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INDUSTRIAL APPLICATION OF GAS TURBINES COMMITTEE

ACOUSTIC PERFORMANCE CONSIDERATIONS FOR A 'ONCE THROUGH STEAM GENERATOR' (OTSG)

by

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1 INTRODUCTION

Once Through Steam Generators (OTSG) are used by electricity power plants and a host of other industrial and/or commercial centers to recover the heat from a gas turbine exhaust stream. The OTSG works similar to a conventional Heat Recovery Steam Generator (HRSG) passing the exhaust stream from the combustion through tube bundles filled with water. Heat is transferred to the water in the tube bundles. The steam generated can then be used for a variety of purposes. It can be either fed into a steam turbine generator to obtain electricity, or used for district, greenhouses, and a source of process heat in an industrial plant.

OTSGs have operational flexibility over conventional HRSGs in the OTSG's capability of dry operation (not producing steam); therefore a bypass stack is not required (as with HRSGs). This results in reduced leakage and more efficient operation. This makes an OTSG very attractive in a cogeneration power plant. An important property of an OTSG is its acoustical characteristics and its ability to reduce gas turbine exhaust noise (sound power L_w, typically in the range of 140-150 dB re: 1pW).

This paper examines the various parameters that govern the acoustic performance of an OTSG under both steam generating and dry running conditions. In particular, the paper deals with the effects of elevated gas temperature on speed of sound, viscosity, gas flow conditions and their impact on acoustic performance of an OTSG.

2 ACOUSTIC PROPERTIES OF ONCE THROUGH STEAM GENERATORS (OTSG)

The acoustic property of an OTSG installation that attracts significant interest for power plant and cogeneration plant designers is its ability to reduce the noise emission of gas turbine exhausts. OTSG's can have the ability to dramatically reduce the sound power emitted by the gas turbine exhaust stream if the proper considerations are taken during its design and installation. Figure 1 shows the standard arrangement of an OTSG in a typical cogeneration plant.

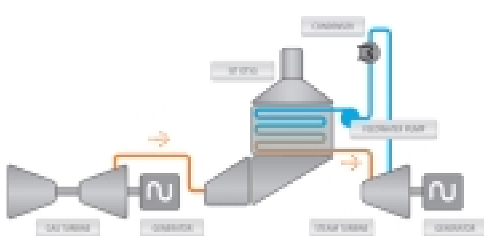

Figure 1: General Schematic of Cogeneration system involving a Once Through Steam Generator (OTSG). Image courtesy of Innovative Steam Technologies (IST)

2.1 OTSG Components and Sources of Noise

The OTSG is generally comprised of the following sections: The inlet from the turbine, inlet plenum (sometimes fitted with a silencer), environmental controls, tube bundles, exhaust hood and exhaust stack.

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The main source of noise in the OTSG originates from the aerodynamic effects and combustion processes present in the sound signature of the gas turbine exhaust. It is critical to have reliable input data of the sound power from the gas turbine to the OTSG. The noise from the turbines exit the circuit in two ways: casing/wall radiated noise, and noise exiting from the exhaust stack. There is also some flow induced noise from the exhaust gas stream going through the various OTSG components.

Figure 2 shows the characteristic noise spectra at the OTSG inlet (from the turbine exhaust) and at the OTSG outlet just upstream of the exhaust stack. It can be seen that the sound spectrum at the OTSG inlet is broadband and weighted towards a lower frequency. The interaction of this sound field with the various components inside the OTSG results in a significantly modified sound spectrum at the OTSG outlet. Ongoing studies are being undertaken to identify the mechanisms of noise generation inside the OTSG in the presence of high velocity gas flow for both conditions of high temperature when running in dry mode and with temperature gradients when producing steam. The acoustic performance of an OTSG cannot be determined from a simple speaker test alone that is conducted under ambient temperature and static conditions. The effects of temperature and high velocity gas flow have a very significant affect on acoustic performance. The upward shift in the speed of sound with temperature and the regenerated noise from interactions of the gas flow with the OTSG components result in unique noise reduction characteristics that vary case by case.

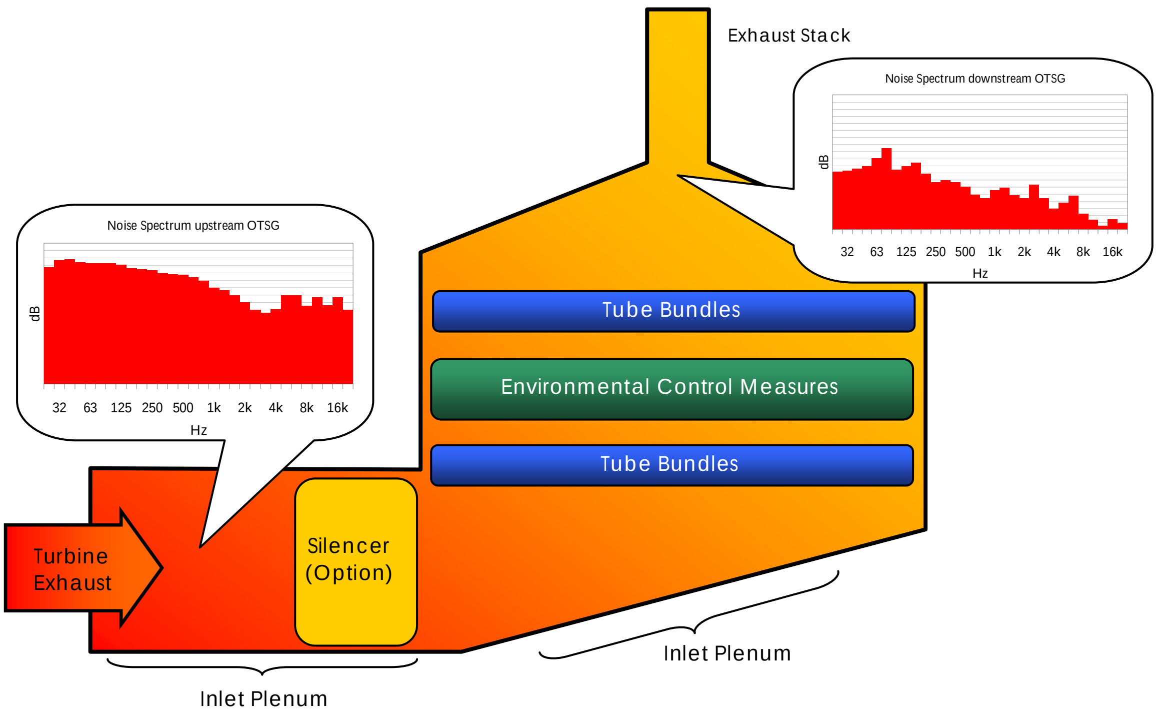

Figure 2: Once Through Steam Generator (OTSG) general Schematic. 1/3rd Octave sound level spectra shown were obtained using a calibrated high temperature microphone assembly with an anechoic termination.

2.2 Acoustic Environment inside an OTSG

The acoustic environment and related phenomena that exist in an OTSG have historically been a source of interest. Studies have been conducted on similar acoustic issues for HRSGs [4], and the prediction of sound attenuation using scale modelling techniques [2]. The following are areas of study that require systematic consideration when analyzing the noise control mechanisms, which dictate the acoustic performance of an OTSG.

Elevated Gas Temperature

Power systems involving Once-Through-Steam-Generators can be run in two modes: dry and wet. Dry running, or simple cycle mode, involves the gas turbines running without producing any additional steam, i.e. no water is fed through the OTSG tubes and no steam is produced. In this mode, the temperature of the exhaust gas stream can approach 650°C. Wet running, or combined cycle, involves the gas turbines running and the OTSG unit producing additional steam by pumping water through the tube bundles which then absorb the heat from the exhaust gas stream and produce steam. Running in this mode can involve gas temperatures near 815°C at the inlet and approximately 95°C when exiting the stack. These elevated temperatures and/or temperature gradients can significantly affect the sound attenuation properties of the various OTSG components. It is known that temperature dependant changes in the speed of sound in a gas affect the acoustic performance of a gas turbine exhaust circuit comprising the OTSG. The speed of sound in a gas "*c*" can be calculated using the following equation [7].

$$c = \sqrt{\frac{\gamma R T}{M}} \text{ (m/s)}$$

where γ is the ratio of specific heats, T is the temperature in degrees Kelvin (°K), R is the universal gas constant (8.314 $\text{Jmol}^{-1}{}^{\circ}\text{K}^{-1}$), and M is the molecular weight of the exhaust gas. Thus, as the temperature increases, so does the speed of sound and wavelength of that sound. A pressure wave of a given frequency range would have a longer wavelength at the elevated temperatures inside the OTSG compared to ambient conditions. For instance, with a conventional silencer, this high temperature condition would more than likely cause a decrease in the acoustic performance in the low frequency range in comparison to the silencer performance under ambient temperature. This effect is compounded in the presence of the temperature gradient in the overall exhaust circuit and the associated `effective' media changes, which result in modified sound propagation properties through the tube bundle elements of an OTSG.

Gas Flow Conditions & Flow Induced Noise

Gas flow from the exhaust stream of the gas turbine generators can reach, or at times exceed, flow velocities of 75 m/s at the OTSG inlet (i.e. exhaust of the GT). At these velocities, flow induced noise mechanisms such as vortex generation and other effects have the potential to become problematic in the OTSG. The insertion of environmental control stages and tube bundles inherently causes turbulence in the flow and can further augment flow induced noise and vibration, which can also give rise to fatigue damage.

2.3 Noise Attenuation Mechanisms

Casing radiated noise is usually controlled by an appropriately designed wall construction of the OTSG. It is generally easier to reduce the casing radiated noise by having a high Transmission Loss (TL) construction of the OTSG than it is to reduce noise exiting from the stack. To reduce the noise emitted by the exhaust stack, noise attenuation mechanisms in the OTSG gas path have to be examined. The main forms of noise reduction through the OTSG are membrane absorption at the interior surfaces, reactive attenuation in the gas flow path, attenuation due to diffusion and scattering of sound, propagation loss due to the flow resistivity of the tube bundles (viscous loss), and the attenuation through possible (i.e. optional) bulk-reacting silencers downstream of the OTSG inlet. Studies have been conducted regarding the analysis of these effects in HRSGs [2].

The flow passing through the OTSG experiences several area changes from section to section. Pressure wave reflection at these points provides some noise reduction [1]. The solid membrane of the OTSG casing wall also provides acoustic absorption, particularly in the low frequency range. Studies and field measurements of HRSGs show the transmission losses across the casing to follow that of simple mass law calculations.

3 SUMMARY OF SENSITIVE PARAMETERS

3.1 Geometry

Geometry plays a major role in the acoustic performance of the OTSG. Area changes in the flow can cause acoustic reflections back upstream of the flow. The reduction due to partial sound reflection is a function of the ratios of the area change [1]. The design, however, should weigh in the benefits of the number of area change reflections with respect to the pressure drop caused by the area changes. Similarly, a change in the flow direction (for e.g. through L-Junctions) also provides attenuation at the cost of flow disturbance and increased pressure drop.

3.2 Casing Construction

Casing construction is an important consideration to ensure that there are no acoustic compromises in the overall performance of an OTSG. The transmission loss across the casing wall should be high enough as to not significantly affect the noise level from the sound exiting the stack.

The construction of an OTSG casing involves heavy and temperature resistant materials to ensure long term viability and to minimize heat loss. A typical construction will have an isolated internal shell, typically made of a moderate gauge steel plate, and an outer shell typically with a heavier/thicker steel construction. The two layers are usually separated by ceramic fibre or similar insulation. Low frequency noise reduction is crucial in this application, so it is important to keep the mass and stiffness of the casing wall high in order to attenuate sound in this frequency range.

3.3 Tube Bundle Arrangement

Tube banks have the ability to reduce noise due to reactive effects of cross sectional area changes as seen by the flow, as well as propagation losses due to the flow resistivity of the tube bundles (viscous loss). The location and orientation of the tube bundles should be very carefully considered when designing an OTSG. There is potential for flow induced acoustical vortex shedding which can potentially give rise to significant flow related acoustic and structural integrity concerns. Several studies [3] [5] [6] have been completed, which show the potential effects of flow through different tube bundle arrangements. The analysis involves obtaining a Strouhal number, *S*, based on tube separation ratios. The vortex shedding frequency is then calculated using this Strouhal number as follows:

$$f_{VS} = \frac{S \times V_{\max}}{D} \text{ (Hz)}$$

The frequency f is dependant on the flow velocity V_{max} and the diameter D of the tubes in the array. In the design of the OTSG, care has to be taken to ensure that the vortex shedding frequencies do not coincide with the resonant frequencies of the tubes or other structures, or with the acoustic modes in the OTSG duct and plenum through which the gas flows.

3.4 Flow Considerations

Flow considerations go side by side with tube bundle arrangements. Since the Strouhal frequency is dependent on the flow velocity of the gas stream, it is important to consider the effects of any environmental controls, tube bundle arrays, plates, cavities or any other obstructions that may impede the flow. Flow velocity changes and profile modifications should be carefully considered to ensure that flow induced vibration or acoustic resonances are minimized.

4 CONCLUSION

Aercoustics has evaluated the potential acoustic effects that influence the acoustic performance characteristics of OTSGs. If designed properly, Once-Through-Steam-Generators have the potential to be quite effective in mitigating the noise emissions from a gas turbine exhaust. Solutions requiring the minimization of vortex generation or detuning of acoustic and/or structural resonances are necessary to ensure that potential regenerated noise inside an OTSG does not undermine its potential benefits.

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