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A Flexible Structure's Active Vibration Suppression Using Smart Materials

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Abstract--- Response quantities like displacement, stress, vibration frequencies, and mode shapes must be calculated in engineering design in relation to a specified set of design parameters. However, because to manufacturing mistakes, measurement problems, and structural complexity, among other factors, the design parameter may be unknown. Numerous references have already treated these unknown structural parameters as probabilistic (random) models. However, uncertainty is not the same as randomness, and probabilistic modeling is not the only technique to characterize uncertainty. In order to address this issue, it is suggested that active control approaches be used using smart structural members made of piezoelectric materials coupled to structural members. A truss structure design and active vibration damping control system that makes use of piezoelectric actuators and sensors are presented. The controllers significantly boost the structure's damping, according to the results. Even when higher order modes and parametric uncertainties that were not taken into consideration during the control design process are present, the resilient H controller offers superior performance compared to the control strategies that were previously provided.

Keywords--- Piezoelectric, Vibration, Sensor, Self-monitoring.

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I. Introduction

High level designs with coordinated self-checking and control capacities are turning out to be increasingly more significant because of the fast advancement of "shrewd" mechanical frameworks and space structures. Since these designs are typically dispersed and adaptable, their exhibition depends on dynamic vibration concealment and conveyed dynamic estimation. It is continuously difficult to control dispersed boundary frameworks (like plates and shells) and stifle vibration, both in principle (Kolekar et al., 2019). Using piezoelectric materials as distributed sensors and actuators, a large number of research findings in active structural vibration control have been generated in recent years. Piezoelectric integrated structures have been analyzed using a variety of analytical and computational models. The majority of them rely on the finite element method and an analytical approach. In engineering, system identification is a well-known modeling technique with many effective uses. In recent years, system identification approaches have become increasingly important for modeling piezoelectric integrated structures. It is challenging to incorporate every component of the system into analytical and finite element models, which adds to the model's complexity (Hashemi et al., 2022). Conversely, the identification-derived model encompasses every facet of the system. The idea of uncertainty is crucial in the study of many engineering issues as, in the majority of real-world scenarios, the loads and structural characteristics are unknown. The most widely recognized way to deal with addressing the vulnerability issue is to show the primary boundaries as irregular factors or fields. All of the data in regards to the primary boundaries under the predetermined conditions is given by the joint likelihood thickness capability (otherwise called the dissemination capability). Tragically, the probabilistic model isn't the best way to depict vulnerability, and vulnerability isn't inseparable from haphazardness. In reality, the presumptions made in regards to the joint likelihood densities of the irregular factors or capability included are not adequately upheld by exploratory information probabilistic methodologies can't deliver exact responses at the fundamental accuracy (Li et al., 2014). Interval mathematics-based uncertainty analysis is becoming more and more significant across all engineering domains. A relatively young and expanding area of applied mathematics is interval arithmetic. All of the parameters' uncertainties are taken into account by interval arithmetic, which treats them as interval numbers whose range includes the uncertainties in those parameters. The uncertainties related to the data are carried over into the subsequent calculations, which are computed using interval arithmetic. This study examines the modeling, control, and experimental assessment of piezoelectrically actuated cantilever beams with interval-form errors. The discrete domain design of the control methods is based on the system output (Olmi et al., 2007; Darus et al., 2011)).

The organization structure of the work as follows: The structure model and the first vibration mode in section 1, The relevant article of the structure model is obtained to represent the first vibration mode in section 2. Feedback controller design and implementation to control the vibration of a smart cantilever beam is presented in section 3, Design and evaluation of a state feedback controller is presented in section 4; and finally in section 5, presents conclusion of this work.

II. Literature Review

Several paradigms have been put forth by the intelligent control approach to accomplish effective control of intricate systems. Specifically, output feedback control techniques based on interval analysis have been successful in the application field primarily because they parallel human reasoning. However, under very broad assumptions, robust control—which has classical roots—has also matured as a method for linear systems that can handle uncertainty in multivariable models. The operation's accuracy and precision could be drastically reduced as a result of the huge and unexpected excursion of responses caused by the uncertainty of structural parameters. A deterministic approach approximates the vibration control problem of an uncertain system. In this part, an interval model periodic output feedback controller is constructed, and an interval arithmetic approach is used to experimentally assess the controller's performance for vibration control of a piezoelectrically actuated cantilever beam (Fei et al., 2010).

Chen & Levy, (1999) tackle the issue of employing interval arithmetic to model a structure with uncertainty. Interval variables are used to model the unknown parameters. The interval method is more successful in assessing the robustness of response of uncertain control systems, according to a comparison between interval analysis and the traditional probabilistic methodology. Chen & Levy, (1999) introduced a novel technique, the interval finite element approach, utilizing the interval analysis method. It is evident that the approach performs better when forecasting the impact of input uncertainty or structural response uncertainty. Response quantities like displacement, stress, vibration frequencies, and mode shapes must be calculated in engineering design in relation to a specified set of design parameters. However, because to manufacturing mistakes, measurement problems, and structural complexity, among other factors, the design parameter may be unknown. Numerous references have already treated these unknown structural parameters as probabilistic (random) models. But uncertainty is not the same as randomness, and there are other ways to describe uncertainty besides probabilistic modeling. Interval analysis has become a tool in many domains since (Song et al., 2000) outlined the fundamental theory underpinning it in his monograph. Tripathi & Gangadharan, (2012) discusses interval analysis of vibrating systems. The structural optimal design was explored using the interval technique; The static response and eigenvalue issues of five structures with bounded unknown parameters were assessed (Atepor, 2009). using the interval set model. Majeed et al., (2013) investigated interval eigenvalue problems using the finite element approach. For systems with deterministic characteristics, the theory of vibration control has advanced significantly. Bravo, (2000), for instance, created the accepted techniques for controlling vibration. As was already indicated, the control problem of the vibration structures is significantly impacted by the uncertain notion. Numerous studies on control problems have been conducted from a mathematical perspective (Song et al., 2006).

III. Methodology

In addition to the rigid (rotary) modes, the first 10 flexible modes of the beam were included for modeling reasons. Only the first two modes were considered for control design considerations. This makes it possible to see how observation and control affect the higher modes. By assigning weights to the inputs and outputs, the open loop transfer function can be altered to improve the controller's response in particular situations, as illustrated in 1. The Open Loop's Shape shown in Figure 1.

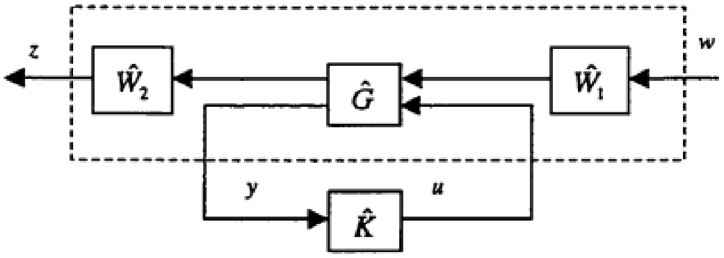

Figure 1: The Open Loop's Shape

There were no loads placed on the framework's contributions. Therefore, the personality framework is the info weight minx Wi. In order to increase execution on clear state components while maintaining a reasonable control signal, the result weight lattice continuously punishes the state and control work. The structure for the result loads in this case is then, at that moment.

$$\hat{W}_2 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.05 \end{bmatrix}$$

The following controller is produced by following the previously described control design procedure:

$$u = u_M + u_q + u_{\dot{q}}$$

The term um gives the input of the inflexible body states, while the tens u and u4 give the criticism of the adaptable states, which are modular amplitudes and modular rates, individually. The molded piezoelectric sensors that give the fundamental proportion of gains for open circuit voltage and short out flow are tracked down utilizing condition (2). The last shapes are displayed in Figure 2.

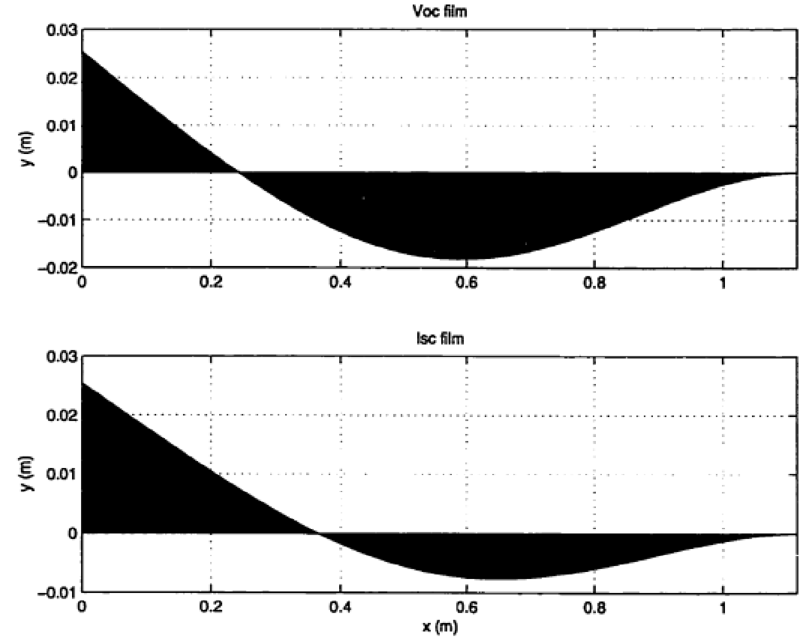

Figure 2: PE Films' Shape for H, Control Design

When measuring the length of the beam, it is important to note that the widths of the sensors are scaled arbitrarily. To achieve the optimal sign to commotion proportion, the movie should ideally be as wide as possible. The sign must be strengthened (or weakened) in order to restore the ideal addition esteem. For this scenario, the maximum width of each film was set at 2.54 cm, or around 50% of the shaft's width. By flipping the cathode's extremity and clipping the film at the sign change point, the example of a sign change resembling the piezoelectric was executed.

IV. Experiments and Results

In this section, two sets of discoveries are presented. The first includes the critique of the flexible states as identified by the developed piezoelectric sensors and is linked to the regulator that was obtained in the previous section. Figures 3, 4, and 5 individually show how the framework responds to a stage reference input in the plot for the joint point, piezoelectric sensors, and control signal. At t=3 S, the joint point must be adjusted from - 57.3 degrees to 57.3 degrees. Even though mode1 lessens the effect of actuator immersion, the reproductions show how the regulator can nevertheless balance the framework with only a small amount of bar redirection. The bar first diverts completely due to the actuator's immersion, but the regulator detects and pipes the motions when the control signal reaches the unsaturated reach.

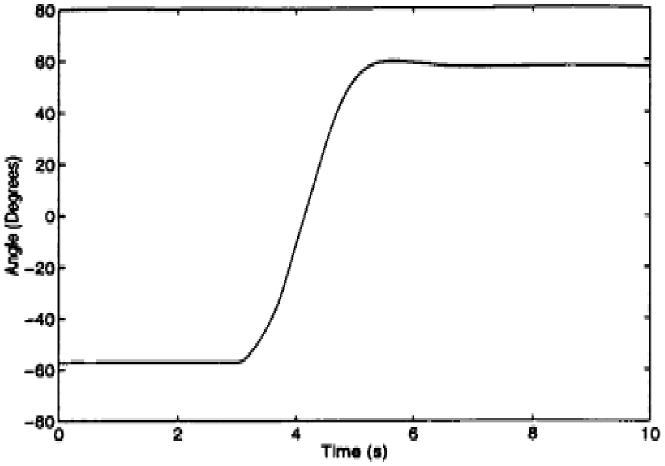

Figure 3: Joint Angle Step Response (Simulation)

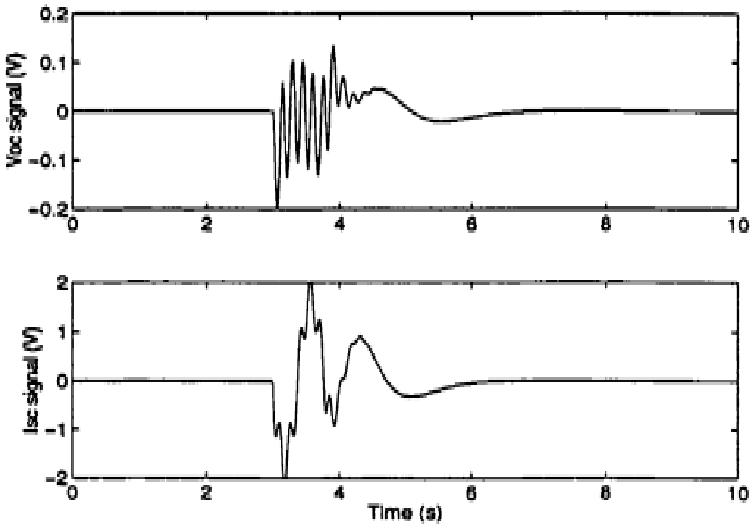

Figure 4: PE Sensor Signals (Simulation) Step Response

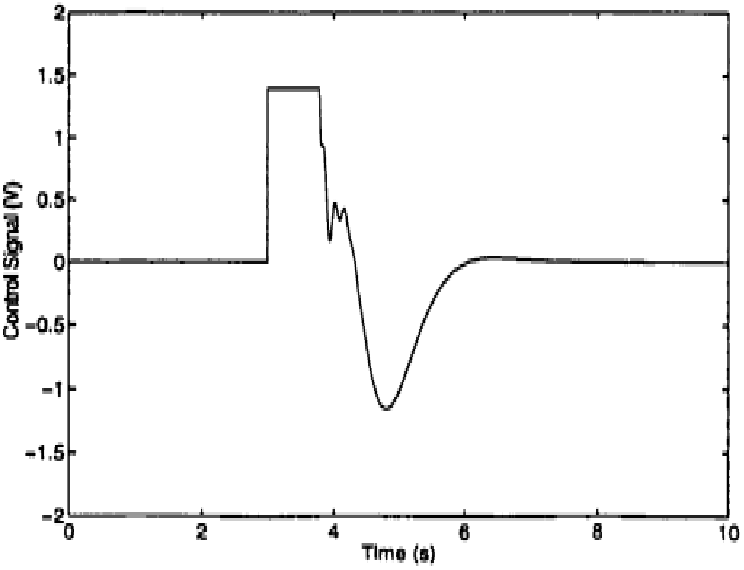

Figure 5: Control Signal Step Response (Simulation)

Figures 6, 7, and 8 show how the framework responds to a stage reference point that is identical to the previous scenario. The motions encouraged by the underlying motive are, in any case, dampened out much more slowly when the regulator remains constant due to primary damping and, less importantly, the cross coupling between the unbending body and adaptive states.

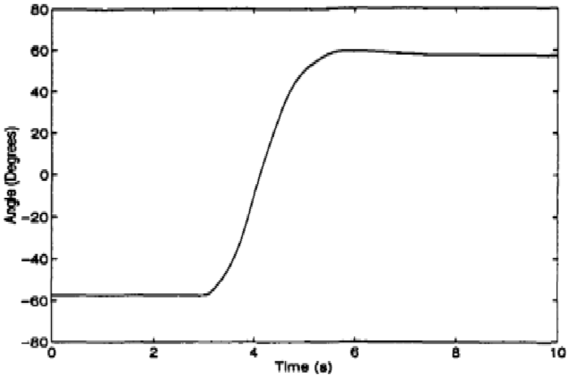

Figure 6: Joint Angle Step Response (Simulation). Absence of PE Feedback

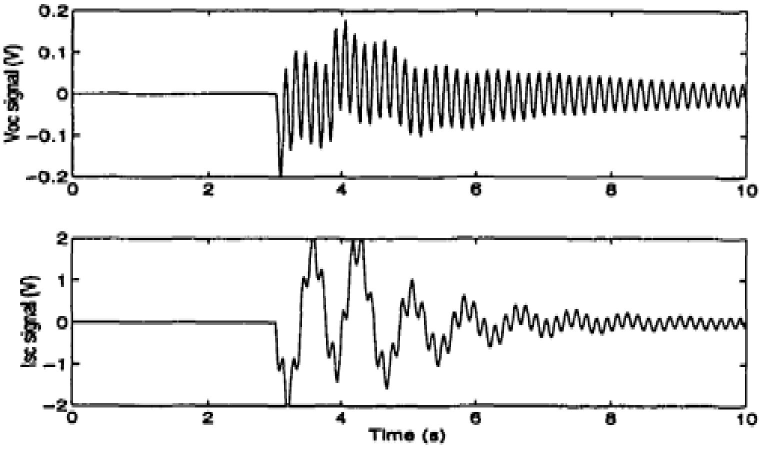

Figure 7: Step Response: Simulation of PE Sensor Signals. Absence of PE Feedback

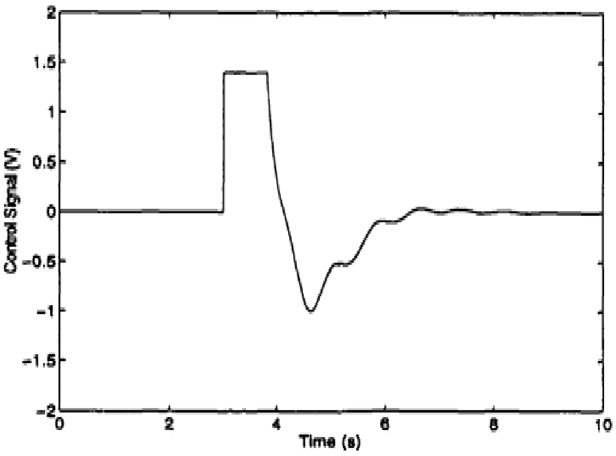

Figure 8: Control Signal Step Response (Simulation). Absence of PE Feedback

The control framework discusses in detail the problem of constructing state criticism regulators for direct time-invariant frameworks using span examination. Boundaries in straight models of real frameworks usually have unclear properties, but they are confined in minimized sets, which are frequently referred to as shut stretches. For every possible configuration of the framework qualities, the control problem is to determine a state criticism gain that will place all closed circle posts in the left-hand side of the complex plane (vigorous adjustment) or in a particular district of it (hearty execution).

V. Conclusions

The feedback system should preserve stability and closed-loop performance requirements, or stability robustness and performance robustness, respectively, in the face of plant parameter uncertainties. Any realistic motivated feedback design's primary goal is this. The state feedback controller is constructed to suppress a piezo-actuated cantilever beam's initial vibration mode using the simplex and interval polynomial methods. The closed-loop system matrix has been subjected to Heinen's condition. A linear programming issue has been created by minimizing a specific objective function while taking restrictions into account. The simplex method has been used to solve the problem and acquire the state feedback gain. To lessen the vibration amplitude at first resonance, the controller is made for the second order internal model utilizing an interval polynomial approach. In order to use the interval polynomial to robustly stabilize the closed loop system, the characteristic polynomial of the system is determined and the transfer function in interval form is developed. Through simulation, the controller's performance has been assessed.

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