Project Title:

Structural Control using Piezoelectric Actuators

- Gowtham V, ME11B023

Guides: Prof. S Narayanan , Dr. Shaikh Faruque Ali

Abstract:

The project deals with the analysis and control of cantilevered structures under non-uniform thermo-mechanical loads. The structure is under non-uniform thermal and mechanical loading. The goal is to reduce the structural deflection by design of control techniques for actuation the piezoceramics(MFCs) using state feedback. It is assumed that PZT patches are bonded at various locations on the beam, and a controller that receives strain input and actuates them accordingly to minimize deflection or dissipate vibrations induced. Hence, a requirement to model the behavior of this system becomes neccessary.

Macro Fibre Composite(MFC) are piezocomposites that can act as an actuator and a sensor can can be powered with a voltage source. On application of voltage, the MFC bends or distorts, making it a viable candidate for structural control application. Multiple such actuators thus form a viable choice to meet the objective.

The project objectives are threefold. (i) The response of piezoelectric actuators using MFC patches, when loaded using electrical, thermal and mechanical is to be studied and modeled. (ii) A cantilevered cylindrical beam, with bonded MFC patch(es), assumed slender to utilize Eulerian small bending theory. This composite system is to be analyzed as a state feedback control system with electrical control input and thermomechanical loading. (iii) This controller should then be designed for given deflection of beam, including dynamics of actuator-beam system, and considering optimal number and position of actuators.

To date in this project, a complete static analysis of the said system is completed, and various responses are studied under static electric supply to the MFCs under various loading conditions.

Modeling Steps:

1. Composite beam modeling: thermal loading.
    - Here, the cantilevered cylinder and PZT are modeled with static loading
2. Basic static control techniques to counter static thermal loading.
    - Here, for a given thermal loading, optimal force control law identified.
3. Electromechanical model of MFC(only the piezoelectric element)

4. Complete Electro-mechanical and Thermal Modeling as a control system
5. Numerical Simulations in Abaqus and MATLAB to visualize structure response.

Work completed:

Eulerian slender beam thoery for small deflections is used. Expressions for bending moment on the beam, and extension created along the axis were obtained. From the expression for bending moment, it is found that bending occurs only if the thermal loading is not axisymmetric. An arbitrary such thermal load was assumed in parameterized form for the beam, and expression for equivalent bending moment was found.

1. Composite beam Model:

A composite beam made of segments of core material bonded to a MFC patch was analyzed for simple mechanical loading, and then for the said thermal loading considering different material properties of the MFC patch and cantilevered beam assumed to be made of aluminium. Both components are assumed to have circular or arc cross section. Constitutive relations for the piezoelectric region are given by :

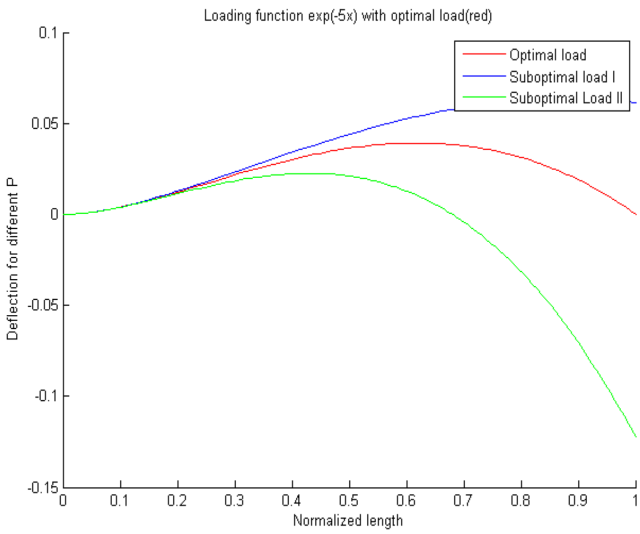
$$\sigma_{xx} = E(S_1 \; - \; d_{31}E_3 \; - \; \alpha\theta)$$

First, as MFC also acts as a passive stiffening element, using standard material values, stiffening effect was computed comparing deflections for tip loads. Around 4-5% reduction could be seen. Then, the thermal field was applied, and analytical expressions for deflection of the composite beam was obtained.

2. Tip Controller for thermal loading:

Here, a simple cantilever system with tip control load, and known asymmetric thermal load is taken. Analytical expressions for the optimal controller were found. Here, optimal is defined using the L-2 norm, where the average squared deflection of the entire beam is minimized. Minmax method to minimize the maximal deflection was also performed to obtain different optimal control results(not shown here).

A simulation here shows the results of application of tip load controllers with varying load magnitudes, and with knowledge of the form of thermal loading along the beam, it is clear that when the optimal controller is used, the mean squared deflection is minimal.



3. Thermal deflection control using tip load:

Now, static deflection controller for reducing the given thermal loading, using tip load is now analyzed. Closed form expression for the “optimal” tip load, that can minimize squared deflection of the entire beam, for a known thermal load magnitude was obtained.

4. MFC patch electrical modeling:

Next, an electrical excitation is given to the PZT material, and the mechanical effects quantified as a bending moment, and a shear force. The MFC patch in between electrodes is modeled as a dielectric capacitor, and it is found that this capacitance is affected due to the mechanical loading of the PZT. Coupled electromechanical simplified linear relations for the response of structure to thermal loading, voltage application and charge storage in PZT are obtained. Finally, a controller for this coupled system, with voltage as control input, and external mechanical loading was designed, with expressions for optimal voltage input for a given loading obtained (minimize L2-averaged deflection).

Equiavalent bending moment generated by arbitrary thermal boundary conditions in the inner and outer radius of an annular cylinder was also obtained.

Future Scope:

1. Modeling the mechanical response of the structure to a transient thermal excitation.
2. Identify a simple model of the electromechanical response to the thermal field, for application into a control law.
3. Convert the response to control input in transfer function form, and use the dynamical Euler beam equation and piezomechanical coupling for the same.
4. Consider the electrical circuitry to the MFC, the RC electrical dynamics involved, and produce an overall coupled transfer function model for the entire system.
5. Identify an energy functional for the control input and the deflection, solve for the optimal control law with the problem dynamics, using optimal dynamic inversion.
6. Extend the system to multiple MFC patches with independent control inputs, providing a vector of control inputs, and resolve the optimal control law problem.

Conclusion:

A complete static thermo-mechanical and electrical analysis of the composite structure has been completed for some sample configuration with 1 MFC patch. Voltage input was was modeled as a control input, and response of the structure is modeled. A method to identify best force input for a given thermal loading was identified. Simulations in Abaqus also verify these results.