Design and Development of Instrumentation for Active Vibration Control of Smart Aerospace Structures

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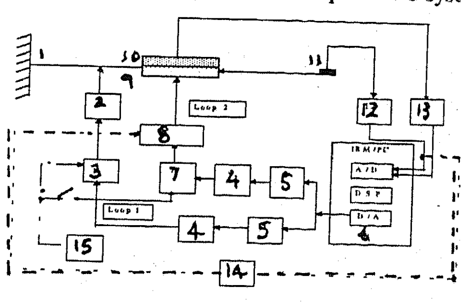
ABSTRACT :

Active vibration control of aerospace structures using smart concept is one of the potential areas of application, the successful implementation of which requires design, development of instrumentation, electronics, digital signal processing techniques, computers, control system, robust control law, structure with built-in sensors and actuators coupled with good analytical and system identification studies. This paper essentially deals with some of the above issues and requirements. Further, it focuses on the design, development of instrumentation catering to piezos being used as sensors and actuators on the host structure to achieve active vibration control. The implementation of active vibration control for a single channel is explained in detail. The paper concludes with the description of adaptation of the above for multi-channel vibration control .

INTRODUCTION :

A substantial amount of research effort has been carried out in the area of smart materials, structures and systems development for its application to Active Vibration Control (AVC) of aerospace structures. There are four major aspects to be considered for the successful implementation of AVC. 1). Analytical aspects, 2). Design and fabrication of smart structure, 3). Hardware development, and 4). Software development. Further the requirements can be broadly classified under three categories i.e., the excitation requirements of the actuator, the response studies of the structure under investigation and the development of control law which involves simultaneous design and development in areas such as electronics, instrumentation, digital hardware, computer & its interface, signal processing, system identification, control system and related software.

Three methods are considered for the implementation of AVC. These methods depend on the manner in which the signal fedback to the secondary actuator is modified and derived so as to suppress the vibratory response of the structure. These methods utilise, feed back of 1). Reference signal from the primary excitation source through a wide band phase shifter with proper gain & phase shift. 2). Signal proportional to the velocity and displacement with required gains, added together. 3). Signal generated by a digital controller (IBM/PC) which implements a filtered X - least mean square (LMS) algorithm by using reference & error response signals for the computation of the error. Figure 1 shows the designed & developed AVC system [1].



1. CFRP smart beam, 2. Electro dynamic exciter, 3. Power amplifier, 4. Low pass reconstruction filter, 5. D/A converter interface, 6. Digital controller with 8 channel A/D & 4 channel D/A converter, 7. Phase shifter, 8. High voltage amplifier, 9. Piezoceramic strip (Actuator), 10. Piezoceramic strip (Sensor) , 11. Piezoelectric accelerometer, 12. Conditioning amplifier, 13. Charge amplifier, 14. Analog controller, 15. Sine/Random generator.

Fig 1: The Active vibration control (AVC) system configuration

ANALYTICAL ASPECTS:

A composite cantilever beam (250mm x 25mm x 3mm) bonded with piezo actuator is used to control the dynamic deflection of the beam. Finite element method is used to formulate the equation of motion which is given as:

$$[M]\{\ddot{x}\} + [K]\{x\} = \{F(t)\} \quad (1)$$

where, $\{F(t)\}$ - control force vector, $[M]$ - mass matrix, $[K]$ - stiffness matrix

$$\{q\} = [\phi]\{x\} \quad (2)$$

then using the transformation given in Eq (2), Eq (1) can be written as,

$$\lceil m \rfloor \{\ddot{q}\} + \lceil k \rfloor \{q\} = [\phi]^T \{F(t)\} \quad (3)$$

where 'q' is the generalised co-ordinates, 'ϕ' is the eigen vector matrix and 'x' is the physical co-ordinates.

But $$[\phi]^T \{F\} = -[g]\{q\} - [h]\{\dot{q}\} \quad (4)$$

where 'g' and 'h' are calculated using 'modified independent modal space control '(MIMSC)' method [2].

Therefore, $$\lceil m \rfloor \{\ddot{q}\} + \lceil k \rfloor \{q\} = -[g]\{q\} - [h]\{\dot{q}\} \quad (5)$$

Right hand side of the Eq (5) is implemented by suitably modifying the response signal from the accelerometer mounted on the structure. Knowing the displacement and velocity responses the control force {F(t)} can be calculated from Eq.(4). Dynamic analysis and free vibration tests were carried out on the beam indicated above.

HARDWARE DEVELOPMENT:

Hardware design & development is carried out for the following. The important design considerations of charge or high voltage amplifier include strain or force level, output or input impedance of piezos, bandwidth of the structural response and the required amplification.

Charge Amplifier

The piezoceramic sensor develops a charge output proportional to the vibration response. The charge amplifier converts this charge into an equivalent voltage level, suitable for further amplification and processing. Fig. 2 shows the schematic of the charge amplifier[3].

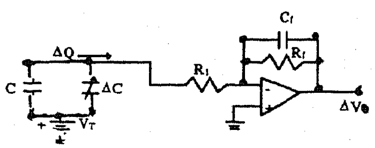


Fig 2: Charge Amplifier

$$\Delta V_0 / V_T = -\Delta C / C_f \quad (6)$$

where, ΔQ = Quantity of charge transferred, ΔC = Capacitance change, V_T = Constant voltage across the transducer, C_f = Feedback capacitance and ΔV_0 = Output voltage change.

High Voltage Amplifier

The amplifier is required in between controller output and the piezoceramic actuator which requires high voltages (for e.g.: ± 200 volts) to develop the required force to actuate the structure. Figure.3 shows the schematic of the highvoltage amplifier [3].

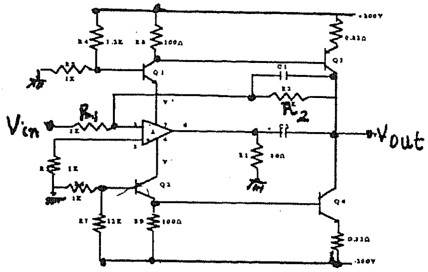


Fig 3: High Voltage Amplifier

$$V_{out} / V_{in} = -R_2 / R_1 \quad (7)$$

Phase Shifter

Phase shifter is required for the implementation of method 1. The output amplitude of the phase shifter is made independent of frequency and phase shift. The phase shifter provides a phase adjustment of output with respect to input from -180° to + 180°. Figure 4. shows the schematic of the wide band phase shifter[3].

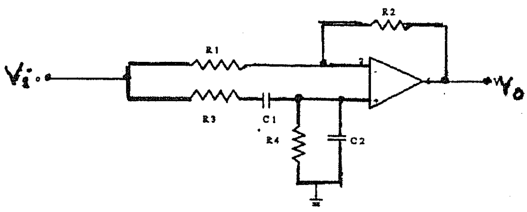


Fig 4: Phase Shifter

$$V_o / V_i = 1/5 * (1-j X/3) / (1 + j X/3), \quad (8)$$

where, $X = (2\pi f RC) - (1/2\pi f RC)$ and phase shift $\phi = -2 \tan^{-1}(X/3)$

Analog Controller

Figure 5 shows the schematic of the analog controller, developed. The first two stages are integrators followed by amplifiers and a summer. The integrator produces an output voltage proportional to the input voltage[3] which is given by,

$$V_o = -1 / R_1 C_f \int V_I \, d t \quad (9)$$

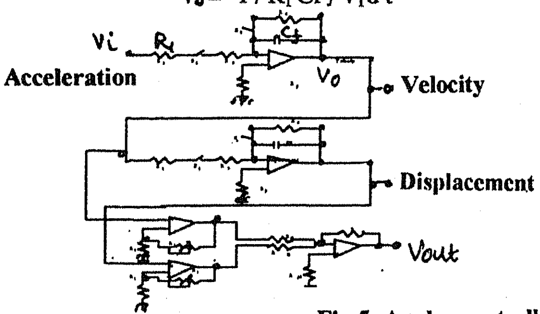


Fig 5: Analog controller

The piezoelectric accelerometer output (conditioned and normalized) serves as input to this controller circuit. The first integrator gives velocity and the second the displacement. The output from this controller circuit is suitably scaled in amplitude such that it does not overdrive and saturate the piezoceramic actuator.

DIGITAL TECHNIQUES FOR AVC:

To implement the digital controller techniques for AVC, analog to digital (A/D) and digital to analog (D/A) converter hardware are developed to digitise, acquire the vibration response from the piezo sensors and to convert the processed data in digital form to analog signal for driving the exciter and piezo actuators.

Analog To Digital Converter

To implement single channel AVC, 4 data acquisition channels available on the PC compatible card are utilised. Piezoceramic sensor response, piezoelectric accelerometer output, primary excitation source and controller output (secondary actuation) form the inputs to these 4 channels. The data acquired from these 4 channels is stored in the computer for further processing.

Digital To Analog Converter

A PC compatible four channel digital to analog converter card for signal generation has been developed. This has been interfaced to a PC compatible TMS320C30 based Digital Signal Processor card. Figure.6 shows the hardware developed for the implementation of active vibration control using digital techniques.

The hardware developed can be extended for multi channel AVC implementation.

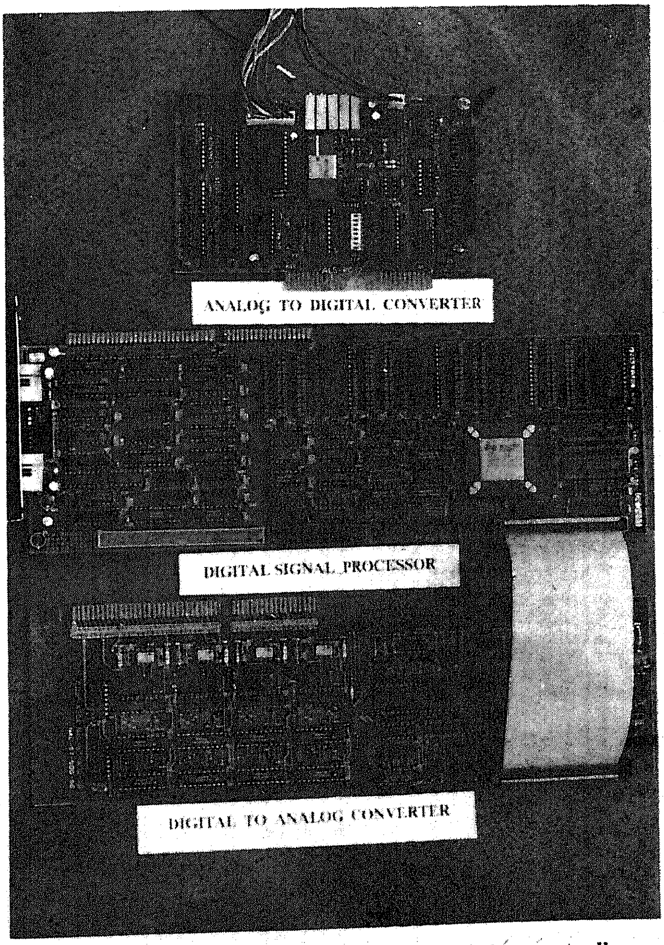


Fig 6: Hardware developed for digital vibration controller

SOFTWARE DEVELOPMENT:

Software is developed to acquire the primary and secondary actuation signals as well as the responses from piezosensor and accelerometer. This software also controls the interface hardware.

Development of control algorithm

Additional vibration in antiphase required for AVC is introduced through secondary source to interact with the primary source. The frequency or spatial distribution of the primary source and the control parameters may change with time. Adaptive systems have the ability to track such changes and provide optimal control. To this end, the implementation of filtered-X LMS algorithm is required. The algorithm must simultaneously perform system identification and control. The full details about the implementation of this adaptive algorithm using digital signal processing techniques in real-time is available in [4].

Implementation

The LMS adaptive algorithm has been implemented on IBM Pentium II 350MHz Personnel Computer in MATLAB,'C' and HP-VEE (Visual Engineering Environment). The program has been made user friendly and tested with simulated signals for changes in input parameters in their respective environments. Figure (7) shows the structure of the adaptive traversal filter that has been implemented. Figure (8) shows the details and the resulting plots from the C & MATLAB program and fig (9) shows the resulting plots from the HP-VEE environment.

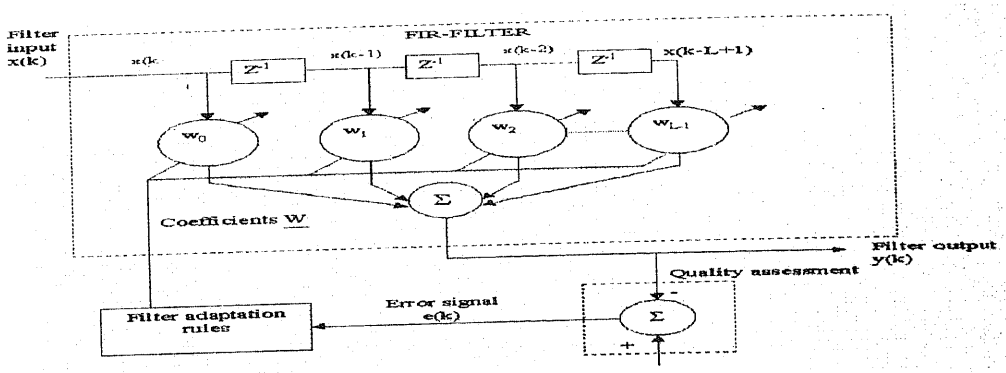


Fig 7: The structure of an adaptive transversal filter

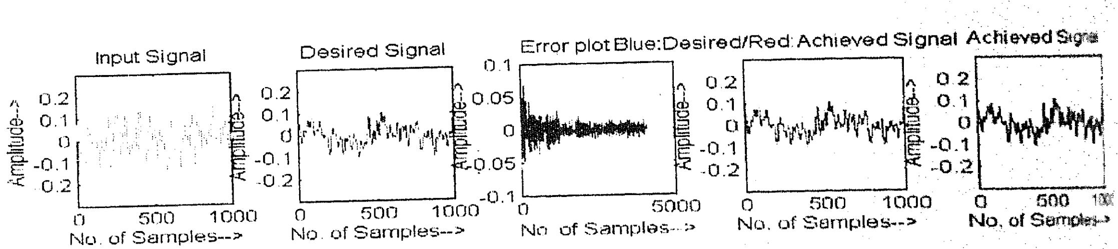


Fig 8: Plots obtained from LMS program developed in MATLAB and C environments for Arbitrary Desired Signal

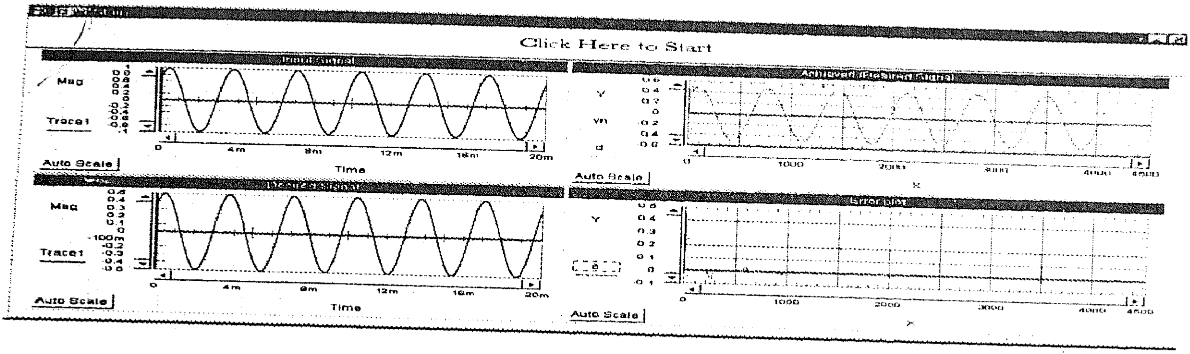
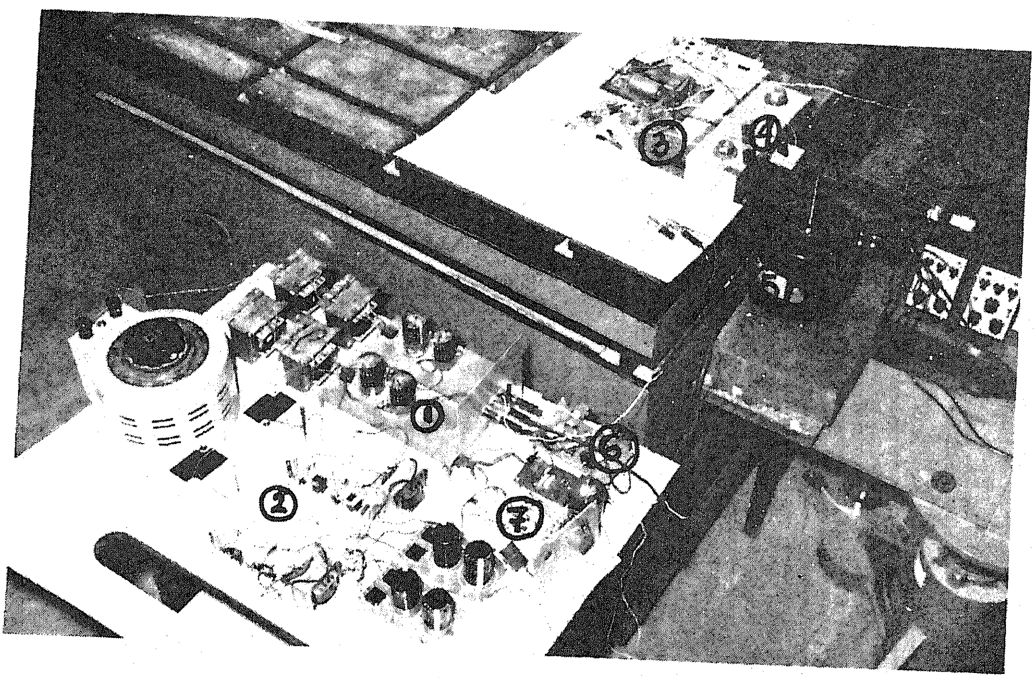


Fig 9: Plots obtained from LMS program developed in HP-VEE environment

SINGLE CHANNEL ACTIVE VIBRATION CONTROL SYSTEM:

The configuration used for the implementation of single channel vibration control system is shown in fig(1). The experimental setup required for the implementation of AVC for single channel is shown in fig(10), [5].



1. Mains driven power supply 2. Battery driven power supply 3. Charge amplifier 4. Smart piezo beam 5. Electro dynamic exciter 6. High voltage amplifier 7. Phase shifter & integrator

Fig 10: Single channel active vibration control setup

EXPERIMENTATION:

Vibration tests were conducted on the system (fig.10) with sine and random excitation inputs upto a frequency range of (200 Hz). Outputs from piezoceramic sensor, accelerometer, signal generator and controller were measured and acquired. Method 1 & 2 were implemented by choosing the corresponding elements of the system. Implementation of method 3 requires, digital controller hardware along with software (LMS algorithm). Further, for the case of sinusoidal excitation, the adaptive filter developed must match the optimal magnitude and phase characteristics at any set frequency.

The system developed is tested for sinusoidal input excitation signal at any set frequency. It was observed that the output of the piezoceramic sensor with respect to input to the piezoceramic actuator is having a linear relationship which is an important requirement for the controller development. In such an application, the adaptive filter (method 3) must match the optimal magnitude and phase characteristics at any set frequency.

CONCLUSIONS:

Three methods for the implementation of active vibration control have been considered. The design and development of analog and digital hardware with related software is explained. Requirements and implementation of all the methods are discussed. The hardware developed can be easily adapted for multichannel AVC system development, using modular concept. For the implementation of AVC concept in actual structures the instrumentation developed is miniaturised to reduce size, weight and power requirements. Future work involves development of the algorithm for the control of multiple modes using multichannel concepts for applications involving actual aerospace structural components.

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