.
- **Temperature-responsive polymers are materials** which undergo changes upon temperature.
- **Halochromic materials** are commonly used materials that change their colour as a result of changing acidity. One suggested application is for paints that can change colour to indicate corrosion in the metal underneath them.
- **Chromogenic systems** change colour in response to electrical, optical or thermal changes. These include electrochromic materials, which change their colour or opacity on the application of a voltage (e.g. liquid crystal displays), thermochromic materials change in color depending on their temperature, and photochromic materials, which change colour in response to light—for example, light sensitive sunglasses that darken when exposed to bright sunlight.
- Another good example is starch-based custard.
- Ferro fluid
- Photomechanical materials change shape under exposure to light.
- Self-healing materials have the intrinsic ability to repair damage due to normal usage, thus expanding the material's lifetime
- Dielectric elastomers (DEs) are smart material systems which produce large strains (up to 300%) under the influence of an external electric field.

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