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LOW FREQUENCY NOISE ATTENUATION – APPROACHES AND DESIGNS FOR COMBUSTION TURBINES

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INTRODUCTION

Recent worldwide trends for siting power generation facilities include designing plants to fit on smaller properties, ever closer to centers of population. Many of the new generating facilities are incorporating combustion turbines in simple cycle, combined cycle, and cogeneration configurations. The requirement to ensure that combustion turbine based generating facilities impose minimal acoustical impact on surrounding communities dictates an increased vigilance on the part of project developers. This paper discusses the sound energy generated by the combustion turbine exhaust and the approach undertaken by Westinghouse to control low frequency sound emissions at sensitive locations.

THE PRINCIPLE PARAMETERS

Low frequency sound emissions, below 40 Hz, is generated by the combustion turbine combustion process and by the exhausted hot gas flow. There is substantial data available showing correlation between dynamic pressures within the combustors and far field sound pressure levels[1]. Furthermore, work by Parzych and Schott[2] has revealed the degree to which exhaust flow noise, whether generated by the jet of the engine itself, or as a result of the so-called self noise of the silencers, plays a significant part in the total sound emissions. The industrial combustion turbine industry has historically assumed that the exhaust sound power is generated within the engine's combustors or by the turbine. Therefore, all silencing has been designed to reduce the noise generated within the engine with disregard for the possibility that turbulent flow interacting with the stack's turning vanes, the exhaust stack plenum design, or sound generated by flow impacting the rear wall of the exhaust stack can actually increase the apparent sound power level of the engine itself.

Combustion technology, including operating at higher firing temperatures and pressure ratios, as well as air quality emissions control, has evolved radically in recent years. Water and steam injection, used to control the formation of Nitrogen Oxides (NO_x), have been shown[2] to particularly exacerbate combustion-generated instabilities, which can result in increased low frequency noise.

Figure 1 qualitatively portrays the frequency dependent constituent components of combustion turbine exhaust noise. The actual relative levels of these components are unique to each engine type and stack geometry. Figures 1a and 1b represent the higher frequency noise components from the combustion roar and turbine rotor tones. Figures 1c and 1d depict the low frequency characteristics of the jet related noise components and combustion instability. The occurrence of combustion related instability and combustion resonances are associated with tangible parameters such as the water or steam injection flow rate and stack geometry. It must be noted that combustion instability and resonance is not nearly so straightforward, and its spectrum is not nearly as uniform, as the figure implies, particularly the peak frequency or frequency bandwidth.

Flow generated noise would be an obvious target of acoustical noise control in a jet engine exhausting into ambient air, but for flow confined to exhaust ducts typical of large combustion turbines, it has not been the primary object of attention. In fact, historical design practice reflects the commonly held view that jet noise is not significant in the relatively confined space of a combustion turbine exhaust duct. The sound power generated by typical combustion turbine exhaust flows does indeed appear to behave very much like a free jet[2], as evidenced by the data reproduced in Figure 2. In fact, since this data is uncorrected for any of the other sound source constituents discussed here, the dominant noise mechanism in this case could be described as pure jet noise. Unfortunately, free jet noise calculations, based on the Society of Automotive Engineers Aerospace Recommended Practice ARP876[3], underpredict the unsilenced low frequency exhaust sound pressure levels by as much as 10 dB, which raises more questions as to the actual source of the noise.

Prudent designers have always considered silencer self noise, but typically not as a potentially major contributor to low frequency noise. With the need for more effective low frequency acoustical treatment, the splitter type silencers are getting thicker and longer. The extremely thick baffles can increase self noise due to the increased turbulence created as the flow exits the baffle passages.

Lastly, any design which targets low frequency emissions, whether in terms of far field C-weighted criteria, or due to infrasonic considerations, must account for exhaust stack breakout noise. The lack of laboratory data on the transmission loss of composite panels at frequencies below about 100 Hz requires alternate methods, including accurate prediction methodology to estimate the low frequency attenuation in the stiffness controlled regime.

THE DESIGN PARTICULARS

The critical nature of velocity distributions within the exhaust duct immediately downstream of the combustion turbine exhaust plane require controlled exhaust flow divergence angles. It is desirable, but seldom economically feasible, to design the exhaust duct with divergence so gradual that no flow separation occurs.

To control low frequency emissions, the exhaust transition duct region and a portion of the duct containing the silencer baffles contains wall panels of a greater thickness and stiffness than in conventional combustion turbine stack designs. Depending upon the application, and the specific combination of far field C-weighted and A-weighted sound level requirements, external acoustical shroud is commonly added around the transition portion of the duct, serving as a secondary acoustical barrier. The location of the first stage baffles is also critical in that they must be located far enough downstream to be in an acceptably low velocity field, yet close enough to the combustion turbine exhaust plane to limit the onset of low frequency turbulence. This can be most easily achieved with a horizontally mounted silencer. The use of a horizontal silencer in conjunction with a right angle turn to a vertical exhaust stack affords an opportunity to apply duct lining to the elbow for increased attenuation. The horizontal silencer baffles also provide an anechoic termination to noise generated within the combustion turbine, minimizing potential coupling with combustion resonances. The silencer baffles themselves are designed to attenuate low frequency noise using relatively thick baffles with low flow resistivity fill material and gradually tapered tails. Flow induced noise is minimized by maintaining flow velocities within the baffle passages to less than 55 meters (180 feet) per second.

Finally, the shape and slopes of interior wall surfaces are critical. Sharp corners, both inside and outside turns and changes in flow direction, are smoothed and chamfered wherever possible.

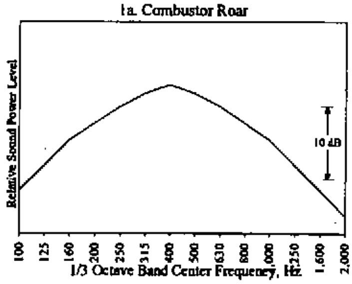
SUMMARY

A number of useful guidelines and design principles have been addressed which can lead to the successful attenuation of low frequency combustion turbine exhaust noise. Such designs must consider the critical nature of stack wall stiffness to control breakout noise, the reality of flow noise within the exhaust stack itself, and the need to avoid combustion related resonances. These measures are costly departures from conventional exhaust systems and should be used judiciously in noise sensitive areas.

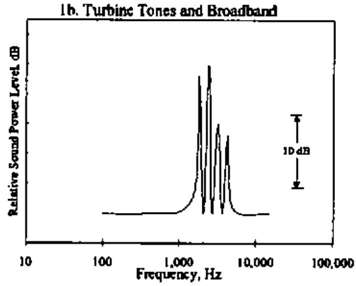
REFERENCES

1. Westinghouse Internal Report, " Coherence, SPL, and Combustor Pressure Analysis", F.S. McKendree, September, 1992.
2. "Understanding the Noise Generation Mechanisms of Industrial Combustion Turbines and Designing Effective Noise Control Treatments", D.J. Parzych and G. A. Schott, Inter-Noise 95 Proceedings, 159, 1995.
3. "Gas Turbine Jet Exhaust Noise Prediction", S.A.E. Aerospace Recommended Practice 876D (1994)

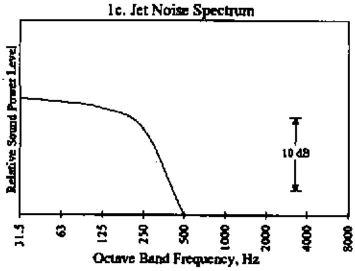
1a. Combustor Roar



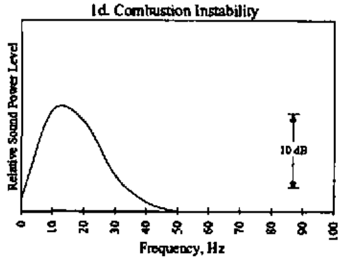
1b. Turbine Tones and Broadband



1c. Jet Noise Spectrum



1d. Combustion Instability



2. Effect of Exhaust Flow on Low Frequency Noise