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Design of Random Vibration Controller using Adaptive Filtering

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***Abstract*— In this paper a control scheme for electro-dynamic shaker control is proposed. The proposed controller is best suitable for random vibration control in which the excitation signal is a random signal. The controller designed is using acceleration power spectral densities and adaptive filtering technique. The proposed scheme eliminates the requirement of tracking filters in the vibration control and it is not affected by the uncertainties in the modeling. The proposed controller is tested for different acceleration profiles and the simulation results are presented.**

***Index Terms:* Electro dynamic Shaker, Vibration Control, Acceleration PSD, Adaptive Filtering.**

I. INTRODUCTION

Industries like aerospace, auto-making, manufacturing, wood and paper production, power generation, defence, telecommunications, consumer electronics and transportation are dependent on structural vibration and it has got an important role to play in their growth. It is mainly used to improve product quality by identifying and suppressing the unwanted vibrations.

Vibration testing is performed to provide the test item vibration environments expected in its shipment and application environment. Vibration testing is usually performed by applying a vibratory excitation through a shaker to a test object and monitoring the structural integrity of the object and its performance of its intended function. Generally, one or more "input" or "control" points on the DUT (Device Under Test) are kept at a specified vibration level.

The vibration testing arrangement is shown in Fig. 1. The main equipment used to execute vibration testing includes an electrodynamic shaker, a power amplifier and an acceleration controlling and monitoring system. The test article is attached to the table of the shaker along with an accelerometer mounted to measure and feedback the input (or control) acceleration a. To match the specified reference profile (magnitude and frequency), the control platform excites the shaker with an appropriate power amplifier by generating the drive signal.

Yosuke Hirowatari et al. [1] has discussed about vibration control using a tracking filter. The system for consideration is not a shaker but an electro-hydraulic servo system. But the use tracking filter provides exact tracking of the magnitude and phase of the fundamental frequency waveform from a noisy signal.

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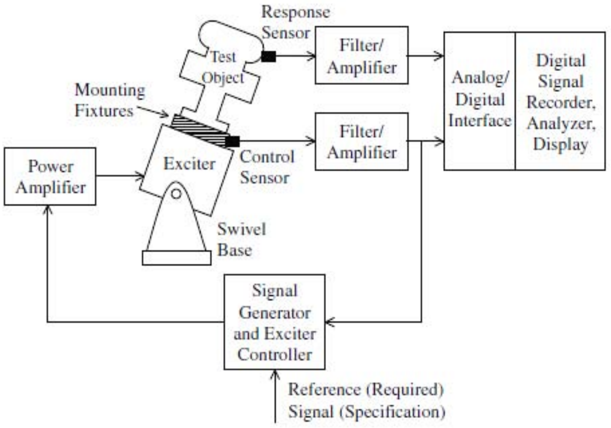

Fig.1 Vibration-testing arrangement [6]

M. Fujita and Y. Uchiyama [3 and 4], achieved the electro dynamic shaker robust control by means of the acceleration and displacement control of the shaker's table. Flora and Gründling [5], designed a digital acceleration controller for sinusoidal vibration tests using a switching-mode AC power source-ACPS with an electrodynamic shaker. The scheme is based on two control loop interaction: one of them for the acceleration regulation and the other one for the ACPS voltage output. But this method gives satisfactory results only for sine vibration testing.

In this paper a control scheme for random vibration control presented. Here the controller is implemented by calculating acceleration power spectral densities, generating a control signal by applying adaptive filtering technique. The simulations carried out in MATLAB and results are presented.

II. VIBRATION CONTROL

It is required to control the vibrations through shaker because it causes fatigue and failure of the components that are under vibrations, and discomfort for the people.

The two primary functions of the shaker control system in vibration testing are

1) To guarantee that the specified excitation is applied to the test object and

2) To ensure that the dynamic stability (motion constraints) of the test setup is preserved.

An operational block diagram illustrating these control functions is given in Fig. 2. The reference input to the control system represents the desired excitation force applied to the test object. In the absence of any control, however, the force reaching the test object will be distorted.

To compensate for these distorting factors, the responses of the shaker, the test table, and the test object are measured. These responses are used to compare the actual excitation felt by the test object at the shaker interface, with the desired (specified) input. The drive signal to the shaker is modified, depending on the error that is present.

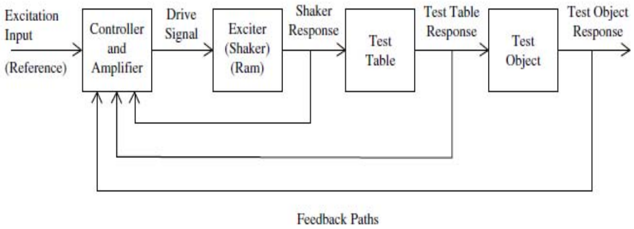

Fig.2 Operational block diagram of shaker control system [6]

III. RANDOM VIBRATION

3.1 Random Signal Generator

In modern random signal generators, SC devices (e.g., zener diodes) are used to generate a random signal that has a required (e.g., Gaussian) distribution. This is accomplished by applying a suitable DC voltage to a SC circuit. The resulting signal is then amplified and passed through a bank of conditioning filters, which effectively acts as a spectrum shaper. In this manner, the bandwidth of the signal can be adjusted in a desired manner. Extremely wideband signals (white noise), for example, can be generated for random excitation vibration testing in this manner. The block diagram in Fig. 3 shows the essential steps in a random signal generation process. A typical random signal generator has several (typically eight) bandwidth selections over a wide frequency range (for example, 1 Hz to 100 kHz) [6].

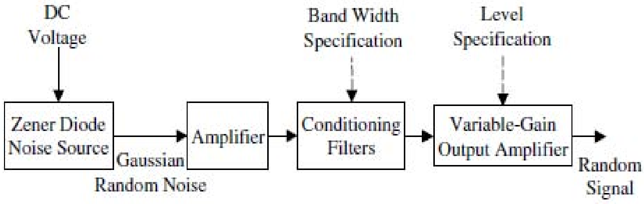

Fig.3 Block diagram of random signal generator [6]

3.2 Random Vibration Control

The main tasks of a modern shaker arise from the various types of controller systems available. These tasks can be classified into two classes

1) Periodical vibration and
2) Random vibration.

Applying periodic vibration to the devices is the main cause of failure. The simulation of such periodic disturbances by laboratory sine excitation has been common for failure. The simulation of periodic vibration is required since the damage in objects by sine vibration is due to magnified effects of resonance.

The sine sweep vibration test could be used to adequately simulate the damage growth (often due to unbalancing). Since the frequency is swept through a large band frequency, most of the resonant vibration modes can be excited and evaluated according to its severity. These tests are used for terrestrial vehicles, vessels and aircrafts since these tests sweep each frequency sequentially at a low cost.

The random vibration induced by jet engines related to top aircraft flying has demanded new design criteria and new test procedures to assure the reliability of devices in such an environment. When the random vibration is measured on field this signal can be used as boundary parameter to define reliability criteria to be reach. Sometimes the actual acceleration signal of a working environment is not the most suitable way to characterize this vibration and latter be used on a shaker or exciter system in an accelerated test. In addition there are other intervening factors that show these signals will not probably be reproduced again since there is presented some level of randomness [10].

One of the best ways to analyze this type of signal is by the Acceleration Power Spectral Density (PSD) obtained from an actual acceleration. This PSD is defined by frequency bands of the whole interested frequency domain. So it is provided plots of Acceleration PSD and frequencies. There is a global trend in using Acceleration Power Spectral Densities as a standard for random vibration tests, mainly in environmental vibration tests. The Acceleration Power Spectral Density can be evaluated by the Fourier Transform of the desired auto-correlation signal.

In other words:

$$S_a(\omega) = \frac{1}{2\Pi}\int_{-\infty}^{\infty} R_a(\tau)e^{-j\omega\tau}d\tau \qquad (1)$$

where $R_a(\tau)$ is the acceleration auto-correlation function, j is the imaginary number, ω is the frequency in rad/s units and t is a time separation. $R_a(\tau)$ may also be evaluated by:

$$R_a(\tau) = E\left[a(t)a(t-\tau)\right] = \lim_{N\to\infty}\frac{1}{N}\sum_{r=1}^{N} a_r(t)a_r(t+\tau) \qquad (2)$$

where the symbol E[.] represents the mean value and N means the sample size.

The Standards generally specifies Power Spectral Densities on its one-sided form, i.e., they are specified of positive frequencies bands. The Power Spectral densities definition uses infinity upper and lower limits, so the One-sided Power Spectral Densities are defined as indicated by equation

$$G_a(\omega) = 2S_a(\omega) \tag{3}$$

For the pseudo-acceleration signal generation it can be used sine series as indicated by equation

$$a(t) = \sum_{i=1}^{N} [\sin(\omega_i t)] \sqrt{2S_a(\omega_i)\Delta\omega} \tag{4}$$

where the Power Spectral Density was divided by N frequency interval Δω, so the process is supposed to be a superposition of sine periodical processes.

In order to accomplish the correct acquisition of the acceleration PSD, care is necessary in the frequency resolution selection, sampling rate and total time for acquisition. Specifically, for a given Standard PSD with lower and upper frequency band limits, the total time should be enough to acquire not less than three cycles of the lowest frequency component.

3.3 Adaptive Filtering

An adaptive filter is a filter that self-adjusts its transfer function according to an optimizing algorithm. Because of the complexity of the optimizing algorithms, most adaptive filters are digital filters that perform digital signal processing and adapt their performance based on the input signal

The adapting process involves the use of a cost function, which is a criterion for optimum performance of the filter (for example, minimizing the noise component of the input), to feed an algorithm, which determines how to modify the filter coefficients to minimize the cost on the next iteration. As the power of digital signal processors has increased, adaptive filters have become much more common.

The block diagram, shown in the Fig. 4, serves as a foundation for particular adaptive filter realizations, such as Least Mean Squares (LMS). The idea behind the block diagram is that a variable filter extracts an estimate of the desired signal.

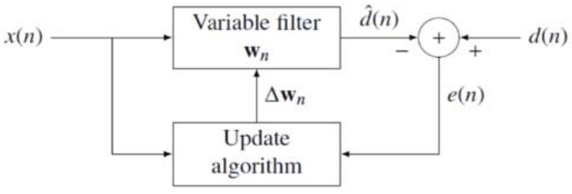

Fig. 4 Block diagram of adaptive filtering

Following assumptions are made for the analysis:

1) The input signal is the sum of a desired signal $d(n)$ and interfering noise $v(n)$
$$x(n) = d(n) + v(n) \tag{5}$$
2) The variable filter has a Finite Impulse Response (FIR) structure. For such structures the impulse response is equal to the filter coefficients. The coefficients for a filter of order p are defined as
$$W_n = [w_n(0), w_n(1), \ldots\ldots, w_n(p)]^T \tag{6}$$
3) The error signal or cost function is the difference between the desired and the estimated signal
$$e(n) = d(n) - \hat{d}(n) \tag{7}$$
4) The variable filter estimates the desired signal by convolving the input signal with the impulse response. In vector notation this is expressed as
$$\hat{d}(n) = W_n * X(n) \tag{8}$$

Where $X(n) = [x(n), x(n-1), \ldots\ldots, x(n-p)]^T$ (9)

is an input signal vector. Moreover, the variable filter updates the filter coefficients at every time instant

$$W_{n+1} = W_n + \Delta W_n \tag{10}$$

where ΔW_n is a correction factor for the filter coefficients. The adaptive algorithm generates this correction factor based on the input and error signals. LMS and RLS define two different coefficient update algorithms. Motivation for the Adaptive Filtering is

a) Adaptive approaches are very important in situations where
    1. Signal statistics are not available, and/or
    2. Signal statistics may be time-varying
b) Adaptive algorithms help to incorporate self-learning and self-correcting abilities in practical systems.
c) Use of adaptive algorithms equips practical systems with the feature of graceful degradation.
d) It is important for practicing engineers to have the knowledge of the general principles governing the
    1. development of adaptive algorithms for a particular application,
    2. suitability of an adaptive algorithm for a particular application, and
    3. Analysis and quantification of the performance of adaptive algorithms.

IV. DESIGN OF THE RANDOM VIBRATION CONTROLLER

The controller implementation is given in the flowchart of Fig.5. The idea is to start generating pseudo acceleration signals according to the prescribed standard power spectral density. In this method first acceleration behaviour of shaker is acquired from the accelerometer placed on shaker table near to the DUT and its one sided power spectral density is evaluated. The desired standard signal's one sided power spectral density is also evaluated. Then the two power spectral densities are compared and the weights are calculated. The PSD of the standard signal is updated by making use of these weights and pseudo acceleration signal is generated. Now the adaptive filtering is applied to eliminate noise. This signal is amplified and fed back to the shaker and the loop is repeated until the error reaches the specified limits.

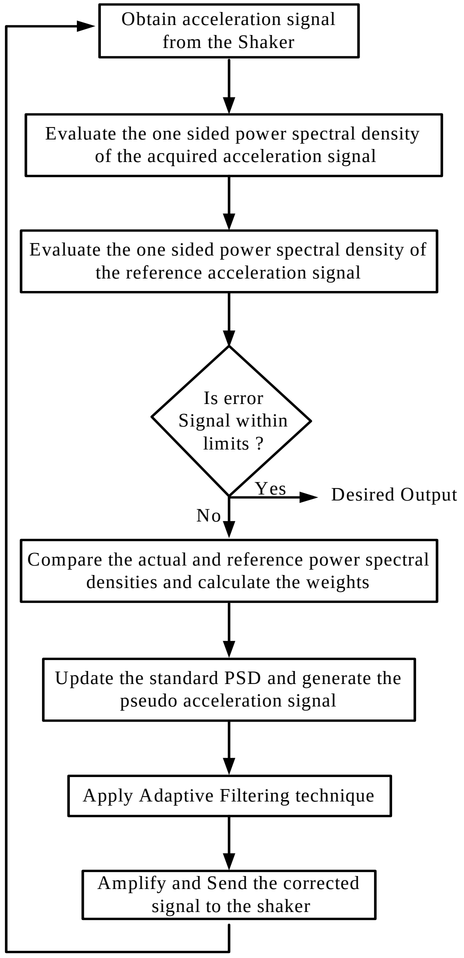

Fig.5 Flow chart of the random vibration controller

V. SIMULATION RESULTS

Fig. 6 shows the PSD of the standard signal which is the desired acceleration profile by the shaker. Fig. 7 is the PSD of the random input signal which is the input to the shaker table. In fig. 8 system response of the shaker, power amplifier is given. In fig. 9 and fig. 12 the PSD of the desired and observed signals for different acceleration profiles is shown, in which both the signals are almost in coincidence with each other. Fig. 10 is the error plot which is achieved zero.

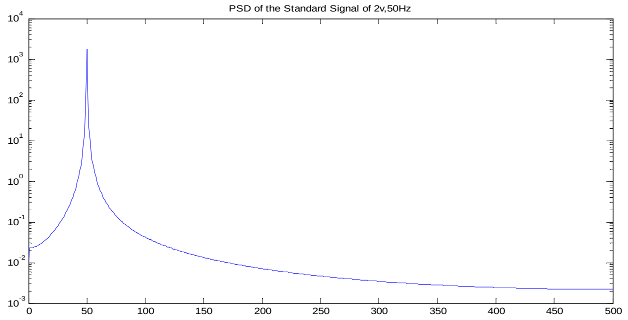

Fig.6 PSD of the standard signal (2v, 50Hz)

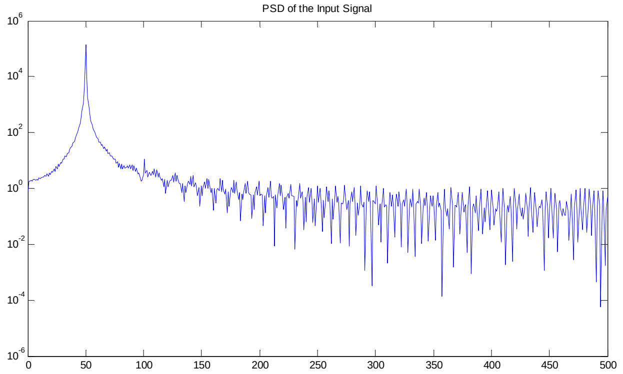

Fig.7 PSD of the input signal

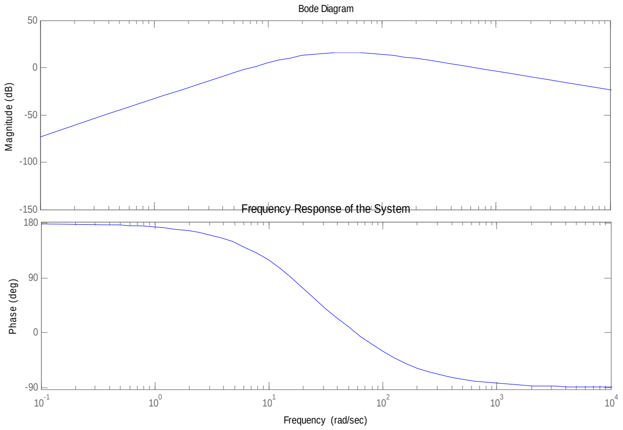

Fig.8 Frequency response of the system

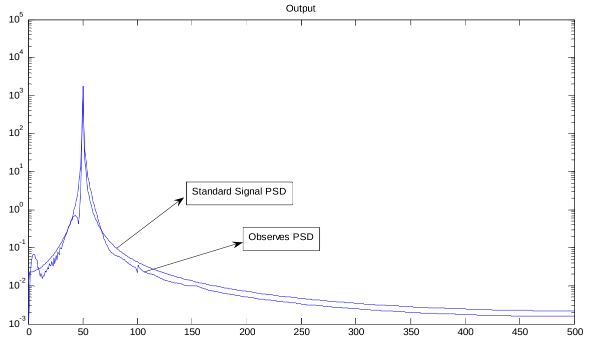

Fig.9 PSD of standard signal and observed signal (for ref: 2v, 50Hz)

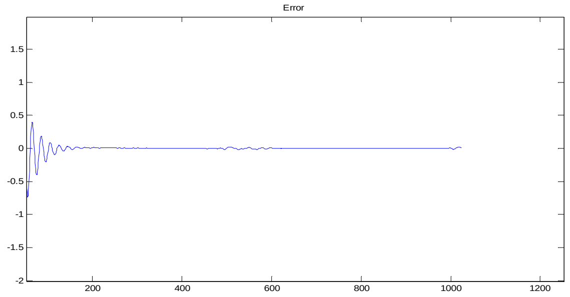

Fig.10 Plot of the error signal (for ref: 2v, 50Hz)

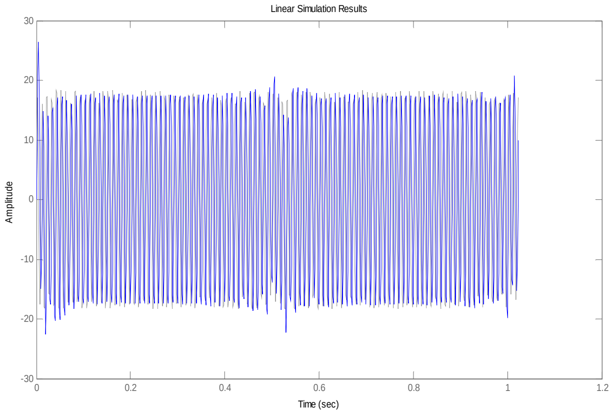

Fig.11 Simulation result of the random vibration controller (for ref: 5v, 10Hz)

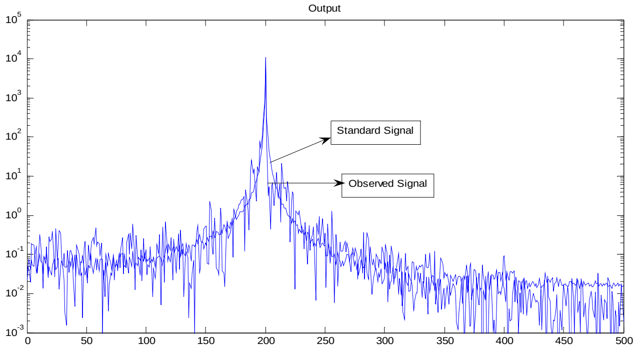

Fig.12 PSD of the standard signal and observed signal (for random signal)

VI. CONCLUSION

Application of adaptive filtering technique in the random vibration control of an electrodynamic shaker provides superior performance and application flexibility not achievable by conventional control methods. This method reduces the no. of iterations required to achieve the desired response. The proposed controller of the random vibration testing eliminates the use of band pass filters. Proposed method achieves the desired acceleration levels in lesser no. of iterations than the method in which adaptive filtering is not employed. The simulations shows that the PSD's of the desired and observed acceleration signals are exactly matching. Since at low frequencies displacement is the dominant variable, inclusion of which as control variable may give the better results even at low frequencies.

VII. REFERENCES

[1] Yosuke Hirowatari, Ken Ichiyru, "Active Vibration Control by Tracking Filter,".

[2] V.S.SriRam, "Design of Controller for Shaker", Dissertation Report, Electrical Engg. Dept., IIT Roorkee, June 2008.

[3] Yasuhiro Uchiyama and Masayuki Fujita, "Robust Acceleration and Displacement Control of Electrodynamic Shaker," in Proc. 2006 IEEE International Conference on Control Applications, pp.746-751.

[4] Yasuhiro Uchiyama, Masakazu Mukai, and Masayuki Fujita, "Robust Acceleration Control of Electrodynamic Shaker Using µ–Synthesis," 44th IEEE Conference on Decision and Control, December 12-15, 2005.

[5] Leandro Della Flora and Hilton Abilio Grundling, "Acceleration Control of an Inverter-Fed Electrodynamic Shaker," in proc. 2006 Power Electronics Specialist Conference, pp1-7.

[6] Clarence W. de Silva, "Vibration Monitoring, Testing, and Instrumentation," A CRC Press Book.

[7] Chang-Ming Liaw, Wen-Chin Yu, and Thin-Huo Chen, "Random Vibration Test Control of Inverter-Fed Electrodynamic Shaker," IEEE Transactions on Industrial Electronics, vol. 49, no. 3, June 2002.

[8] L. Della Flora and H.A. Gru¨ndling, "Time Domain Sinusoidal Acceleration Controller for an Electrodynamic Shaker," IET Control Theory Appl., 2008, Vol. 2, No. 12, pp. 1044–1053.

[9] Martino O Ajangnay, Matthew W Dunniga and Barry W Williams, "Hybrid Partitioned Frequency/Time Domain Adaptive Filtering Algorithm for Shaker Control," in Proceedings of the IASTED International Conference on Circuits, Signals and Systems, Nov 28 – Dec 1, 2004.

[10] Herbert M. Gomes, Franklin S. Ferreirab Carlos A. K. Thomes and Douglas S. Gaspareto, "An Automatic System for Electrodynamic Shaker Control by Acceleration Power Spectral Density," Mecanica Computational, vol. 26, Oct 2007.

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