inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 0.0

A CASE STUDY OF THE ATTENUATION OF WASTE HEAT BOILER LOW FREQUENCY RESONANCE

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Keywords:
BOILER, LOW, FREQUENCY, RESONANCE

ABSTRACT
During the commissioning phase of a combined cycle power station very loud tonal and low frequency noise arose at the waste heat recovery steam generators. Detailed investigations show that the reasons for the very loud tonal noise at the 80 Hz one-third octave band was acoustic resonance in the boiler internal area. This paper presents the field survey results with and without additional noise control measures. Predictive methods are given, and corrective measures are described, to minimize acoustic resonance inside waste heat recovery steam generators and heat exchangers.

1 - INTRODUCTION

During the commissioning phase of a combined cycle power station very loud tonal and low frequency noise arose at a heat recovery steam generator (HRSG). Detailed investigation showed that the reasons for the very loud tonal noise, occurring at the 80 Hz one-third octave band, was due to acoustic resonance internal to the HRSG. This resulted in sound pressure levels of as much as 150 dB inside the HRSG as shown in Figure 1. Such levels can be audible at great distances and may lead to material damages inside the HRSG.

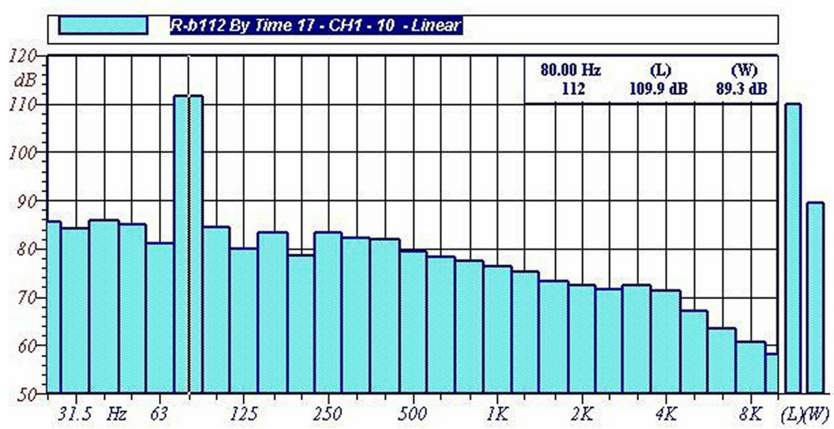

Figure 1: Typical sound pressure levels, measured at 1 m distance from the boiler surface.

2 - ACOUSTIC RESONANCES

Discrete tonal sound is generated by flow past obstacles, and is caused by vortex separation (Karman Vortex Trail). If HRSG heat exchanger tube bundles are immersed in the gas flow, periodic pressure fluctuations can be generated inside the flue gas channel by vortex shedding, or flow oscillation. If the frequency of these vortex shedding pressure fluctuations corresponds to a natural frequency of the surrounding space, resonances are possible, which can lead to very loud tonal noise with a very high sound power. Usually the natural frequencies of the flue gas channel transverse to the tube bundles of the HRSG will be stimulated as depicted schematically in Figure 2. However, excitation of modes parallel to the tube bundle axis or between the separate stages or clusters of tube bundles is also possible. If this potential resonance condition is present, a single tone can be generated merely by increasing the flow rate.

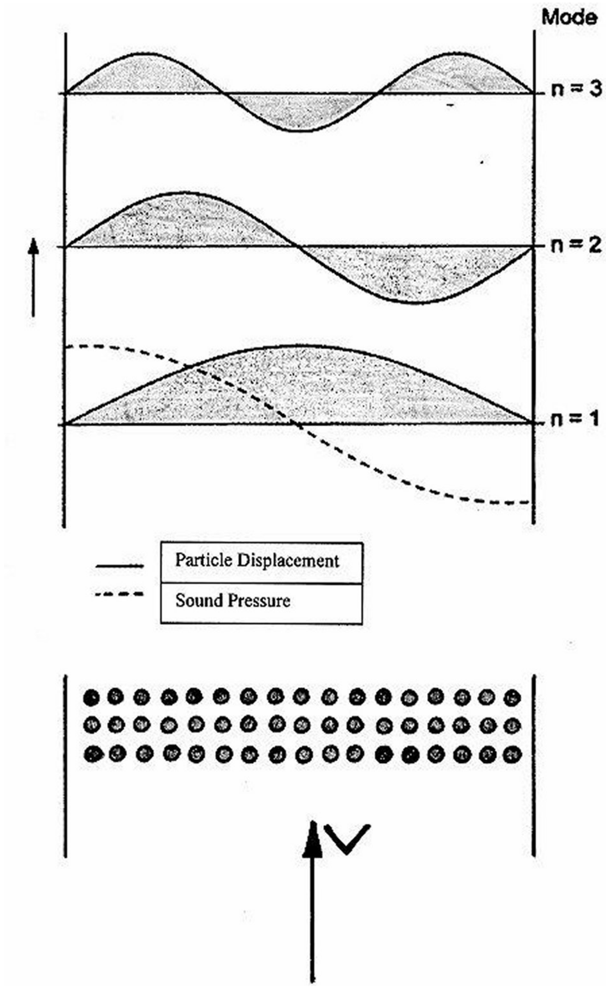

Figure 2: Possible resonances.

The Karman or Strouhal Frequency, the vortex shedding frequency, is calculated as follows [1] and [5]:

$$\mathbf{f_{St} = St^{*}v/D} \qquad \mathbf{[Hz]}$$

- $\mathbf{f}_{st}$ – Karman or Strouhal Frequency [Hz]
- **St** – Strouhal Number (first approximation for gas turbine HRSG is about 0.23) [nd]
- **v** – flue gas velocity in front of the heating surface [m/s]
- **D** – pipe diameter [m].

The calculation of the Strouhal Frequency presupposes an exact knowledge of the Strouhal Number. In a first approximation for gas turbine HRSG this can be set about 0.23. Measurements results of the Strouhal Number for HRSG's with in-line (straight) and staggered tube bundle arrangements, as well as laboratory tests, can be obtained from the literature [2], [3], [4]. Results show that for a given frequency a range of Strouhal Numbers may be applicable. Therefore a similar range of Strouhal Numbers should be considered in the design and acoustical evaluation of HRSG's.
The natural frequencies of the flue gas channels inside the HRSG's are determined as follows:

$$\mathbf{f_n = 2^{*}B/nc} \qquad \mathbf{[Hz]}$$

- **f_n** – natural frequency of the flue gas channel [Hz]
- **B** – width or height, as applicable, of the flue gas channel [m]
- **n** – 1,2,3 (number of mode) [-]
- **c** – sound velocity of the flue gas [m/s]

Because the flue gas temperature in HRSG's changes as the gas passes through the HRSG, from approximately 550°C at the boiler entrance to approximately 150°C at the boiler exhaust, typically, the acoustic velocity in the flue gas is also changing. Therefore the natural frequencies for the flue gas channel dimensions have to be determined for the various temperatures. Usually it is sufficient to consider only modes 1 through 3, because they contain the bulk of the acoustical energy.
The resonance condition is regarded as being present if the following criterion is fulfilled [2]:

$$\mathbf{0.8 < f_{St}/f_n > 1.2}$$

The frequency range within which the Karman Frequency goes into resonance with the flue gas channel dimensions is also called "lock in". The range from 0.8 to 1.2 accounts for the actual behavior of HRSG's under the influence of varying and changes in flow rates at a given position. If this resonant condition occurs, a single tone with high sound power can be generated by small increases in the flow rate.

3 - CORRECTIVE MEASURES

The possibility of resonance should be evaluated during the design phase of all HRSG's, although too often acoustical measurements on an operating unit are the first indication of the presence of resonance. In the event resonance is predicted or discovered, the following corrective measures can be considered:

- **Separation of the flue gas channel**
  One corrective measure is to partition the flue gas channel with so called "absorber sheet steel plates". The natural frequencies of the flue gas channel will be shifted upward, since a separation in the middle of the channel increases the natural frequency by the factor two. In existing HRSG's, the free space behind and between the heat transfer tube bundles can be partitioned. An effective preventive measure is to add partitions between the tube bundles although this is dependent on the separation and diameters of the tubes. With the installation of a diagonal sheet or wire mesh, standing waves both transverse to and parallel to the tube axis can be prevented.

- **Flow distribution devices**
  The flow distributions at the entrances of horizontal and vertical HRSG's are different. Depending upon the type of HRSG, very different flow velocity profiles may occur, and it is only after the first bundle of tubes that an equal flow distribution is established. If the acoustical prediction or operational measurement at an existing HRSG indicates that localized high flow velocities are responsible for resonances, then the resonance might be reduced by improving the distribution of flow at the entrance to the HRSG using flow guide vanes, a flow straightening grid, or similar measures.

- **Absorbing lining**
  Finally, the use of a sound absorbing inner liner for the HRSG should be mentioned. Theoretically, standing sound waves can be attenuated by a sound absorbing inner liner consisting of perforated sheet steel with an interior acoustically absorptive material. Flue gas composition or very low frequency sound waves may prevent the practical application of absorptive liners, however.

4 - CASE STUDY

In the case study the amplitude of the 80 Hz one-third octave band resonances were attenuated by dividing the flue gas duct between the high pressure economizer tube bundles and the low pressure evaporator tube bundles with so called "absorber plates". This scheme yielded the sound pressure level reductions shown in Figure 3. A further installation of absorber plates between the staggered tubes was not feasible, for structural reasons. Nevertheless, a sound reduction of about 25 dB was achieved. A residual, but acceptable, audible hum remains.

5 - CONCLUSIONS

A variety of potential remedies to HRSG cavity resonances are available. If the resonances already exist in an operating HRSG, the practical possibilities for retrofit are limited and remedial measures will

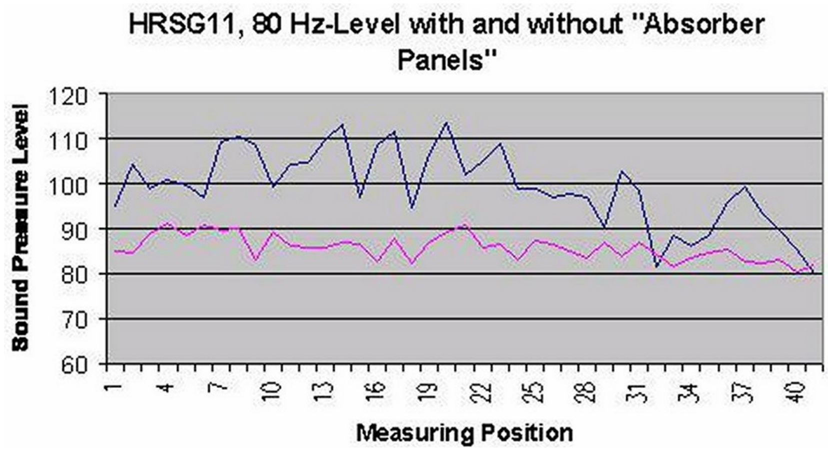

Figure 3: Case study – level differences with and without "absorber panels".

tend to impact operational schedules and budgets. The ability to predict, with suitable accuracy, the likelihood of the existence of HRSG cavity resonances is crucial, in order to avoid the added expense and operational disruption of retrofit measures. A knowledge of these acoustic phenomena and application of the relatively simple rules given here, is necessary to good HRSG design.

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