Principles of Active Vibration Control: Piezoelectric Accelerometers

Introduction:

Active vibration control is defined as a technique in which the vibration of a structure is reduced or controlled by applying counter force to the structure that is appropriately out of phase but equal in amplitude to the original vibration. As a result two opposite force cancel each other and structure stops vibrating. Smart structure technology (or intelligent technology) can be used to create structures that embody sensors and actuators which function like the nerves and muscles of a human. There are many cases in which vibration has to be controlled. Smart structures have been actively studied in the aeronautics and space fields where weight and space are limited. The solid actuators used in these fields generally produce only small displacements but force is high. By incorporating these actuators in main structures, unlimited applications such as for facilities, buildings, and transportation will become possible. The converse piezoelectric effect may be readily utilized in active vibration control as a source of actuation force. At the same time, the direct piezo effect allows to use piezoelectric materials as sensors as well. The availability, price and electro-mechanical properties of piezoelectric transducers set these devices at the forefront of vibration control applications. Various studies have shown that such applications in the fields of buildings and transportation will contribute to practical use. Piezoelectric materials are typically ceramic or crystalline in structure, with permanently aligned electric dipoles. The dipoles allow for separation of positive and negative charges within the material, but the symmetry of the crystal assures that there is no internal electric field. However, if the crystal is stressed then the crystal symmetry is broken and an internal electric field is generated between surfaces of the piezo. If the internal field is not compensated, for example by shorting one side of the piezo to the other, it results in an induced voltage. The effect of stressing a piezo to generate a voltage is called the direct piezo effect. The converse piezo effect involves inducing a stress in the piezo element by apply an external electric field or potential.

Piezoelectric actuators are roughly classified into the unimorph type and lamination type. Both types slightly distort (expand) when a voltage is applied.

Although light and compact, they generate very strong forces. Therefore, it is possible to introduce active vibration control of a structure by integrating actuators into the components, without significantly changing the shape or weight of the main structure. In the field of active vibration control, the use of piezo-sensing device continues to be popular among both engineering practitioners and researchers. Because experimental studies aimed at the active vibration control of flexible beams predominantly use piezoceramics as actuating elements. Controlling mechanical motion and damping unwanted vibrations in flexible structures can be achieved using piezoelectric transducers (piezos). Piezoelectric materials are crystals or ceramics that generate an internal voltage when stressed. If a piezoelelectric element is rigidly mounted to a flexible structure, then vibrations and deformations in the structure are coupled to the attached piezoelectric transducer. Using the voltage induced in the piezo as an input signal the stress may be monitored or controlled using an external shunt or feedback circuit.

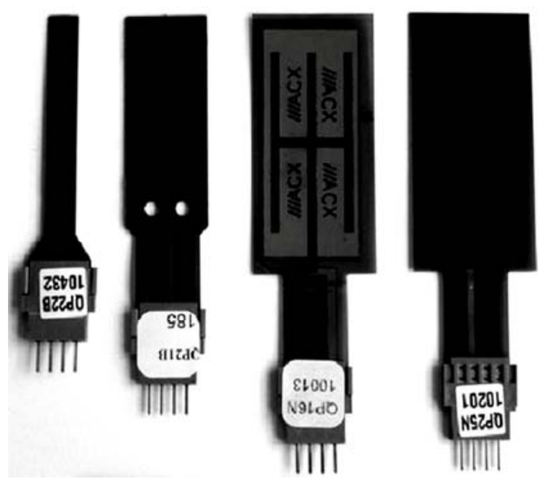
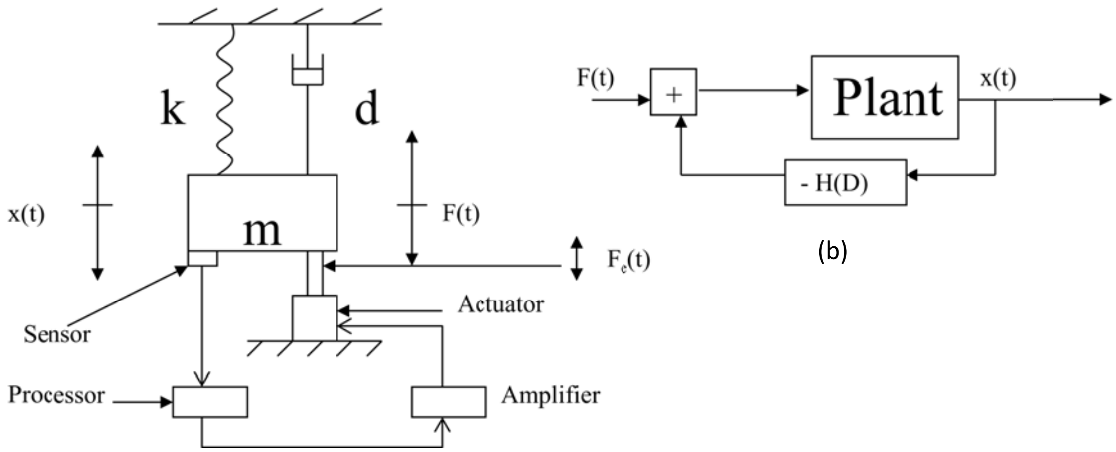


Fig. 8.15 Various piezoelectric transducers

Fig. 8.15 illustrates a range of commercially produced piezoelectric transducers. A wide selection of transducer shape and size configurations is currently available on the market; moreover they can be manufactured according to the needs of the customer. The transducers shown in the figure come in a pre-packaged form with the necessary electric leads bonded on the surface, equipped with a protective foil and a connection terminal. The longer transducer pictured at the bottom (marked as QP45N) and the transducer on the right (marked as QP25N) contains two layers of piezoceramics. These two layers can be used either with the same input signal to achieve larger actuation force or one layer can be utilized as an actuator while the other as sensor to achieve near perfect collocation. To use a piezo as either a sensor or actuator for a vibration control device it must be rigidly mounted to the vibration sensitive part. This assures that any stress or strain in the static structure is rigidly coupled to the piezo and vice versa. Piezos used as sensors are often light and flexible to provide the best transmission of the mechanical vibration into the piezo for detection. Piezos used as actuators are often denser so that the stress induced in the piezo by an applied voltage is large enough to stress the structure as well.

Vibration Control for SDOF system:

In a spring mass damper system with single degree of freedom, the vibration amplitude x (t) can be controlled using piezoelectric sensor and actuator as shown in Fig. 8.16. One of the simplest vibration control circuits is a collocated pair of sensor/actuator piezo elements. Collocated means that the two piezos are placed in the same position on two different sides of a flexible structure, as shown in figure 8.17. Assuming the two piezos are identical, meaning they have the same internal capacitance, if the structure flexes the voltages induced in the two piezos will be equal but 180º out of phase. After correctly resolving the transfer functions between the vibrating structure and the voltage generated in the sensor and between the voltage measured by the sensor and the voltage applied to the actuator, feedback control can be established between the sensor output and actuator to oppose the vibration. This simple model is easy to imagine implementing; however, in practice small errors in the transfer functions can quickly destabilize the feedback.



(a)

Fig. 8.16 Active Control technique for SDOF system

The equation of motion is:

$$m\ddot{x} + d\dot{x} + kx = F(t) - F_c(t) = F(t) - H(D)x(t) \quad (8.5)$$

If

$$H(D) = C_o D^2 + C_1 D + C_2 \quad (8.6)$$

then,

$$(M + C_o)D^2 x + (C + C_1)Dx + (K + C_2)x(t) = F(t) \quad (8.7)$$

The control input parameter can be chosen based on the H (D) as shown in Fig. 8.16 (b).

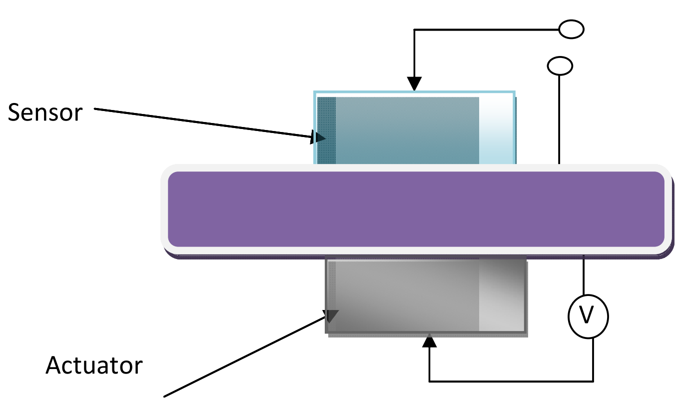


Fig. 8.17 Structure with piezo sensor and actuator

Based on the above concept, an experiment can be performed using piezo-electric materials as sensor and actuator. A cantilever beam is designed with the material of Aluminum for performing the active vibration control using smart structure as shown in Fig. 8.17. The cantilever beam is used with material density and its strength and the dimensions can be taken as (20x 2.0 x 1.5) cm. This beam is clamped on the horizontal table with proper mechanism to move in linear and rotational movement as desired. A patch is added to be used as sensor, which is the material attached to the fixed end of the beam and is responsible for the sensing of the stress produced in the beam and generate voltage proportionally. The current produced is called piezoelectric current as it is generated from pressure applied on the body. The material used is generally PZT (Lead Zirconate Titanate) or PVDF (Polyvinylidene Fluoride). PZT is used in our setup and it is made up of Perovskite (Pv), which is a calcium titanium oxide mineral species composed of Calcium Titanate with the chemical formula $CaTiO_3$. When there is a deflection in the host structure then due to the stress induced in sensor patch the crystals present in the sensor realigns them self and in the process develop piezoelectric current though this current is very less but if we combine many crystals together then we can generate enough amount of power.

When a certain amount of voltage is provided to the sensor then it produces the opposite effect and acts like an actuator. It is used to produce mechanical stress in the host structure and this voltage comes from the control system which gets the input from the sensor.

For proper actuation in the beam, the actuator is located at the fixed end as highest amount of stress is produced in that part also the bending moment is maximum there. A sinusoidal wave generator can be used to generate a function usually sinusoidal, Square or triangular wave form, the profile of wave form generated lets us induce similar kind of vibration in the entire beam. An amplifier which receives the signal from the wave generator is very weak and is no enough to drive the exciter, hence the this generator is coupled with an amplifier where the signals are amplified and finally fed to the exciter. DAQ system is responsible for the encryption of the input/output system, the signal which we receive form the sensor is an electrical signal, and is not compatible with the computer. So this system is used to convert this signal into acceptable form and then fed to the computer, and after the calculation in computer, the signal is again given to the D/A system to again convert it into suitable format before it is fed to the Actuator.

The aluminum beam (substrate) is fixed at one end on the set table and other end is hanging freely hence is a cantilever beam from the end control vibration has been supplied. This is accomplished by using an exciter and the function of the exciter is to produce under control vibration on the beam. The nature of the vibration will depend upon the input signal form the function generator, whatever will be the nature of the waveform similar kind of vibration will be produced in the beam. The wave generator is used to generate the desired wave form which can be either of sinusoidal, triangle and square.

Frequency range can be adjusted and can be set between 1Hz to 1000 KHz. The frequency is high but the amplitude of the wave form is very low to produce any notable vibration in the beam hence an amplifier is used to amplify the signal. The range of amplification can be varied using the knob provider at the amplifier and it should not amplify more than the safe limit of the exciter and also the quality of the vibration will be degraded and also the PZT patches may be damaged. Vibration produces deflection in the beam, which is maximum at the free end and to measure this deflection scanning laser Doppler vibrometer is used, it is very accurate and can record even the smallest deflection which is produced in the beam. The uncontrolled and controlled vibration signature has been shown in Fig. 8.19 and 8.20 respectively. Fig. 8.21 shows the controlled vibration response under forced vibration condition.

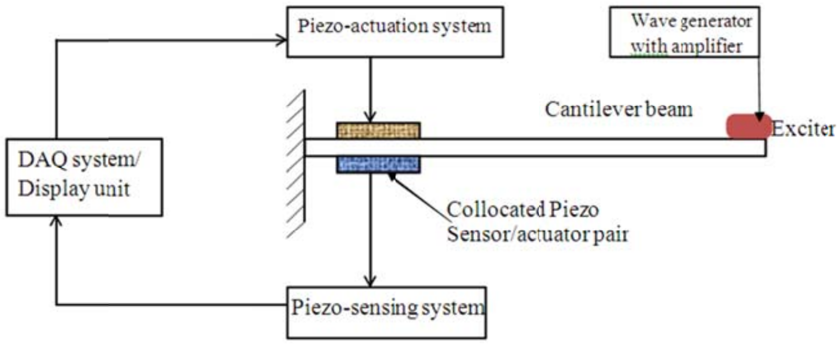


Fig. 8.18 Experimental Set-up

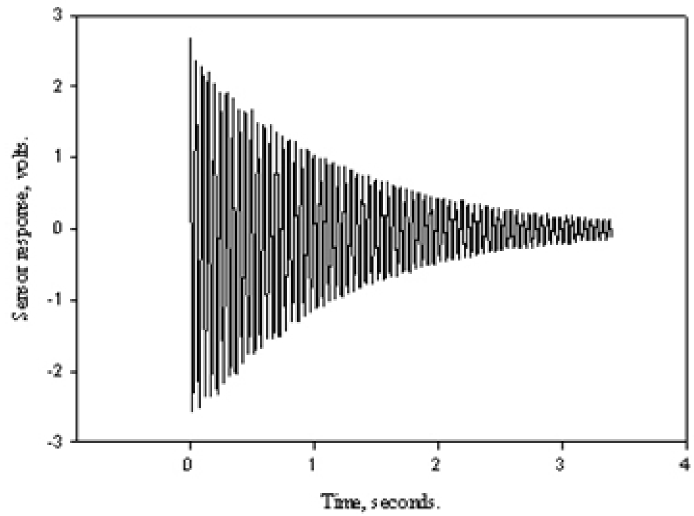


Fig. 8.19 Uncontrolled time response

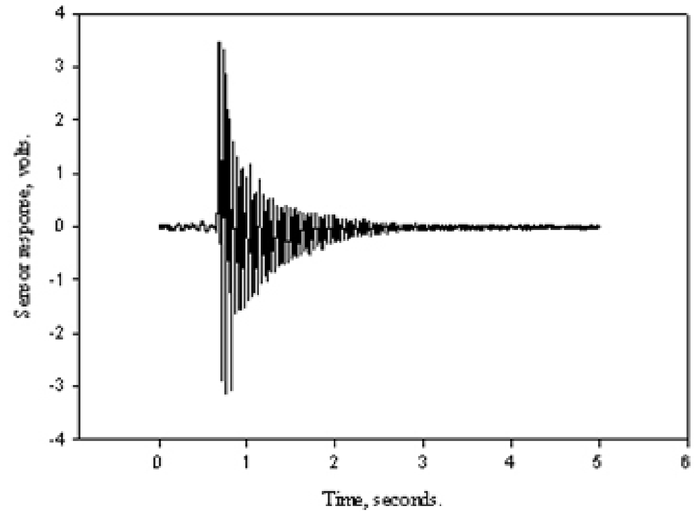


Fig. 8.20 Controlled time response

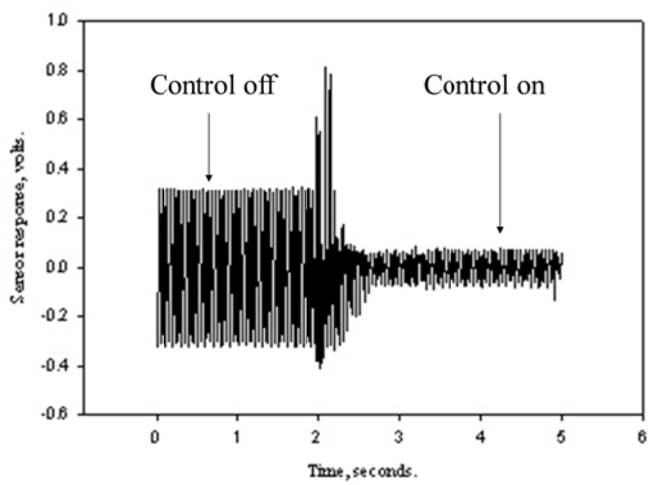


Fig. 8.21 Forced Vibration Control

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