NOISE-CON 98
Ypsilanti, Michigan
1998 April 5-8

AN EXPERIMENTAL INVESTIGATION OF COMBUSTION TURBINE EXHAUST STACK SILENCER PERFORMANCE

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INTRODUCTION

As combustion turbine power generation facilities are sited closer to residential areas and the market for power generation equipment becomes increasingly competitive, noise control engineers and silencer manufacturers are continually challenged to develop more effective and less expensive silencing treatments. The design of the exhaust stack silencer is of particular significance since it is one of the most costly noise control components of the combustion turbine packaging. The exhaust stack silencer must be designed to attenuate a broad frequency range associated with the combustion turbine's exhaust, including high frequency turbine tones as well as the low frequency combustion roar and flow related noise components[1,2,3]. The silencer best suited for this broad task generally consists of parallel splitter baffles filled with various types of acoustically absorptive fibrous fill. Recent availability of low flow resistivity absorptive ceramic fill materials, suitable for high temperature environments, has provided an attractive alternative to mineral wool because of it's acoustic characteristics and improved ability to survive the hostile environment of the exhaust stream.

The limited accuracy of silencer prediction methods has generated a need for high quality in-situ test data of various design parameters to provide a truly optimized silencer design. However, obtaining quality test data in an environment as hostile as the exhaust gas path of the combustion turbine is not a trivial endeavor. Gas temperatures exceeding 1000 degrees Fahrenheit do not allow for simple in-duct measurements with standard microphones. Also, high amplitude dynamic pressures due to the turbulent gas flow can be greater than the sound pressure level within the silencer passage.

A comprehensive experiment, jointly conducted by Westinghouse Electric Company and C&W Fabricators, has been developed in an effort to define the in-situ performance of an exhaust stack silencer with both ceramic and mineral fiber absorptive materials. The experiment was based on a specially designed and fabricated exhaust stack used as a test bed for the silencing materials. Measurements were made at both static, cold, conditions using a loudspeaker as the noise source and at actual hot operating conditions.

DESCRIPTION OF EXPERIMENT

A Westinghouse 501F simple cycle combustion turbine in combination with an exhaust stack/silencer designed and fabricated by C&W Fabricators was used as an operational test bed. A picture of the facility is shown below in Figure 1.

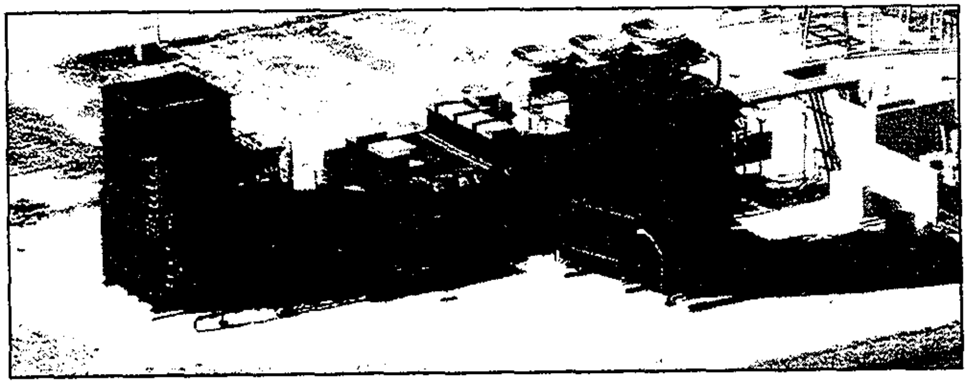

Figure 1 Westinghouse 501F Simple Cycle Combustion Turbine

The experiment was designed to address the performance of two different types of fibrous absorptive materials used as fill in the silencer's parallel baffle splitter panels. One silencer baffle panel, located parallel and adjacent to the exhaust stack's outer wall, was filled with a low flow resistivity ceramic fibrous material. The other outermost silencer baffle was filled with a mineral wool material equal to approximately twice the flow resisitivity of the ceramic baffle. Acoustic test ports, penetrating through the exterior walls and terminating flush with the inner walls, were located within the exhaust transition and along the side walls of the exhaust stack. A waveguide with an anechoic termination was attached to each of the ports. A microphone was then flush mounted, perpendicular to the inner wall of each waveguide. The sound pressure level within the stack was measured at the transition and at the test ports on both sides of the stack. A sketch of the experimental setup is shown in Figure 2.

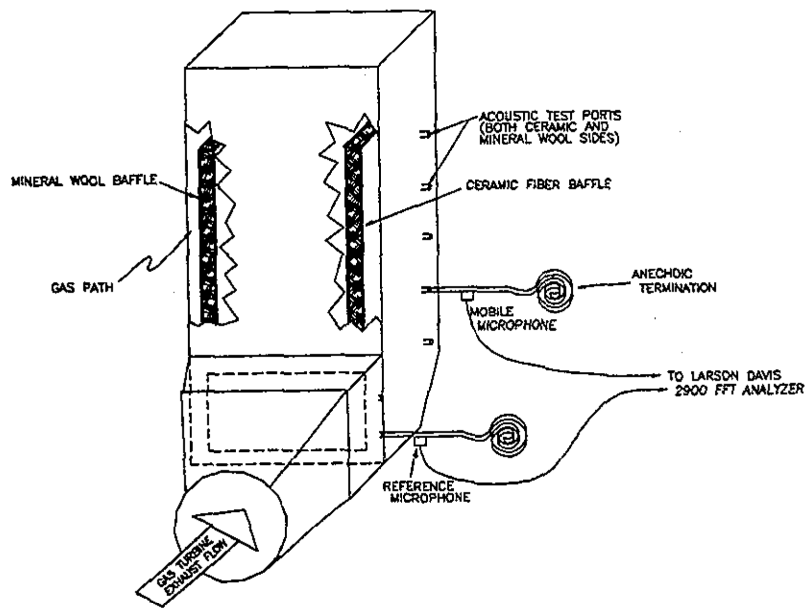

Figure 2 Cut-Away of Exhaust Stack Silencer and External Test Ports

Data were obtained with the absorption material subjected to both cold and hot conditions:

1.) the combustion turbine was shut off (cold) and a noise source consisting of an amplified high power loudspeaker was located within the exhaust transition downstream of the last turbine stage
2.) the combustion turbine was operating at a normal power generating operating condition

The data was obtained with a two channel Larson Davis 2900 FFT analyzer. The reference microphone was located within the exhaust duct transition and was used to defined the source noise while the other "mobile" microphone was moved to the various ports located within the gas path passages of the silencer baffles.

DATA RESULTS AND DISCUSSION

The overall performance of parallel baffle type silencers is influenced by several effects. Beranek[4,5] and others have shown the following effects to govern the overall silencer performance:

1.) **The attenuation of the plane wave mode:** This is typically regarded as the least attenuated mode and generally is the limiting parameter of the silencer's performance. The attenuation of the plane wave mode is believed to behave linearly with silencer length.
2.) **An oblique incidence absorption entrance loss:** The oblique incidence absorption occurs within a length of silencer equal to the first few baffle passage gaps and is regarded as constant for all given silencer designs provided the duct geometry is maintained and the minimum necessary length is obtained.
3.) **The exit loss:** This is another constant or non length varying effect for a given silencer design. The exit loss generally is assumed to be small and is typically neglected.

Additional attenuation in this experiment includes the effect of the 90 degree bend located between the reference microphone in the transition and the silencer.

The measurement of the sound attenuation inherently includes a combination of all of the effects discussed above. Separating these influences into components is useful when estimating attenuation of the overall exhaust stack silencer performance. The various attenuation mechanisms of the silencer are either linear with silencer length, as with the plane wave attenuation, or non-varying with silencer length, as with oblique incidence effects and other effects described above. For a given silencer panel design, the varying and non-varying effects can be extracted from the measured data taken within the silencer gas passages by manipulating pairs of simultaneous equations. Each pair of equations corresponds to the noise reduction measured at two discrete silencer lengths. The results of each data pair can then be averaged with other measurements taken at various combinations of silencer lengths.

To extract the effect of the plane mode attenuation, the equations defining the attenuation, in terms of silencer gas passages were defined as follows:

$$\ell_1\beta + \kappa = A(\ell_1)$$
$$\ell_2\beta + \kappa = A(\ell_2)$$

where:

ℓ_1, ℓ_2 = two different silencer lengths, normalized by the width of the silencer gas passage

β = the attenuation due to the assumed plane wave attenuation, normalized in dB per gas passage width

κ = the constant attenuation due to oblique incidence absorption and other effects non-varying with silencer length, in dB

$A(\ell_1)$ = the measured attenuation (noise reduction), in dB, between the reference microphone and the gas passage microphone for a silencer length equal to ℓ_1 silencer gaps.

$A(\ell_2)$ = the measured attenuation (noise reduction), in dB, between the reference microphone and the gas passage microphone for a silencer length equal to ℓ_2 silencer gaps.

The equations above can then be solved for the normalized plane wave attenuation, β, or the constant attenuation, κ.

Loudspeaker Test Results. The normalized attenuation, β, of the mineral wool and ceramic fiber was extracted from the data and is presented in Figure 3 for the cold (loudspeaker) test.

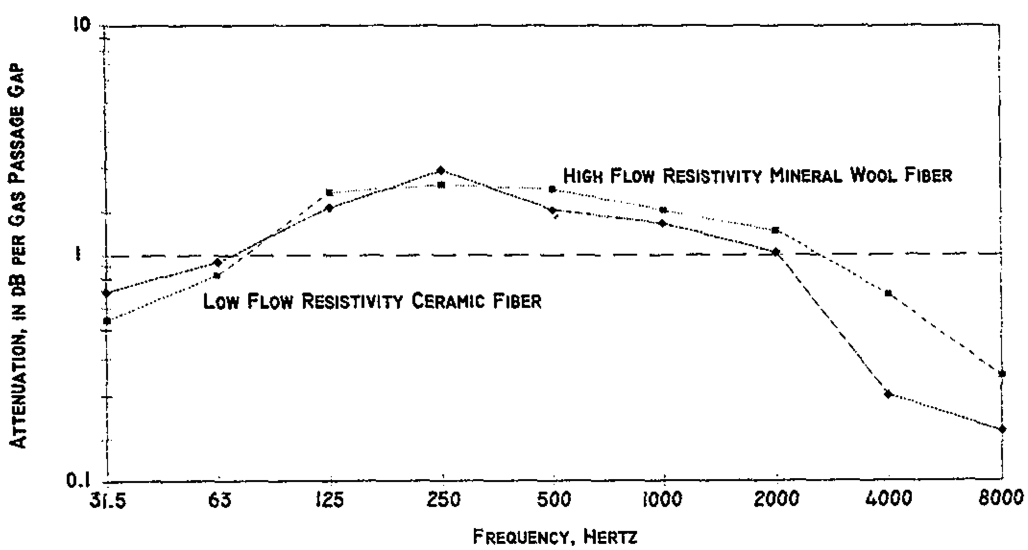

Figure 3 Comparison of Ceramic and Mineral Wool Silencer Performance with a Loudspeaker Noise Source

It can be seen that the low flow resistivity ceramic fiber provides substantially better low frequency attenuation than that of the higher flow resistivity mineral wool fiber fill. However, the high frequency attenuation of the ceramic fiber baffle appears to be significantly degraded relative to that of the mineral wool. In cases where high frequency turbine tones are major contributors to the overall exhaust sound power level, the ceramic material may not provide adequate results. The trends are consistent with theoretical expectations.

Limits of Standard Autospectrum Measurements in Hot Gas Flow Passages. With the combustion turbine operational, the maximum attenuation measured within the silencer passages is typically limited by the fluctuating pressure caused by turbulent gas within the silencer passages. While the unsilenced combustion turbine's exhaust noise generally is dominant over the dynamic gas pressure fluctuations by several decibels, the varying dynamic pressure can be significantly greater than the acoustic source after some silencing has been applied. When dynamic pressure dominates the measured "noise" within the gas passages, the data tends to appear constant with increasing silencer length. A naive acoustical engineer or consultant might in the latter case assume the silencer is not performing to expectations or in extreme cases, not performing at all. In reality, the silencer may be working adequately and the fluctuations due to turbulence will not likely radiate entirely as noise.

In this study, the measured frequency dependent "noise reduction" across the transition and silencer was limited to about 15 to 30 dB due to fluctuating velocity components. Figure 4 shows the typical dynamic pressure within the exhaust silencer baffle passage when passage velocities approach 200 feet per second.

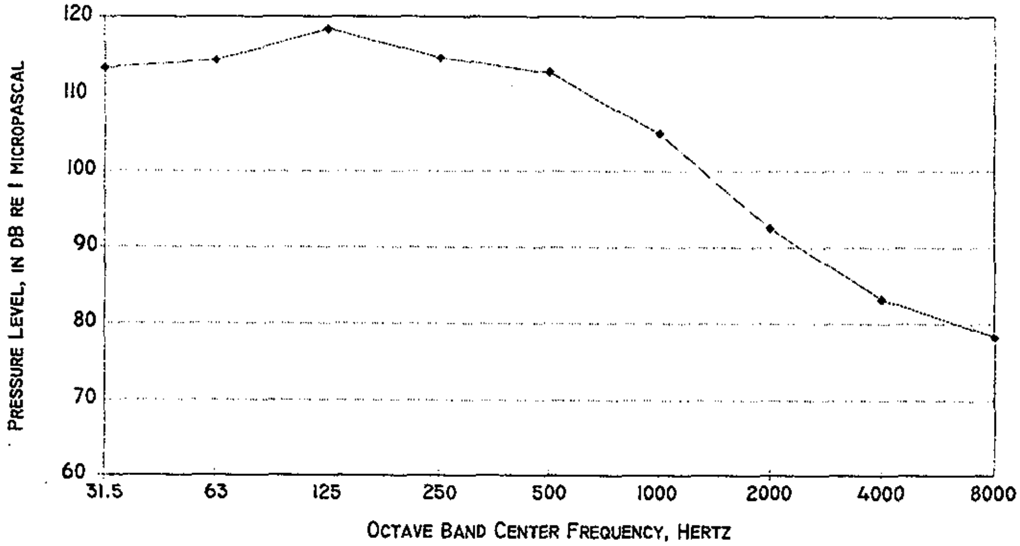

Figure 4 Typical Dynamic Pressure Limits within the Exhaust Gas Silencer Passages

In cases where the noise spectrum is at or below the dynamic pressure, meaningful data cannot be reliably obtained without additional processing, such as with the use of coherent output power. The coherence between the sound pressure measured in the transition and the residual dynamic pressure spectrum above was found to be less than 0.1, providing added evidence of the dynamic pressure dominance. As of this writing, further data processing and measurement techniques are being explored to extend the measurement range beyond the current 15 to 30 dB limit.

SUMMARY

A combustion turbine exhaust stack has been developed as a test bed for measuring the in-situ performance of a parallel baffle type silencer. Loudspeaker testing has shown the ceramic fiber material to provide improved low frequency attenuation over that of mineral wool, however it comes at the expense of the high frequency attenuation.

At operating temperatures, the apparent sound attenuation within the silencer's gas passages was found to be limited by the dynamic pressure, caused by turbulent flow, to about 15 to 30 dB. Additional data processing and measurement techniques are being explored to extend the measurement range beyond the observed 15 to 30 dB limit.

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