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Detection of best location for the placement of the piezo pair on smart beams using FOS technique

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Abstract*—This paper deals with the detection of a best location for the optimum placement of the Piezo sensor actuator pair on the smart beam using FOS technique. Vibration control plays a very important role in the modern day world especially in control of earthquakes & in aerospace engineering. With reference to this, research is being carried out in this exciting field. Control of vibrations in smart intelligent structures for a SISO case using periodic output feedback method is presented in this paper for the best location, which is normally near the root or the fixed end, where the beam is fixed at one end. Simulation is carried out in Matlab & the results show the effectiveness of the method presented in this paper. This is just a simple exercise to show how powerful the effects of vibrations are near the fixed end of the smart beam.

***Index Terms*—Smart structures, Periodic output sampling, Vibration control, Beams, Sensors, Actuators.**

I. INTRODUCTION

A smart material is defined as any material that is capable of being controlled such that its response and properties change under a stimulus. A smart structure or system is capable of reacting to stimuli or the environment in a prescribed manner. Smart Materials and Structures is committed to the understanding, expansion and dissemination of knowledge in this subject matter. To this end, the Journal publishes articles in the following areas [60]:

- Smart materials development and application—including, but not limited to, shape memory alloys and polymers, electro and magneto rheological materials, piezoelectric, ferroelectrics, piezomagnetics, electro and magnetostrictive materials, thermoelectric, photovoltaic's, electro and magneto caloric materials, electrochromics, IPMCs, electro active polymers, energy storage materials, ferroelectrics, self-healing materials and multifunctional materials in general [60].
- Smart materials utilized as sensors and actuators with applications at any scale [59].
- Adaptive structural systems, actively controlled structures with smart materials and other non-traditional actuators [58].
- Sensor and sensor networks for smart materials and structure applications, processing of sensor information for adaptive control or structural health monitoring as well as integration of these sensor networks into materials and structures [57].
- Smart optical materials for modification in spectral shifts and refractive index shift [56].
- Structural health monitoring with applications to ground vehicles, aircraft and civil infrastructure [55].
- Intelligent systems, integrated with sensors, actuators and controllers, applied to automation and robotic systems that utilize smart material systems [54].
- Energy harvesting systems including modelling, applications and implementation issues [53].

Smart materials such as sensors & actuators together integrated or embedded into the structure are what is called a "Smart Structure" and are often called as the intelligent structures, which are used for control of vibrations in structures & earthquakes [52]. Smart materials are a subset of the smart structure [1]. Thus, a smart structure is a distributed parameter system that employs sensors & actuators at different finite element locations on the beam and makes use of sophisticated feedback controllers that analyze the responses obtained from the sensors and use different control logics to command the actuators to apply localized strains to the plant to respond in a desired fashion. Smart structures have also got the capability to respond to the changes in the environment on the plant, whether internal or external such as load changes or temperature changes [2].

A smart structure system comprises of 4 important sub-parts such as sensors, controller, actuators and the plant (flexible beam), whose condition is to be controlled [53]. Each component of this smart structure system has a certain functionality and the entire sub-systems are integrated to perform a self-controlled smart action, similar to a living creature who can "think", make judgment and take actions on own at the appropriate time, thus inducing the smart & intelligentness [3].

The paper is organized as follows. A brief review about the smart structures is presented in the introductory section. The FOS control law used in the research work is presented in section 2 followed by the control simulations in section 3. Justifications of the simulation results are presented in section 4. The section 5 presents the conclusions of the work done. This is followed by the references & the author biographies.

II. FAST OUTPUT SAMPLING FEEDBACK CONTROL LAW (FOS)

The concept of how the control law is developed using the fast output sampling feedback control technique is shown in the Fig. 1 as

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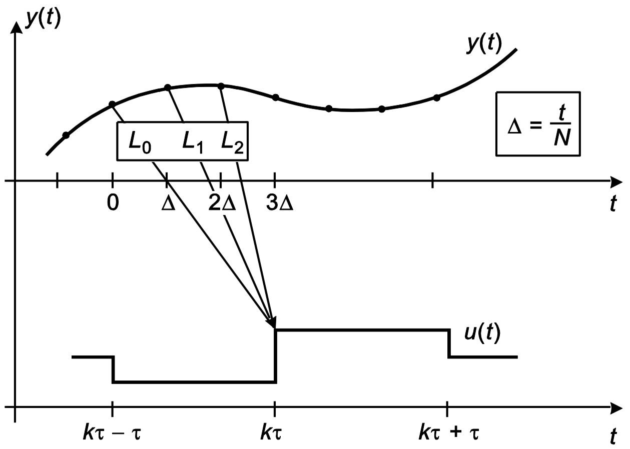


Fig. 1 : FOS method (graphical illustration)

III. CONTROL SIMULATIONS

In this section, a single input single output model of the plant is used as shown in the Fig. 2 [1] – [10]. The mathematical model is developed, the fast output sampling feedback controller is designed, put in loop with the plant, the open loop response, closed loop (with the state feedback gain & the FOS gain L), the control input u required to damp out the vibrations are observed and are shown in the figures below. From the simulation results (done for all the 20 models of the plant), it is observed that when the beam is divided into 20 finite elements, the results with the piezo pair kept at the fixed end (system 1) is more satisfactory than the results with the piezo pair kept at the free end (system 20). From the results, it is observed that without control, the transient response is unsatisfactory & takes more time to settle & with control, the vibrations are suppressed in no time, which shows the control effect [11] – [20].

The single input single output state space model (state equation and the output equation) of the smart structure developed for the system shown in Fig. 4 starting from the first principles is given by [50]

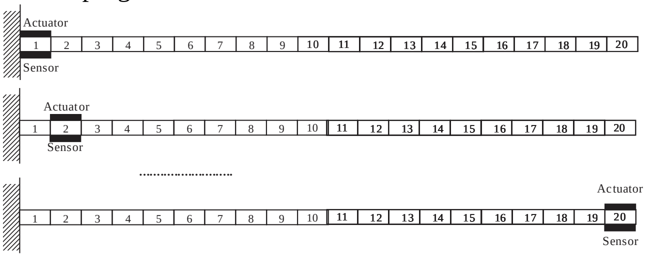
$\dot{\mathbf{x}} = \mathbf{A}\,x(t) + \mathbf{B}u(t) + \mathbf{E}r(t),\ y(t) = \mathbf{C}^T\,\mathbf{x}(t) + \mathbf{D}u(t)$, with

$$\mathbf{A} = \begin{bmatrix} 0 & I \\ -\mathbf{M}^{*-1}\mathbf{K}^{*} & -\mathbf{M}^{*-1}\mathbf{C}^{*} \end{bmatrix}_{(4\times4)},$$

$$\mathbf{E} = \begin{bmatrix} 0 \\ \mathbf{M}^{*-1}\mathbf{T}^{T}\,\mathbf{f} \end{bmatrix}_{(4\times1)}$$

$$\mathbf{B} = \begin{bmatrix} 0 \\ \mathbf{M}^{*-1}\mathbf{T}^{T}\mathbf{h} \end{bmatrix}_{(4\times1)}, \quad \mathbf{C}^{T} = \begin{bmatrix} 0 & \mathbf{p}^{T} \end{bmatrix}_{(1\times4)}, \quad \mathbf{D} = \text{Null Matrix},$$

where the parameters $r(t)$, $\mathbf{u}(t)$, $\mathbf{A}, \mathbf{B}, \mathbf{C}, \mathbf{D}, \mathbf{E}$, $\mathbf{x}(t)$, $y(t)$ represents the external force input, the control input, system matrix, input matrix, output matrix, transmission matrix, external load matrix, state vector and the system output (sensor output) [49]. This model is used for developing the controller in simulink environment [48].



The model 1 is touchier to the first mode as the moment of bending is most extreme, strain rate is higher, least tip diversion, better sensor o/p and less prerequisite of the control impact (control will be more compelling at the root). The model 20 is less sensitive to the first mode as the bending moment is minimum, strain rate is lesser, maximum tip deflection, less sensor output and more requirement of the control effect (control will be in effective at the root) to dampen out the vibrations. Hence, it is concluded that model 1 is the best for AVC as response characteristics with F and L are improved, for the sake of simplicity, only the control simulations near the fixed end (sensor actuator pair placed at FE position 1) & the free end (sensor actuator pair placed at FE position 20) is shown here [21] – [30]. .

From the simulation results shown in the figures 2 & 3 it is observed that sensor o/p (CL o/p in black color) is suppressed compared to the sensor output (open loop response in red color), also the control signal is shown in the first figure, which is used to reduce the vibrations. The LMI was solved, optimization was obtained & L, the FOS feedback gain in obtained, which can be shown from the matlab output results from the command prompt [31] – [40]. Here, only the simulation results for the piezo pair placed at fixed end and for the piezo pair placed at the free end is shown here for the sake of convenience. LMI is used to solve & get L.

IV. SIMULATION RESULTS - MATLAB OUTPUT TAKEN FROM THE COMMAND WINDOW PROMPT OF MAIN WINDOW

>> fos_sine_1
Solver for straight target minimization under LMI limitations
Cycles : Best target esteem so far [41] – [50].

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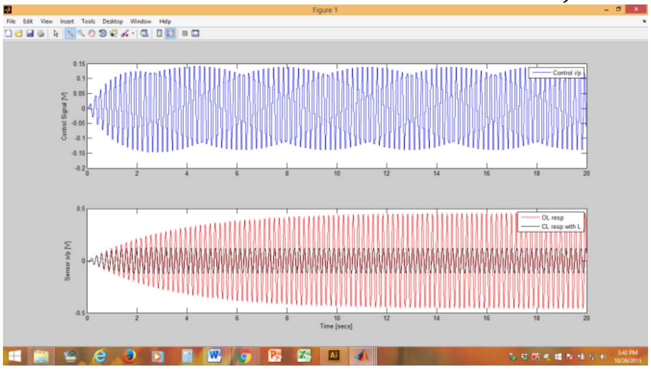

Fig. 2: OL & CL responses with & w/o the controller for model-1 piezo at FE1

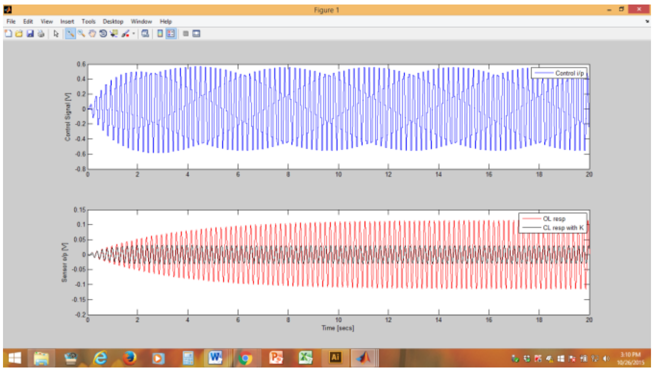

Fig. 3 : OL & CL responses with & w/o controller for model-20 piezo at FE20

1
* * * new value of the bound: -3.654470e+11
2 -19.325464
*** New lower bound: -1.285900e+11
3 -19.325464
*** New lower bound: -4.439526e+10
4 -8.606513e+08
*** New lower bound: -1.295022e+10
5 -9.736850e+08
*** New lower bound: -5.901534e+09
6 -9.736850e+08
*** New lower bound: -2.657682e+09
7 -9.919324e+08
*** New lower bound: -1.121999e+09
8 -9.991313e+08
*** New lower bound: -1.068453e+09
9 -9.998569e+08
*** New lower bound: -1.032263e+09
10 -9.998569e+08
*** New lower bound: -1.003894e+09

Result: achievable arrangement of required precision best targeted value : –9.998569e+08 Guaranteed accuracy in the relative mode : 4.04e-03 f-radius saturation: 99.986% of R = 1.00e+09

L = –8.5560 –6.5908 –3.7283 –0.2600

>> **Table 1: Quantitative justification of the simulation results**

Sensor/Actuator Pair	Open loop	Closed loop	Control Signal
FE posn 1	0.1 V	0.025 V	0.6 V
FE posn 2	0.5 V	0.1 V	0.15 V

From the quantitative results shown in the table above, it is justified that when the sensor actuator pair is placed near the free end, more control effort (0.6 V) is needed to curb down the vibrations, also sensor output is less, whereas when the sensor actuator pair is placed at the fixed end, less control effort (0.15 V) is needed to curb down the vibrations, also sensor output is more as the strain rate is very high near by the fixed end [51] – [60].

V. CONCLUSIONS

In this paper, control of vibrations in smart intelligent structures for a SISO case using FOS method was presented. The simulation results show the effectiveness of the method developed for vibration suppression. The beam was divided into a number of finite elements & the best location for the placement of the piezo sensor actuator pair was found out through simulations done in Matlab. The results show the effectiveness of the method developed.

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