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Semi-active Vibration Control Using Piezoelectric PZT Composite Films

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ABSTRACT

This interdisciplinary research work of civil and electrical engineers deals with the piezoelectric ceramic material, lead zirconate titanate (PZT) and its potential future use as a semi-active structural control device in a civil engineering context. The study examines first what is currently known about piezo ceramics and their existing applications in fields such as energy harvesting and as sensors. The main part of the paper deals with implementing piezoelectric ceramics as a semi-active damping system for the vibration control of lightweight non-structural components. This procedure is experimentally analysed for the damping response of an oscillating aluminium cantilever beam. The study shows that, by using an RLC equivalent circuit in conjunction with a piezoelectric ceramic transducer, the vibrations in the beam due to an initial disturbance is significantly reduced. By correctly optimizing the components within the circuit, the resonance frequency of the circuit can be tuned to the natural frequency of the beam. The experiments show that an optimal choice of circuit parameters may increase the damping performance up to 180 %.

Keywords: *Semi-active, smart materials, piezoelectric, piezo ceramic, PZT*

1 INTRODUCTION

The monitoring and control of vibrations in civil engineering is vital to ensure both the long and short-term integrity of structures. Excessive vibrations can lead to not only structural problems, bridges oscillating at their natural frequency will sway excessively, earthquakes can cause excessive dynamic forces that endanger the integrity of the building, but also to the overall quality of the environment surrounding the structure. The effects of vibrations can in that context further cause excessive noise, moving non-structural components and unsightly cracks, whether in the form of sound waves, such as traffic noise or kinetic motion, as is the case when there are many machines with cyclical loading patterns e.g. washing machines and other industrial types of engines. In order to limit the dynamic vibrations of a structure, auxiliary damping systems can be used. Damping is a process that reduces oscillations in a component by either dissipating the energy or converting it into another form, e.g. heat. This can be also achieved by providing a force or displacement that acts in the opposing direction to the original force or displacement. The magnitude of the opposing vector determines how quickly the oscillations are reduced to an acceptable level. There are many practical examples of this, such as the tuned mass damper (TMD), which is often used in production cars and in tall buildings such as Taipei 101.

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A relatively new method of damping aims to make use of piezoelectric ceramics, a special type of material that employs the piezoelectric effect. The piezoelectric effect is a form of energy transfer in such a way, that a mechanical deformation causes the rearrangement of the positive and negative charges within a material, the resulting excess of positive charges at one end and negative charges at the other leads to a voltage being induced. This process is currently being researched intensively as a potential solution to the growing demand for clean, renewable energy, however its practical application in real-life scenarios seems to be, until now, fairly limited.

Of significant interest to researches is the fact that this effect is reversible i.e. a mechanical deformation can be produced by applying an electric current to a piezoelectric component. This is known as the inverse piezoelectric effect. This has particular relevance in the area of damping since these deformations could be used to counteract the vibrations caused by dynamic loading. In this way, both processes of the piezoelectric effect can be utilized. During the direct piezoelectric effect, initial vibrations caused by an outside actor can induce an electric voltage across the piezo elements. Subsequently by using the inverse effect, this voltage is used to create the necessary counter deformation needed to damp the system.

Lead zirconate titanate (PZT) Pb[ZrxTi1-x]O3 is a common piezoelectric ceramic material, which is commercially used as actuators and sensors especially in automotive and aerospace industry, s. Fig. 1. Typical PZT applications include also telecommunications, medical products and several further consumer products such as computer hard drives or ultra-thin speakers. Examples for the vibration control using piezo actuators are active systems suppressing the vibrations of aircraft wings and large space structures such as the International Space Station (ISS). The authors intend to use PZT composite films for the semi-active vibration control of lightweight nonstructural components of civil structures in low and high frequency range. PZT films are piezoelectric bending actuators consisting very thin and flexible elements, which can deform through bending and have a better durability than the bare piezoelectric ceramics. Because of their flexible characteristic, they can also be placed on curved surfaces. For civil structures, a semi-active control method is preferred to avoid the vulnerability and the complexity of the active systems due to the large number of required PZT patches. Moreover, compared with the passive systems, the semi-active systems have the advantage to retune themselves to changing environmental conditions and show therefore more efficiency in the damping.

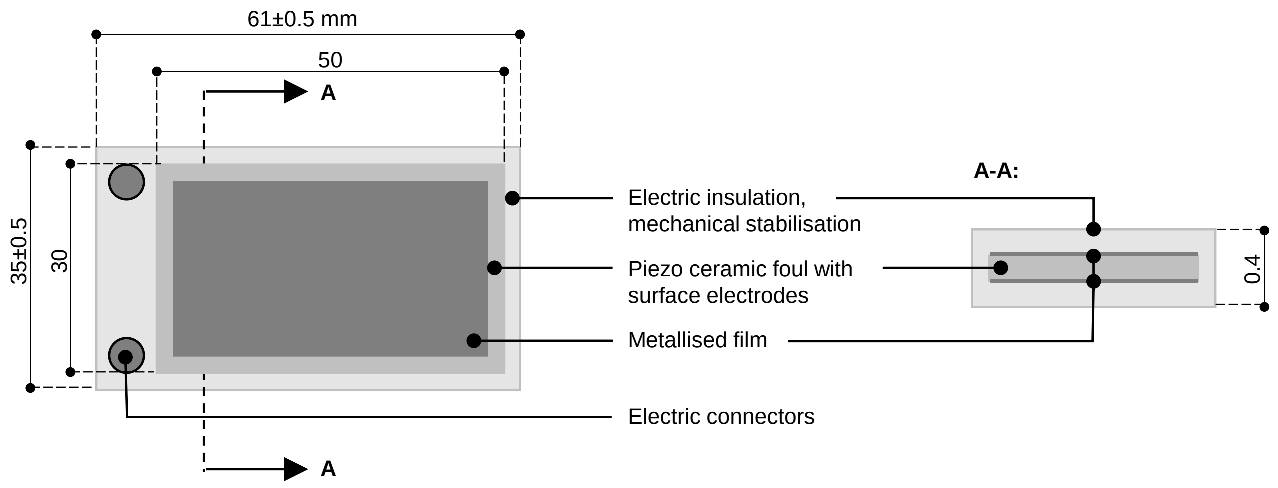

Figure 1 – Layout of a PZT composite film

2 RECENT APPLICATION EXAMPLES IN CIVIL ENGINEERING

While piezoelectric components have been commonplace in other branches of engineering for the last decade, the application of piezo ceramics in civil engineering is a relatively new phenomenon. As a result, examples of this technology in practical use are mostly limited to short-term experiments as opposed to fixed, permanent components of structures. Furthermore, the use of piezo ceramics as a damping device is even rarer.

2.1 Piezo Ceramics in Energy Production

Energy production has been the largest employer of piezo ceramics in the last ten years, with numerous experiments being carried out to determine whether piezo elements are a viable source of electrical energy. One such example was the testing of a power-generating floor in Japan in 2006 [1]. The power-generating floor is a floor panel, which contains piezoelectric elements within the material. Consequently, when pressure is applied to the surface of the panel, e.g. by someone walking across, the piezo elements convert the associated deformations into electrical energy. By placing the panels in strategic locations with large volumes of foot traffic, it was hoped that significant amounts of electrical energy could be generated. This energy could then be used to power the ticket gates, electrical notice boards and advertising hoardings [2]. The panels were tested in two train stations in Tokyo over the course of seven weeks. Their location in front of the ticket gates ensured that the maximum possible foot traffic was achieved. A maximum daily production of 10 kWs was achieved, which is sufficient to power a 100 W light bulb for 100 seconds. During a second testing phase in 2008, it was hoped that the production of electricity could be increased tenfold to 100 kWs and the product could be proven as commercially viable. However, in the intervening years the power-generation floor has been implemented sparingly and even then to raise awareness for green electricity as opposed to a genuine power source.

Piezoelectric panels were also installed underneath the road surface of a 100 m stretch of a highway in Israel in 2009. Tests showed that an energy production of 2 kWh could be achieved by converting the vibrations from moving vehicles into electrical energy. Based on these result, an extension of the project from a single-lane highway to a 1 km stretch of a four-lane highway could produce as much as 1 MWh, which is enough power to supply 2,500 households [3].

2.2 Piezo Ceramics in Vibration Damping

While energy production utilises the direct piezoelectric effect by converting mechanical stress into electricity, the converse effect can be used to dampen vibrations in a system. One area that has recently begun to apply this knowledge is sound/vibration damping by vibration control of lightweight nonstructural components. Sound plays an important role in ensuring a comfortable and pleasant built environment. Unacceptable levels of noise can damage hearing, disrupt sleeping residents or affect productivity levels in an office environment. As a result, the ability to reduce noise levels entering or exiting a building is a considerably important and sought-after commodity.

Conventional methods of sound damping comprise passive systems, such as double or triple glazed windows with an insulated layer in between or sound absorbing materials, and are effective at medium and high frequencies typically greater than 1000 Hz. However, their relative inefficiency at lower frequencies means that greater quantities of damping materials are required. This additional mass leads to greater loads on the structure. Consequently, stronger structural columns and beams are required which increases the overall cost of the project.

An alternative approach to passive damping is active damping. These systems consist primarily of several piezoelectric actuators and a control system and, as such, add very little extra mass to the structure but need a permanent energy source. One such system currently being developed is called Active Structural Acoustic Control (ASAC). ASAC consist of a multitude of piezoelectric elements placed on a flat, usually vertically component of a structure and a control system. The piezoelectric elements act initially as sensory and detect incoming sound waves through the deformation in the opposite direction. These two deformations effectively cancel each other out, resulting in the dissipation of the associated sound energy. A demonstrator façade incorporating this active damping technology has been developed in Germany [4]. Constructed from double-glazed windows and aluminium panels, the façade incorporates piezoelectric patches on the surface which actively react to incoming sounds. As part of a European-wide research project InMAR – Intelligent Materials for Active Noise Reduction special piezoelectric materials are produced which can be placed on a window and then allowed to vibrate under external sound loading. A sensor monitors the motion of the window and sends this to a control algorithm. An opposing motion is then generated by the piezo elements, damping system. Initial tests showed that the façade lead to an overall reduction of up to 15 dB in the sound level passing through the façade [5].

2.3 Piezoelectric Elements as Sensors

The use of piezoelectric elements as sensors is the most widely researched and therefore commonly used application field in civil engineering. The unique sensitivity of the elements to small mechanical strains enables their usage in measuring changes in temperature, pressure, acceleration and other physical phenomena that cause such strains. These precise sensors make use of the direct piezoelectric effect, in that they produce an electric current when they undergo a mechanical deformation. One example of a most common application of piezo elements as sensors is the piezoelectric accelerometer. Accelerometers are used to measure the proper acceleration i.e. the g-force, of an object. The piezoelectric accelerometer uses a seismic mass, attached to a spring or acting as a cantilever, which vibrates as the system undergoes acceleration and strikes against a piezoelectric component. This imparts a force on the piezo, which is then converted into an electrical signal through the direct piezoelectric effect. While the acceleration itself is not directly measured, the linear relation between force and acceleration and the accuracy of piezoelectric sensors in converting forces and displacements into electrical signals ensures the considerable accuracy of the system.

3 MATHEMATICAL DESCRIPTION OF PIEZOELECTRIC ELEMENTS

3.1 Governing Equations

A mechanical stress on a piezo ceramic material results in a rearrangement of the charges within the material and forms an electric current. Therefore, both mechanical and electrical effects must be simultaneously considered. This is achieved through the coupling of two basic equations:

$$D = \varepsilon \cdot E \,. \qquad (1)$$

The first equation considers the electric behaviour of the material. It describes the electric charge density D, as being a function of the permittivity ε and the electric field strength E. In this instance, permittivity is a measure of a material's ability to resist an electric field.

The second equation

$$S = s \cdot T \qquad (2)$$

considers the mechanical behaviour of the material and is essentially comparable with Hooke's Law. It relates the mechanical strain S with the elastic compliance s and the mechanical stress T.

By coupling these two equations, the effects of the electric charge density on the mechanical stress and vice versa can be considered. Coupling yields the following equations:

$$D = d \cdot T + \varepsilon^T \cdot E\,, \tag{3}$$

$$S = s^E \cdot T + d \cdot E\,. \tag{4}$$

Where d represents the piezoelectric charge coefficient or piezo modulus, the superscript T refers to a constant or zero stress field and the superscript E refers to a constant or zero electric field.

It should be noted that these equations hold only for small amplitudes of strain and small electric fields. Under these conditions, the relationships above can be regarded as linear and the coefficients constant. Should the amplitudes increase beyond a certain limit, the relationships would become nonlinear and Eq. (1) and Eq. (2) would cease to be valid.

3.2 Displacements Modes of Piezoelectric Actuators

Piezoelectric actuators are devices that can produce mechanical strains when provided with an electric field. There are a number of different ways to achieve mechanical strains. The actuators can be differentiated based on the relationship between the electric field and the direction of polarisation. The direction of polarisation means the axis along which charged particles flow when the electric field is applied.

The focus of this study, bending actuators, are created by connecting a contracting actuator to a passive, non-deformable substrate or by connecting two contracting actuators together with different voltages resulting in a subsequent difference in length of the two layers causing a displacement ΔL_{bend} and a bending moment, as shown in Fig. 2.

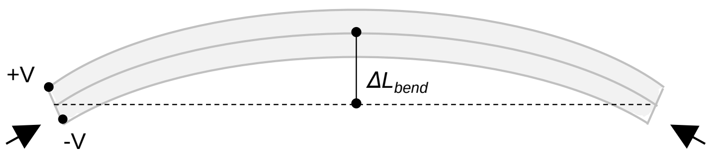

Figure 2 – Bending actuator consisting two contracting actuators attached lengthwise and subjected to different voltages.

4 ENGINEERING DESIGN ASPECTS

4.1 Piezo Ceramic Actuators

Piezo ceramic actuators utilise the piezoelectric effect to convert electrical energy in the form of input voltages into mechanical energy i.e. mechanical deformations. They can be classified depending on many factors, including their geometry, displacement modes and the material from which they are made. A PZT film is, as a patch transducer, a very thin laminated strip, consisting of a piezo ceramic plate, electrodes and various polymer materials embedded in the plate to improve the structural stiffness. The patch is easily flexible and thus utilises bending as a displacement mode. The transducer can be customised for use and so comes in many different sizes and thicknesses, with thickness being a key factor in the bending ability of the material. One can also choose between a single- and multi-layer patch transducer and a multi-layer transducer, which will typically produce greater mechanical deformations. A wide range of materials is commercially offered, each with different chemical compositions and therefore electrical, mechanical and thermal properties.

The PZT patch transducer is essentially a thin layer, usually between 100 and 500 µm of piezo ceramic foil, whose top and bottom surfaces are coated in a metallised material, often silver. As piezo ceramics alone are often very brittle, the coated foil is embedded within a polymer structure to provide electrical insulation and mechanical stability. The whole system therefore acts as a capacitor, whereby the non-conducting ceramic layer acts as a dielectric and the two metallised surfaces function as electrodes on either side. When a voltage is then applied across the electrodes through the electric connectors, a build-up of positive charges at one end and negative charges at the other causes an electric field across the dielectric. The creation of an electric field has two effects on the transducer. Firstly, the transducer expands in the plane of the electric field i.e. the electrodes move further apart. Secondly, the transducer contracts in the other planes perpendicular to the electric field. This extension in the direction of the electric field and contraction in the perpendicular plane is known as the transverse piezoelectric effect and is analogous to the Poisson's Effect in structural mechanics.

By adjusting the electric field acting across the electrodes, the amount of contraction within the transducer can be controlled. While generally an increase in voltage leads to a decrease in the dimensions of the transducer in the perpendicular plane, the behaviour between the two is not linear. Depending on the material and the geometric dimensions of the patch, the correlation between voltage and displacement changes. Therefore, for a given constant voltage, different displacement values will be observed for different transducers.

4.2 Damping Behaviour

Piezo ceramics can be attached to a variety of structural elements and their unique piezoelectric properties utilized to dampen the vibrations of such elements. This can be achieved through three processes: passive damping, semi-active damping and active damping.

Passive damping can be generally describe as "non-reactive" damping. It works by altering the basic properties and characteristics of a system, such as the stiffness or natural frequency, in order to reduce the effect of dynamic forces. Passive systems cannot be directly controlled or influenced by the user and do not contain adaptive components i.e. the system does not react to real-time changes. A typical example of a passive damper is a broadband or "dry" damper. A broadband damper works like a mass-spring-damper in that it dissipates mechanical energy through friction into heat. In the case of the broadband damper, this is done in two stages. First, the piezo ceramic patch converts the mechanical motion into an electrical signal. Secondly, the piezo ceramic patch is connected to as resistor, which then converts the electrical energy into heat. The equation for the rate of heat energy gained from such a system is

$$P = I^2 R = \frac{V^2}{R} \tag{5}$$

Where P is the rate of heat energy gained, I is the electrical current, R is the resistance of the resistor and V is the voltage.

Semi-active damping systems react in real-time to changes in incoming forces and displacements and alter the characteristics of the system regarding stiffness and resistance, in order to best negate the effects of these changes. It can thus be said that semi-active damping is an adaptable and reactive passively damped system. They do not go as far as active systems, which actively provide a force to counteract the disturbing effects, however semi-active systems are therefore advantageous as they require a much smaller power source than active systems and additionally are regarding as more stable [6]. A semi-active system can be created by connecting the PZT piezoelectric patch with an RLC circuit. An RLC circuit comprising a resistor, an inductor and a capacitor can be connected in parallel or series. By tuning the parameter, the frequencies of the critical modes of the structure can damped. They are typically used in acoustics as high-, low-or band-pass filters but are also being implemented into other areas where vibration control is important such as baseball bats or snowboards, where the comfort of the user can be greatly improved by damping large vibrations.

Semi-active systems should be tuned as accurately as possible to the natural oscillating frequency of the member it is trying to dampen. The more accurate the tuning, the more effective the damping will be. It is therefore advantageous to know the incoming excitation frequencies so that the system can be adjusted to best dampen the vibrations. It is possible to connect several RLC circuits in parallel, where each circuit is specially designed to dampen a certain frequency. The incoming frequencies are then measured, an electric signal generated and according to the signal, the appropriate circuit is then triggered. Through this method, a large range of excitation frequencies can be accurately damped by using many circuits, each one designed for a certain small frequency range. Consequently, the system is able to control a frequency range of a broadband damper, while retaining the accuracy of a narrowband-tuned system. A more advantageous alternative semi-active approach would be to change the electric behaviour of one RLC circuit with the help of active elements and some logic steering.

4.3 Calculation of the Optimal Parameters of the Electrical Components

In order to optimise the damping effect of the transducers, the components of the RLC circuit must be specifically tuned so that they damp the critical natural frequency of the oscillating system. The mathematical process behind this tuning will be outlined in this section.

In an RLC circuit, an inductor and a resistor are connected to a piezoelectric actuator. The job of the inductor is to tune the circuit to a resonant frequency that matches the natural frequency of the to-be-damped structure. The resistor is then used to reduce the amplitude of the vibrations by dissipating electrical energy into heat. In a parallel circuit, the resonant frequency dependent on the inductance L and capacitance C

$$\omega_s = \frac{1}{\sqrt{LC}}. \tag{6}$$

and so the circuit can be tuned by the inductor and optimally damped by the resistor independently. The three parameters, resistance, inductance and capacitance, of a circuit connected in parallel can be estimated by first determining the natural frequencies of each mode when the system is short-circuited f_s and open-circuited f_o. By creating short or open circuits, the effects of the resistor and inductor can initially be ignored and the pure, un-damped natural frequencies can be found. A variable called the general transverse electro-mechanical coupling coefficient, K_{31} is the obtained from the short and open circuit frequencies as follows:

$$K_{31} = \frac{\sqrt{f_o^2 - f_s^2}}{f_s}. \tag{7}$$

The capacitance C of the circuit comes from the natural capacitance of the piezo element (PZT) itself and so it cannot be optimised. The capacitance depends on two material properties: The transverse coupling constant k_{31} and the capacitance of the piezo element before it is bonded to the beam C^T. The final capacitance of the PZT C^S after the bonding process can alter and for constant strain is given by

$$C^S = \left(1 - k_{31}^2\right) \cdot C^T. \tag{8}$$

The optimal resistance R is then:

$$R = \frac{1}{2.828\,\pi\, f_s C^S K_{31}}. \tag{9}$$

To determine the optimal inductance, the normalised tuning frequency α is required. It is given by:

$$\alpha = \sqrt{1 - \frac{K_{31}^2}{2}} . \tag{10}$$

Therefore, the optimal inductance L is:

$$L = \frac{1}{C^S \left(2\pi f_s \alpha\right)^2} . \tag{11}$$

By tuning the inductance, the damping system can semi-actively optimise its dynamic behaviour and reach a higher damping performance compared to the passive systems.

5 EXPERIMENTAL STUDY

5.1 Experimental Setup

This research work examines the semi-active vibration control of an aluminium-cantilevered beam with collocated piezoelectric patches bonded on the upper and downer surfaces, s. Fig. 3. Both numerical and experimental analyses are performed. This paper includes the experimental part of the research. Previous studies with PZT patches using cantilevered demonstrator beam focus on the active control of the damping system [7]-[9].

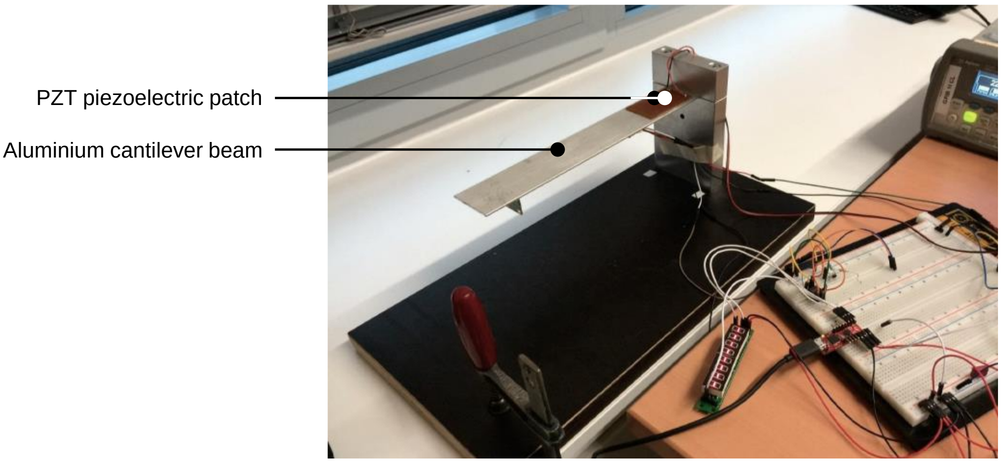

Figure 3 – Experimental setup consisting aluminium-cantilevered beam with collocated piezoelectric patches

To reduce the vibrations of the cantilever the direct piezoelectric effect, converting mechanical stress into electricity, is used. The aluminium beam is connected as a cantilever beam, with a fixed support at one end and a free-end at the other. The dimensions of the beam, along with its basic structural properties are summarised in Table 1.

Table 1: Basic properties of the aluminium beam

Property	Unit	Value
Length	[mm]	250
Width	[mm]	40
Thickness	[mm]	2
Density	[kg/m³]	2700
Young's Modulus	[kN/mm²]	70
Poisson's Ratio	[-]	0.3
Natural Frequency	[Hz]	10

5.2 Properties of the Piezo Ceramic Actuator

The actuator material chosen is a so-called soft piezo ceramic, PIC255 produced by PI Ceramics, a modified Lead Ziconate Titanate (PZT). In piezo ceramics, a soft material is one in which the charged particles are easily able to move about within the ceramic and therefore are quicker to polarise, i.e. they exhibit soft ferroelectric behaviour. This quick response, in comparison to the less responsive hard materials, enables soft materials to be used as sensors, as well as actuators for precise micro and nanopositioning. A summary of the important properties of the PIC255 material, as well as a hard ceramic for comparison, is shown in Table 2.

Table 2: Key properties of the PZT patches used for the experiments in comparison with a hard piezo ceramic

Property	Symbol	Unit	Soft PZT	Hard PZT
Density	ρ	[g/cm³]	7.80	7.80
Curie Temperature	T_c	[°C]	350	295
Relative permittivity - parallel to polarisation - perpendicular to polarisation	$\varepsilon_{33}^T / \varepsilon_0$ $\varepsilon_{11}^T / \varepsilon_0$	[-]	1750 1650	1250 1500
Piezoelectric charge coefficient	d_{31} d_{33} d_{15}	[-]	-180 400 550	-140 310 475
Elastic compliance coefficient	S_{11}^E S_{33}^E	[10^{-12} C/N]	16.1 20.7	12.4 13.0

As can be seen in the table above, the soft PIC255 has higher values for the coefficients of permittivity, piezoelectric charge and elastic compliance as well as a higher Curie temperature. The Curie temperature refers to the temperature, below which the material crystallises and forms dipoles. At temperatures above the Curie temperature, dipoles no longer form and the material loses its piezoelectric capabilities.

In order to act as a bending actuator, the transducers are glued to the surface of the aluminium beam. By gluing the two elements together, the contraction of the actuator can be transferred to the substrate across the whole contact surface rather than at a few fixed points. When a voltage is then applied, the actuator contracts and creates in effect a compressive axial force, which acts on the top surface of the substrate. This compressive force causes the top fibres of the substrate to also contract. In such a scenario, the top fibres of the substrate are now shorter relative to the bottom fibres and so the substrate begins to bend upwards, s. Fig. 4. This deflection of the cantilever end is given the symbol, ΔL. The piezoelectric patches are attached on the top and bottom surfaces of the beam at a distance of 0.5 cm from the fixed end with the given dimensions shown in Table 3.

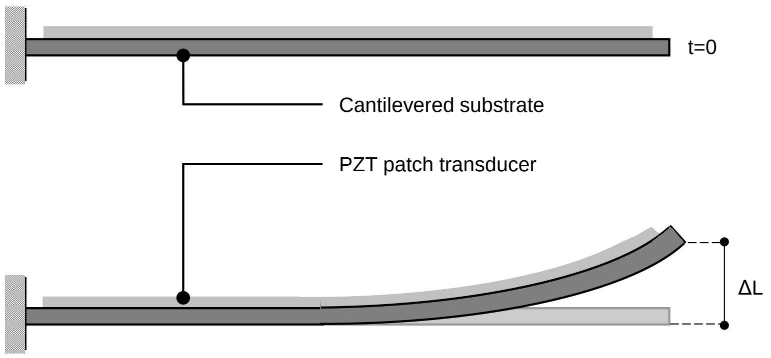

Figure 4 – Application of patch transducer as a bending actuator on a cantilevered substrate

Table 3: Basic geometric properties of the transducer patches

Property	Unit	Value
Length	[mm]	61
Width	[mm]	35
Thickness	[mm]	0.4
Distance from fixed end	[mm]	50

5.3 Properties of the RLC-Circuit

The semi-active system is created by connecting the PZT piezoelectric patches with an electric circuit comprising a resistor, an equivalent network replacing an inductor and a capacitor connected in parallel, which can be tuned to damp the frequencies of the critical modes by modifying the parameters of the inductor. The resistor is used to reduce the amplitude of the vibrations by dissipating electrical energy into heat. The resonance frequency of the electric circuit can be tuned by the inductor. At resonance frequency the damping is defined by the resistor. In order to optimize the damping effect of the transducers, the components of the RLC circuit are specifically tuned to damp the critical frequencies. Fig. 5 shows an equivalent electric circuit representation of the RLC-circuit with the patch transducer and cantilever beam. The parameters are shown in Table 4.

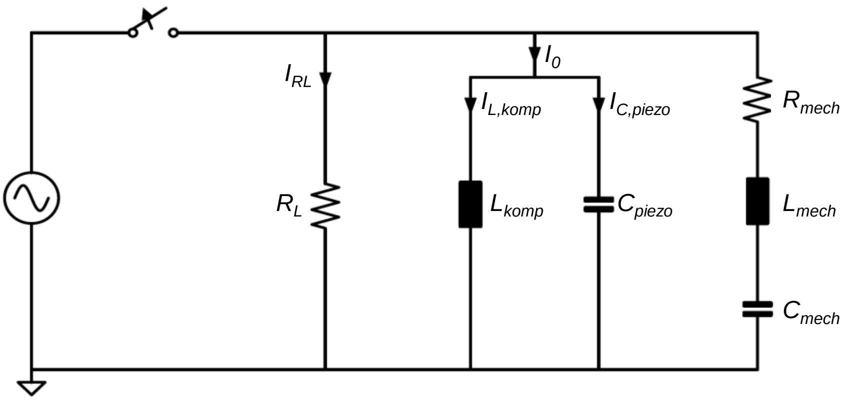

Figure 5 – Equivalent electric circuit representation of the cantilever beam with the semi-active damping system including the PZT piezoelectric patch transducer

Table 4: Parameters of the equivalent electric circuit

Symbol	Description
R_L	Resistance for the dissipation of vibration energy
c_{Piezo}	Capacitance of the piezoelectric patch
R_{mech}	Resistance representing damping ratio of the beam
L_{mech}	Inductance representing mass of the beam
c_{mech}	Capacitance representing stiffness of the beam
L_{komp}	Inductance for the compensation of c_{piezo} and tuning the electric circuit frequency

6 RESULTS

The efficiency of the designed damping system is determined by oscillating an aluminium cantilever using the PZT patch first as an actuator and then shutting the actuator off. The deflection of the cantilever is measured using an accelerometer positioned at the end of the beam. In total, 50 measurements with and without damping system are recorded. Using the semi-active PZT system the damping of the cantilever is increased by up to 180 %. Fig. 6 shows the time history of cantilever deflection with and without the PZT patches. At t = 0 the semi-active system is started. The measured damping ratio of the structure is increased here from 0.36 % to 1.00 %. The next diagram in Fig. 7 compares the number of oscillations until the deflection amplitude reduced by more than 50 %. It shows clearly that for the system without PZT the vibration phase takes longer. 30-32 oscillations were measured during the deflection of the beam without PZT. Due to increased damping, the number of oscillations are decreased to 10-11 for the system with PZT patches.

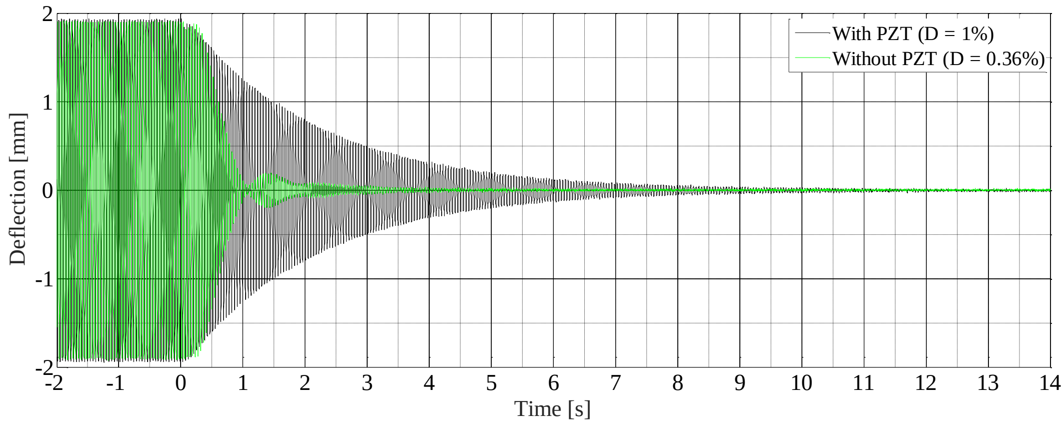

Figure 6 – Time history of cantilever deflection with and without PZT patches. The damping ratio is increased from 0.36 % to 1.00 % using PZT.

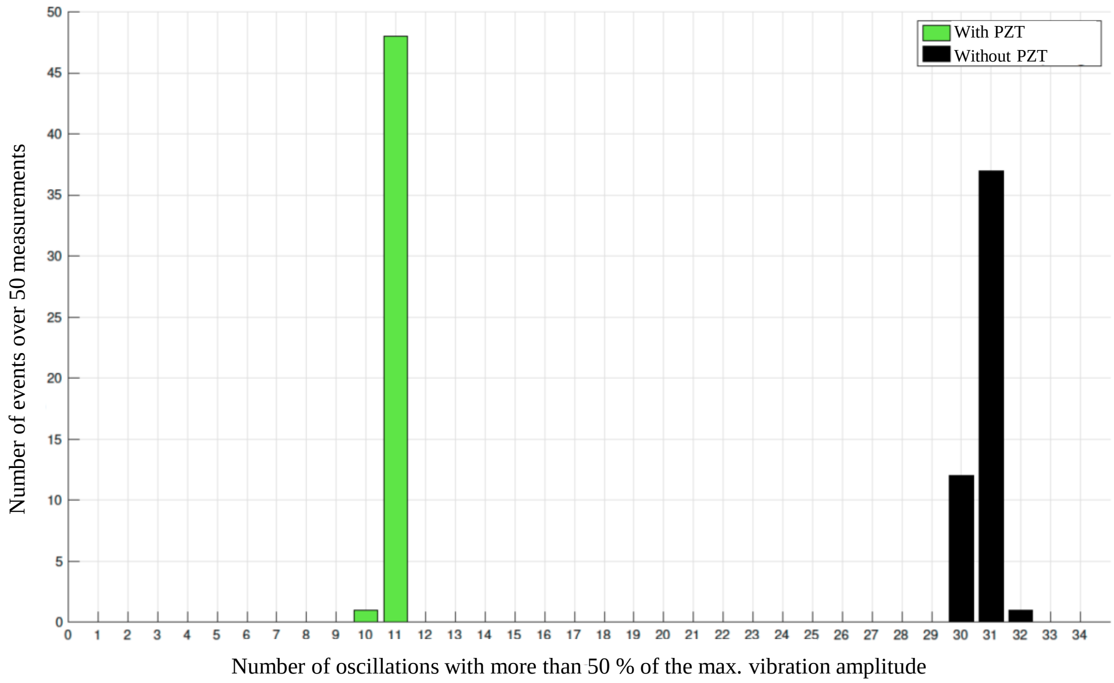

Figure 7 – Comparison of the vibration duration of the beam with and without PZT patches. The system with PZT oscillates shorter due to increased damping.

7 CONCLUSION

Until now, piezo ceramics have been primarily implemented as energy harvesters and sensors, using the direct piezoelectric effect to convert mechanical energy into an electric signal. Such ceramics can be embedded into areas of high traffic, foot or road, and the resulting vibrations caused by objects passing over it are then converted into electrical energy. The object of this study was to explore the inverse process of the piezoelectric effect, the conversion of electric energy into mechanical, and its applicability in a civil engineering content. A semi-active damping system is developed through the implementation of piezoelectric patch transducers into an RLC circuit. By optimising the individual components of the RLC circuit, the resonance frequency of the circuit is tuned to match the natural frequency of an aluminium cantilever beam. Experimental results show a definite potential for the use of piezo ceramics in vibration control. Through a correct tuning to the natural frequency, an increase in the damping ratio of up to 180 % is observed.

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