UNIVERSITY OF ABERDEEN

CEMINACS — CEntre for MIcro- and NAnomechaniCS

Timoshenko Institute of Mechanics

MODELLING AND CONTROLLING VIBRATIONS:

Effect of Thermo-Electro-Mechanical Coupling and Non-linearities on Dynamic Processes in Inelastic Layered Structures

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MOTIVATION

Excessive vibration can

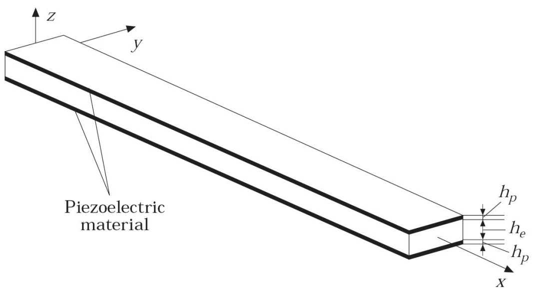
- damage or impair the performance of sensitive equipment and buildings;
- generate unacceptable levels of noise and heating due to dissipative losses;
- effect human health and reduce productivity.

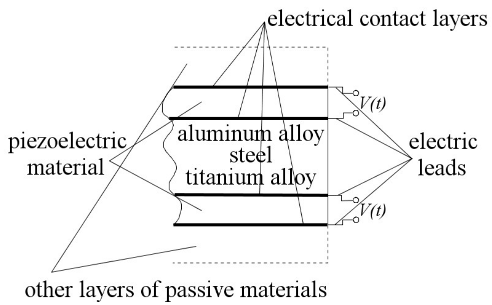
Active control using piezoelectric sensors and actuators is the most effective way of suppressing and controlling vibration.

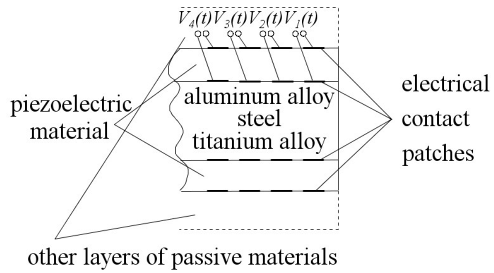
It can ensure that component behaviour conforms to the criteria and demands of a wide range of applications (e.g. in the aerospace and MEMS industries).

GENERATING AND CONTROLLING VIBRATIONS

- Structure consists of passive metal and active piezoelectric layers.
- Piezoelectric layers have thickness polarisation. The upper and lower layers are polarised in opposite directions.
- Negligibly thin electrical contact layer (non-structural):
  - either continuous over the whole layer surface,
  - or placed as separate patches.
- Active layers can be either sensors or actuators.
- Two possible schemes to plug in the electric contacts to the structures can be used:
  - short-circuit electrodes,
  - open-circuit electrodes.
- Electric current or voltage is controllable.
- Continuous electrodes allow one to deal with the lowest vibration modes (i.e. the 1st mode).
- The higher vibration modes are controlled by patched electrodes.
- Supplying the appropriate voltage or electric current to the electrodes:
  - mechanical vibrations can be excited,
  - mechanically excited vibrations can be controlled or suppressed.







AIM

To study the *coupled thermo-electro-mechanical* dynamic and quasi-static processes in layered structures made of non-linear materials.

ENGINEERING MODEL

Assumptions for the general case of forced vibrations:

- processes are electrostatic;
- Kirchhoff-Love hypotheses for layered structures;
- similar hypotheses for piezoelectric layers;
- the squares of rotation angles are taken into account for flexible beams.

Additional assumptions for the case of cyclic loading:

- material response to monoharmonic loading is close to a monoharmonic one;
- concept of complex modulii is applicable to describe the viscoelastic and viscoplastic material behaviour under harmonic loading;
- main field variables and dissipation function are described in terms of complex amplitudes.

MATERIAL MODELS

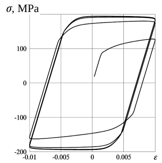
Under arbitrary loading

Passive metal layers:
coupled thermoviscoplastic Bodner-Partom model.

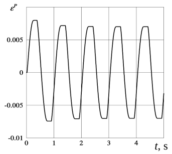
Active piezoelectric layers:
coupled thermoviscoelastic model.

Under harmonic loading

Both **passive metal layers and active piezoelectric layers are described by a coupled thermoviscoplastic model in terms of complex amplitudes of main field variables based on the concept of complex modulii**



Stabilisation of stress-strain hysteresis loop



History of plastic strain

FACTORS INFLUENCING THE SYSTEM RESPONSE

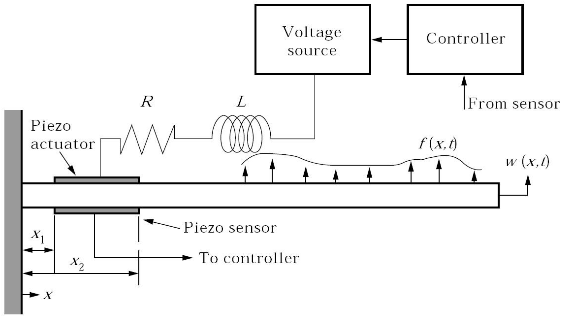
The material may become plastic under intensive loading.

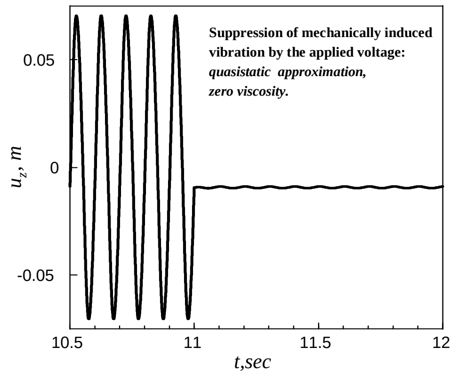
Variable viscoelastoplastic behaviour should be studied when designing:

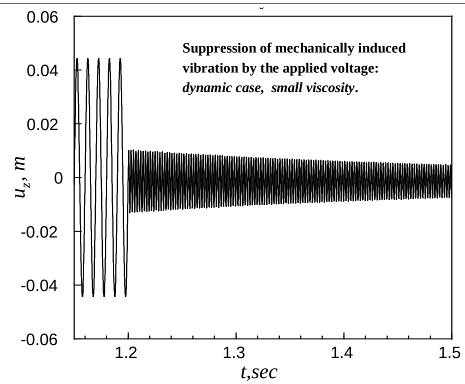
- **metal dampers to minimise the vibration of buildings under wind and seismic loads;**
- **devices for suppressing vibrations in pipelines;**
- **test specimens in low-cycle fatigue tests;**
- **MEMS devices;**
- **microelectronic devices, etc.**

When predicting the dynamic and quasi-static response of structures and their members, a number of effects should be taken into account:

- **nonlinearity of material behaviour: plasticity of passive layers;**
- **geometrical nonlinearity arising from large deformations;**
- **heterogeneity of the stress-strain state: layered structures;**
- **heating due to internal losses in both passive and active layers;**
- **electro-mechanical and thermo-mechanical couplings.**







METHODOLOGY

Step 1: **Develop a fully coupled, thermomechanical version of Bodner-Partom model by direct integration of the equations.**

Step 2: **Extend the model to 3D.**

Step 3: **Mimic that model using viscoelstic theory with complex modulii to gain computational benefits in simulations.**

Step 4: **Extend the model to simulate electrically induced vibrations.**

Step 5: **Develop a feedback system to control/suppress vibrations using electrical load, piezoelectric sensors/actuators and smart structures techniques relying on mechanical, thermal and electric criteria.**

POTENTIAL APPLICATIONS

Smart materials and structures:

- **deeper understanding of the coupled response under complex loading conditions and elevated temperatures;**
- **calibration of sensors and actuators at elevated temperature;**
- **determination of limitations imposed by dissipative heating on functioning of smart structures with piezoactive layers.**

Vibration control:

- **active control/suppression of vibrations;**
- **sensing and actuation;**
- **estimation of actuator efficiency;**
- **heating prevention by means of active control;**
- **prevention of piezoelement workability loss due to heating above Curie point;**
- **design of the most efficient feedback schemes.**

Technology:

- **reliability of members operating under severe conditions of resonance or impact load, elevated temperatures (thermal shock) and high stresses;**
- **developing the damping technologies for manufacturing new equipment and repairing depreciated ones;**
- **fine tuned operational parameters will reduce the costs of equipment manufacturing and servicing;**
- **formulation of the restrictions on a wide variety of technological regimes for beams and layered structures (including impact, cyclic as well as temperature loads).**