Nondestructive Degradation Evaluation of Ceramic Candle Filters using Vibration Signatures[1]

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Introduction

The structural integrity of ceramic candle filters is a key element for hot gas cleanup systems, They protect the heat exchanger and gas turbine components from getting clogged and also prevent erosion. Ceramic candle filters used in the recent demonstration plant have experienced degradation and fracturing. Preliminary examination of these ceramic filters indicated that damage of the filters may have resulted from strength degradation at consistent high temperature operation, thermal transient events, excessive ash accumulation and bridging and pulse cleaning (Alvin et al. 1994 and Spain et al. 1994). The ceramic candle filter is a slender structure made of layers of porous materials. The structure has high acoustic attenuation which has greatly limited the conventional ultrasonic detection capability. In general, stiffness reduction of a structure will cause the change of the modal parameters of the structure (Chen et al., 1995). In this study, the stiffness degradation of the ceramic candle filters will be evaluated by using the dynamic response of the filters.

One Refraction filter and twelve Schumacher Dia Schumalith filters were tested. All these ceramic filters are clay bonded Silicon Carbide (SiC) candle filters. The Refraction filter is of 59 inch (1.5 m) length, and 2.36 inch (60 mm) outer diameter and 1.57 inch (40 mm) inner diameter, while all the Schumacher filters are of 59 inch (1.5 m) length, and 2.36 inch (60 mm) outer diameter and 1.18 inch (30 mm) inner diameter. The Refraction filter is an unused filter. In the case of the Schumacher filters, 7 of them were used for 1705 hours (group A specimens) and 5 of them were used for 460 hours (group B specimens). So a difference in period of usage of 1245 hours exists between the two groups of Schumacher specimens. A comparison was made between the dynamic response obtained from group A and group B specimens.

Project Description

This study proposes a nondestructive approach for evaluating the structural properties of the ceramic filters using dynamic characterization method. The vibration signatures of the ceramic filters at different degradation levels are established using transient impact-response technique.

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A tripod shaped wooden framework was constructed from which the filter was suspended freely using elastic strings to simulate a free-free boundary condition (Figure 1), The filter was subjected to an excitation using an impact hammer and the response was picked by an accelerometer, Two sensor locations L/4 and 0.55L were selected and impact was given at L/S, L/4, L/3, L/2, 0.55L, 2L/3, 3L/4, and 7L/8 where L is the length of the filter and all distances were measured from the open end, Both the input and output waveforms were stored in a digital oscilloscope. Fast Fourier Transform (FFT) was performed on both the input and output waveforms to get the Frequency Response Function (FRF). The FRF shows a plot with various peaks each of which correspond to the natural frequency of vibration of the filter in different modes. The first 8 vibration modes, covering a frequency range of 0-4000 Hz were studied for the filters. A typical FRF plot is shown in Figure 2.

From the FRF plots the frequency and amplitude values were noted for all the impact locations and sensor locations. The frequency obtained in each mode from all impacts were averaged. This was done to minimize experimental errors arising from improper impacts. Also this averaging was done for both sensor locations. Finally, the frequency obtained in each mode for all the group A and group B specimens were compared and the average shifts in frequency response which occurs between the two groups of specimens were calculated. The amplitude values obtained from the FRF plots were used to plot the mode shapes,

Analysis using dynamic finite element method (FEM) was also conducted to compare with the experimental results. Linear elastic modal analysis was performed. To study the effect of local damages in the filter on its frequency response, FEM modal analysis was conducted on models with different damage zone sizes. Damage zones of 4.8%, 10.6%, and 100% of the total length of the filter were modeled and located at the mid-span of the filter. For 4.8'% and 10.6% damage zone, the stiffness of the darnage zone was taken as 50% of the original stiffness while for the 100°/0 damage zone the stiffness of the damage zone was taken as 90°/0 of the original stiffness.

Results

After noting these frequency values for both the A and B specimens in different vibration modes, the percentage frequency shift between the two groups of specimens was calculated. Figure 3 shows the comparison of the Coefficient of Variation (COV) of group A and group B filters with the percentage difference in frequency between the two groups of filters in different vibration modes. A maximum frequency shift was observed in the first mode, of about 6. 19%, and a minimum shift was observed in the fourth mode, of about 4.94°/0, with an average frequency shift of about 5.42°/0. This is equivalent to a stiffness change of about 8.16%. Also, the average coefficient of variation (COV) for the group A and group B specimens was found to be 2.40 and 1.12 respectively. In addition, the COV for both group A and group B specimens was found to be almost the same in all the 8 modes. This indicates that the dynamic characterization method can be used for degradation evaluation of filters for difference in period of usage of 1245 hours and above, The Schumacher specimens were studied using FEM analysis (Figure 4). The FEM simulations were in good agreement with the experimental results with a maximum percentage difference in frequency results of 0.8% and 1.11 % in the case of group A and group B filters respectively, The FEM results show that there is a uniform 8.16 % stiffness degradation of the filters corresponding to the frequency reduction between group A and B filters.

Figure 4 shows the comparison of the undamaged and damaged frequency results in terms of percentage difference in different modes using FEM analysis. Results of FEM models indicated that for a darnage zone of 4.8°/0 of length the deviation from undamaged frequency results was high in the odd modes with a gradual reduction in deviation at the higher modes. For a damage zone of 10,6% of length, the deviation in frequency is high in the odd modes and low in the even modes upto the fourth mode and then attains a constant deviation of about 5%. For a damage zone throughout the length (100Y0) and a stiffness reduction of 10%, there is a constant deviation of about 5 ,5°/0 in all the modes.

Application

Results from this study indicate that the vibration signatures of the filters can be used as an index to quantify the darnage condition of the filters. The results also indicate the feasibility of using the vibration mode shapes to predict the damage location. The application of this study can be implemented to develop a nondestructive evaluation method for future in-situ inspection of the ceramic filters,

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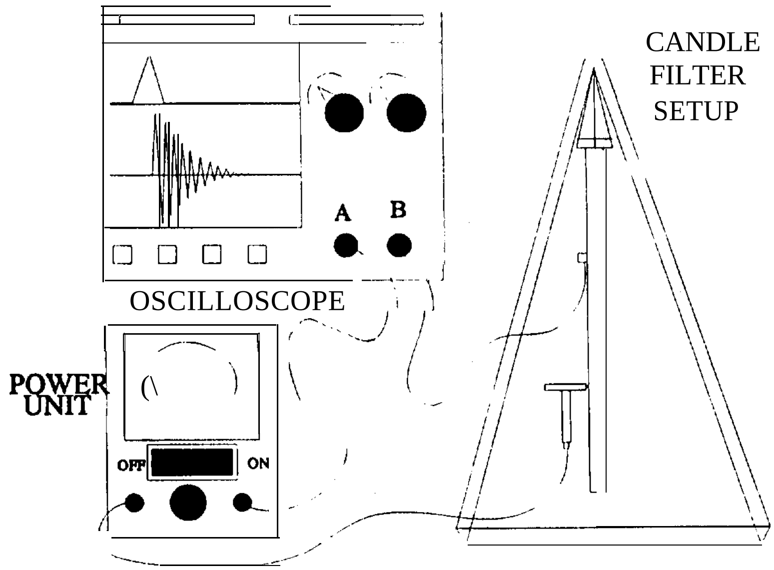

Figure 1 Schematic Drawing of Experimental Setup

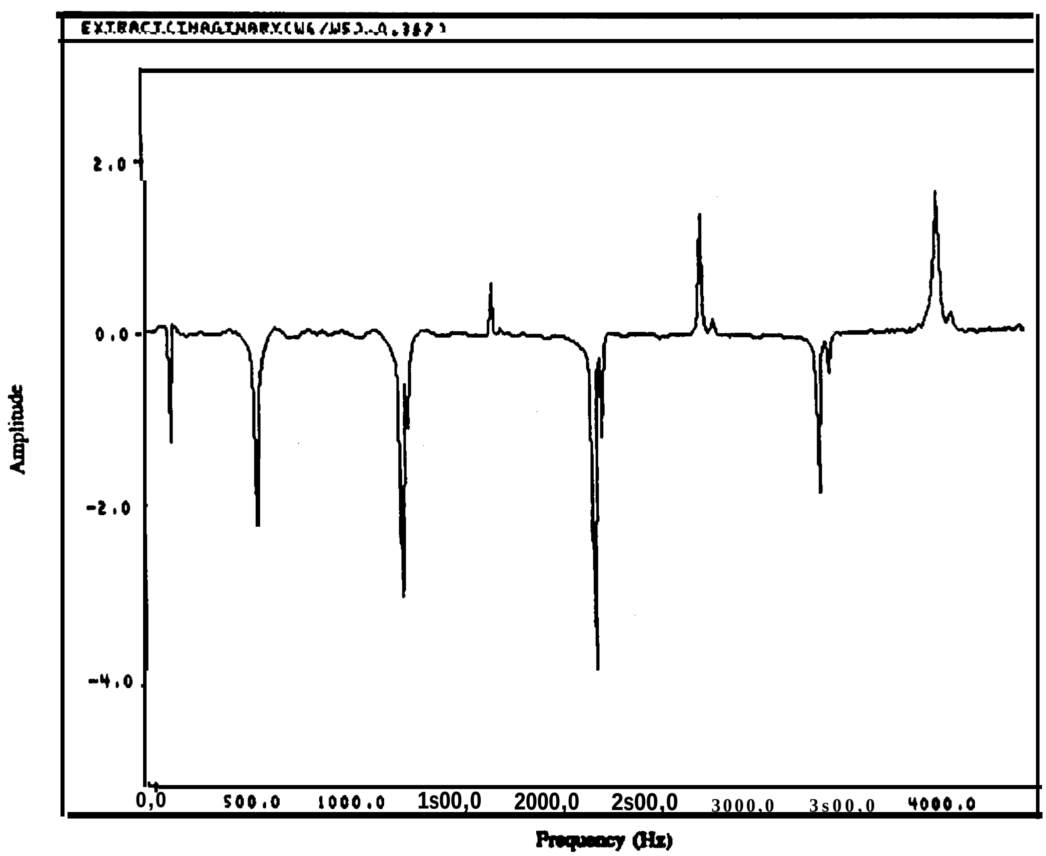

Figure 2 A Typical Frequency Response Function for a Ceramic Filter (Schumacher A Filter)

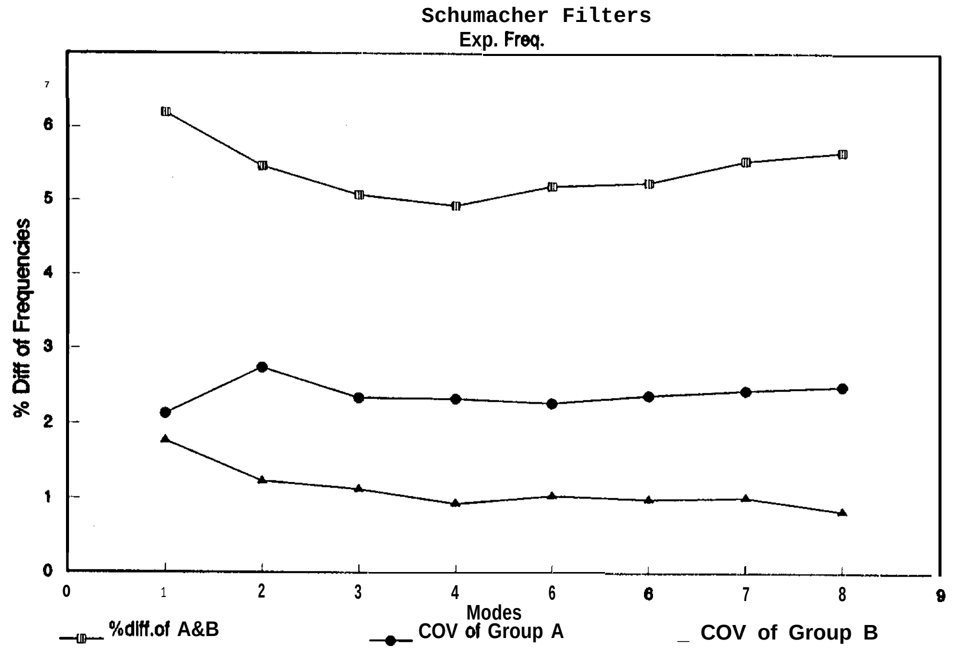

Figure 3 Comparison of COV's of Group A and Group B with Percentage Difference in Frequency between the Two Groups

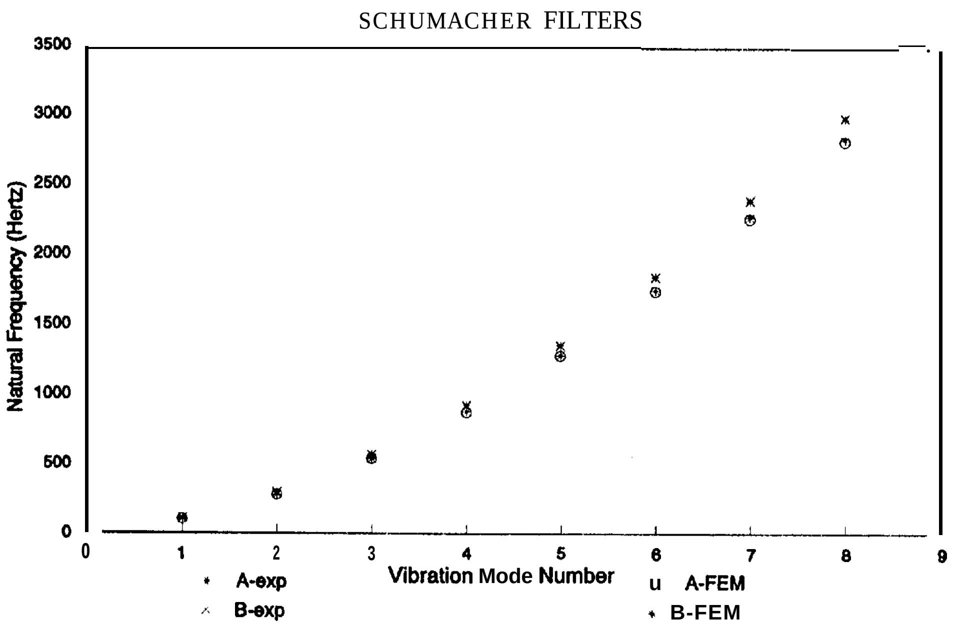

Figure 4 Comparison of Frequencies of Experimental and FEM Results for Schumacher Filters