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MEASUREMENT METHOD FOR THE LOW FREQUENCY ACOUSTICAL BEHAVIOR INSIDE THE EXHAUST SYSTEM OF A COMBUSTION TURBINE

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ABSTRACT

Exhaust systems are one of the most important noise sources at modern combustion turbine power plants. In some cases, acoustical resonances can occur, producing very high sound pressure levels, usually at low frequencies. Reducing such sound levels by secondary measures such as silencers is expensive and usually not the best solution to the problem. The best approach is have a good understanding of the parameters controlling resonance. Modern CT exhaust systems can be very complex. The experience of the last years has shown that the classic standing waves models do not always predict actual measured frequencies. It is necessary to understand the internal acoustics to develop better models. This paper describes a methodology to measure sound pressure level distribution inside of an exhaust system.

1 - INTRODUCTION

Acoustical measurements in the exhaust system of combustion turbines are a very complex task. In the last few years many methods have been developed. Such measurements are complicated by the conditions inside the exhaust system. The speed of the media is in the range of 10 to 80 m/s and the temperature can range from 100°C to 700°C. Local conditions can vary significantly due to flow maldistribution and turbulence. Due to the geometry of the system complex mode shapes can be expected. Any measurement will be influenced by the pseudo noise in the measurement system and by the characteristics of the sound field itself.

The usual objective for measurements in exhaust systems is the determination of the sound power level of the combustion turbine or of the attenuation due to the heat recovery steam generator (HRSG) and/or silencers. Measurements inside the exhaust system can also be used to better understand and develop methods of controlling the acoustic phenomena occurring in the system.

Following is an example of the application of advanced measurement techniques to diagnosing an unusual acoustic problem. The following spectra were measured in the far field and at the stack mouth of a combined cycle power station.

These pure tones are typical of resonance inside the HRSG, stimulated by vortex shedding frequencies of the tubes. The standard approach to evaluating such an acoustical problem would be to compare vortex shedding frequencies to the measured frequencies. Vortex shedding frequencies can be calculated based on Strouhal numbers available in the literature. A tolerance of ± 20% is typically used to account for uncertainties in the Strouhal number. The frequencies of the pure tones are then related to the local speed of sound, and the dimensions of the HRSG, transverse to the tube axis and flow direction. This permits determination of the tube bank where resonance is occurring.

In this case however, the measured pure tones did not correspond to the dimensions of the HRSG. In each of the two main frequency groups, two or three separate pure tones were always present. It was therefore essential to know the actual mode shapes inside the exhaust system. The following questions needed to be addressed:

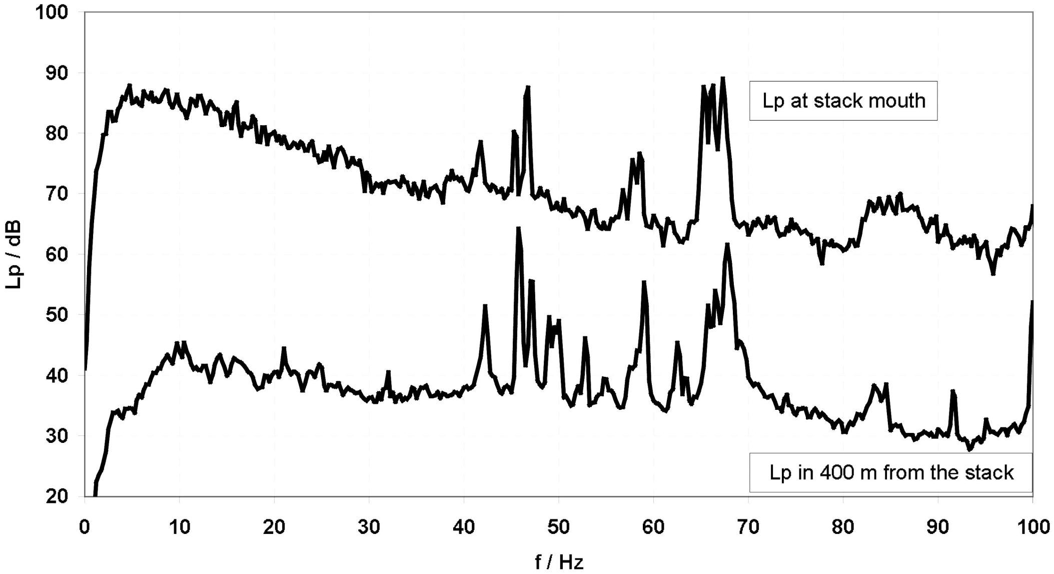

Figure 1: Sound pressure level at the stack mouth and 400 m from the stack.

- What is the pattern of the mode structure?
- Why do two frequency groups, each with three pure tones exist?
- Is it possible to locate the source of the resonance?
- What is the best solution to eliminate or to minimise the emission or generation of these pure tones?

To find answers for these questions, a measurement technique was developed to estimate the mode structure inside the exhaust system.

2 - EXPERIMENTAL TECHNIQUE

A B&K Type 4182 probe microphone as shown in Figure 2 was used in conjunction with probes with lengths of 1 m, 6 m and 9 m, all with an inner diameter of 12.5 mm. A concentric outer shell was added to provide stiffness. The space between the inner probe and the outer shell was filled with sand. The shell and the sand provide additional attenuation for the noise input along the length of the tube and eliminate the vibration of the inner liner, which would also generate noise. A 30 meter length of hose was used to provide a non reflecting end for the probe.

Past experience has shown that every variation of the inner diameter of the probe results in reflections and therefore incorrect readings. A constant internal diameter was maintained for the whole system from the inlet to the non-reflecting end. To reduce the influence of structure born noise via the probe pipe in the microphone, the microphone was mounted not at the pipe but at the hose. The length of the hose was calculated to reach a attenuation of not less than 10 dB in one direction, for the frequency range of interest, so that the influence of the reflection from the end of the hose was about 20 dB below the signal.

In a first step of the test, the eigenfrequency of the probe was estimated. There were no eigenfrequencies of the measurement system in the frequency range of interest. The next step was the measurement of the phase behaviour of the different probes, because of the need to use the phase information between two probe locations. The measured phase corresponded very well with the theory. An example of these measurements is in Figure 3.

With this measurement technique, there is a high level of confidence in measuring the mode structure in the exhaust system. The measurement of phase information with a long probe presents problems because depending on the position of the probe inside the exhaust system, different lengths of the probe were cold or hot influencing the speed of sound and therefore the phase shift of the probe. A modified probe is planed to avoid the influence of the temperature on the probe response.

3 - MEASUREMENTS IN A HRSG

The spectra in Figure 4 show an example of the measurement results inside the HRSG.

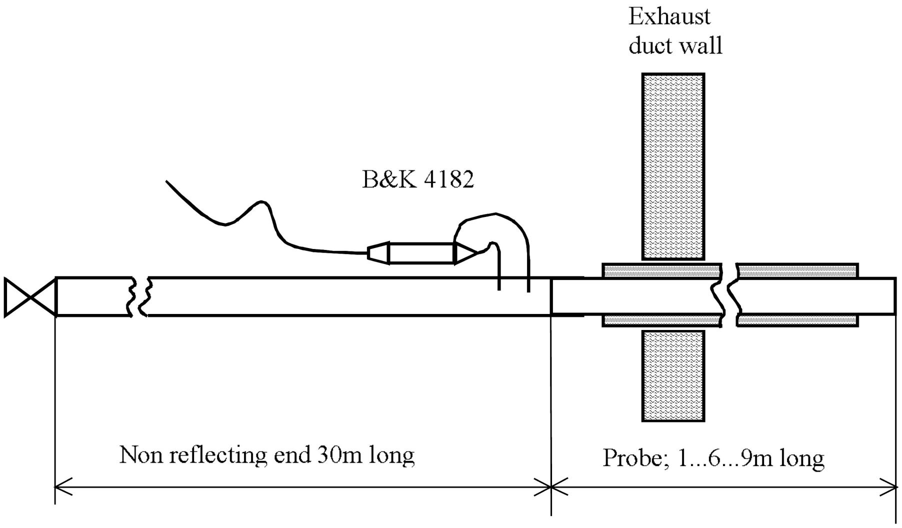

Figure 2: Instrumentation system.

As the spectra shows, the pure tones are about 20 dB above the measured noise; a clear identification of the standing wave pattern was therefore possible.

With this measurement technique, it was possible to get a picture of the mode structure inside the exhaust system of a combustion turbine. Traverses could be done at different locations and directions.

The standing wave patterns measured in the HRSG were not as would be expected, based on previous studies and conventional one-dimensional theory. An example is shown in Figure 5. It can be seen that, at the traverse location, standing waves are present for 4 frequencies. The location of the minimum sound pressure level for each frequency occurs at the same location. To understand this phenomena, it is necessary to take the 3-dimensional mode structure into account.

A Finite Element Model (FEM) was developed to evaluate possible three-dimensional acoustic mode shapes within the HRSG. This model indicated that modes could exist at different frequencies, which will produce the standing waves shown in Figure 5. Figure 6 shows FEM model results at two of these frequencies. Both cases show a full wave across the rear of the HRSG.

The further results of these measurements and their interpretation are not in the scope of this paper.

4 - SUMMARY

A measurement technique has been developed that provides the ability to accurately map sound pressure levels inside combustion turbine exhaust systems. This information can be used to validate advanced acoustic models. The combination of these methods provides the ability to determine the causes of and evaluate alternative methods of controlling resonance in these systems. This provides a substantial improvement over the previously used approach of one-dimensional analysis and trial and error solutions.

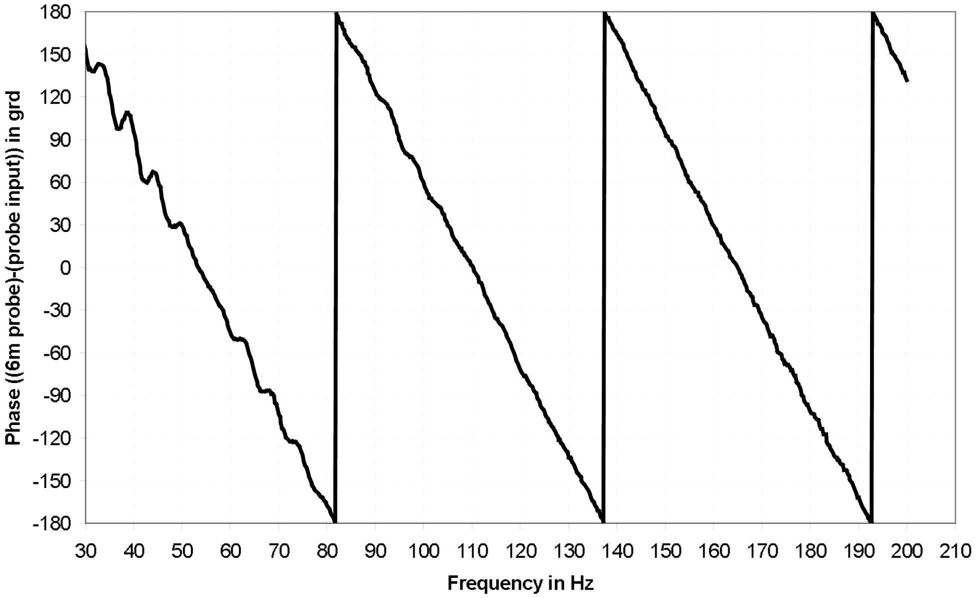

Figure 3: Phase calibration of the 6 m probe.

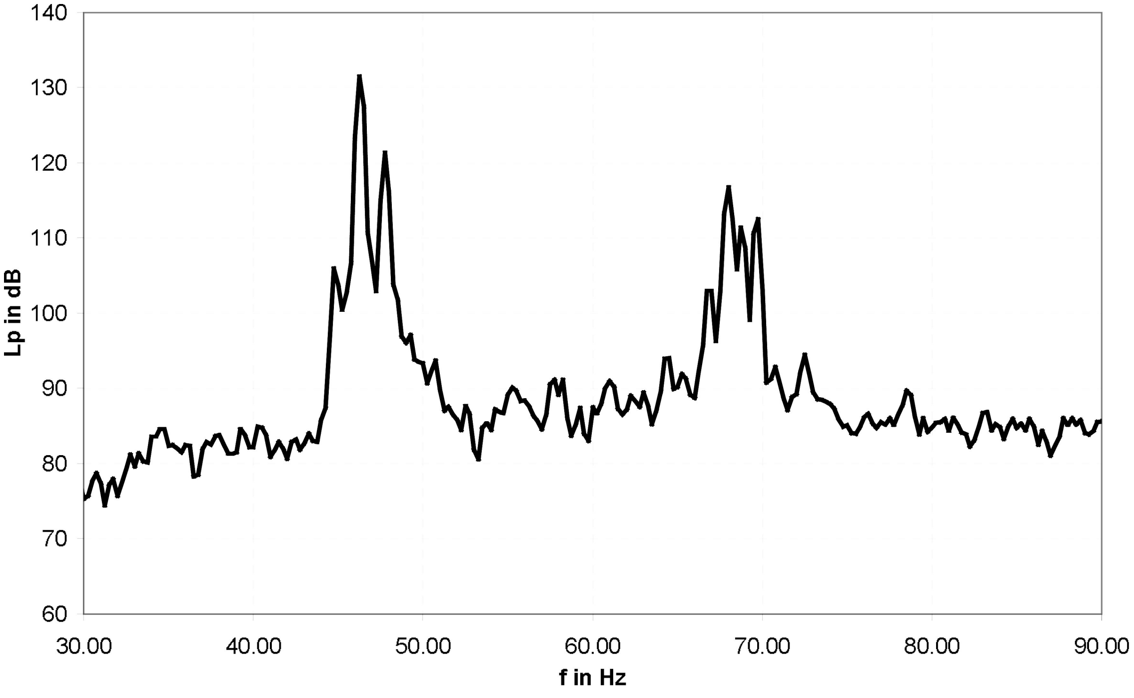

Figure 4: Example of sound pressure level spectrum inside the HRSG.

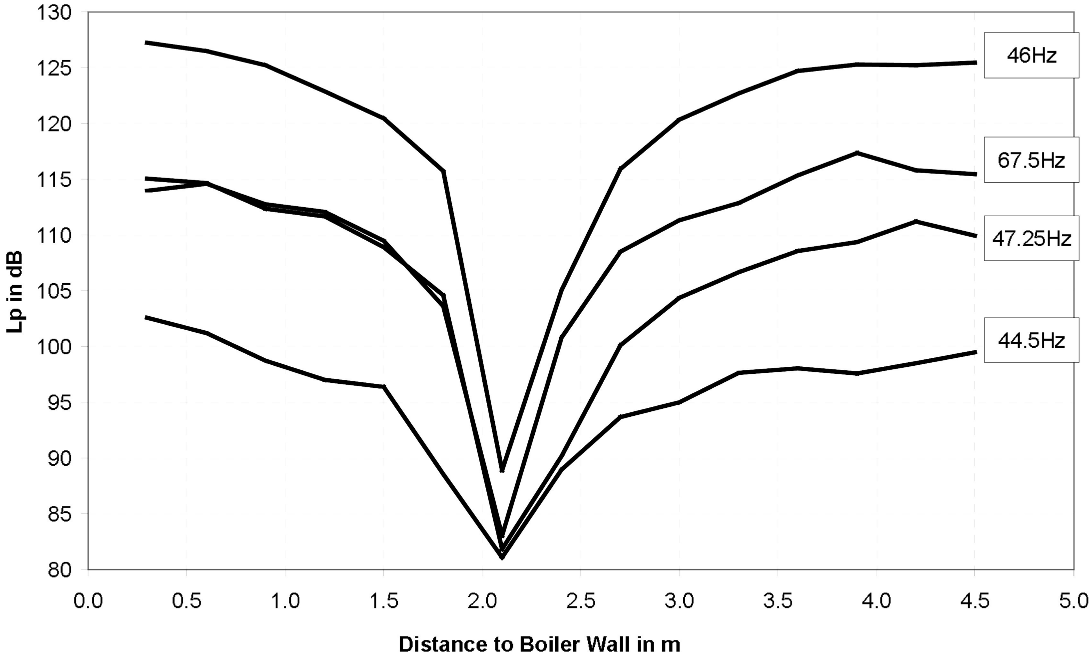

Figure 5: Standing wave pattern, measured in the middle of a HRSG with a width of 9 meters.

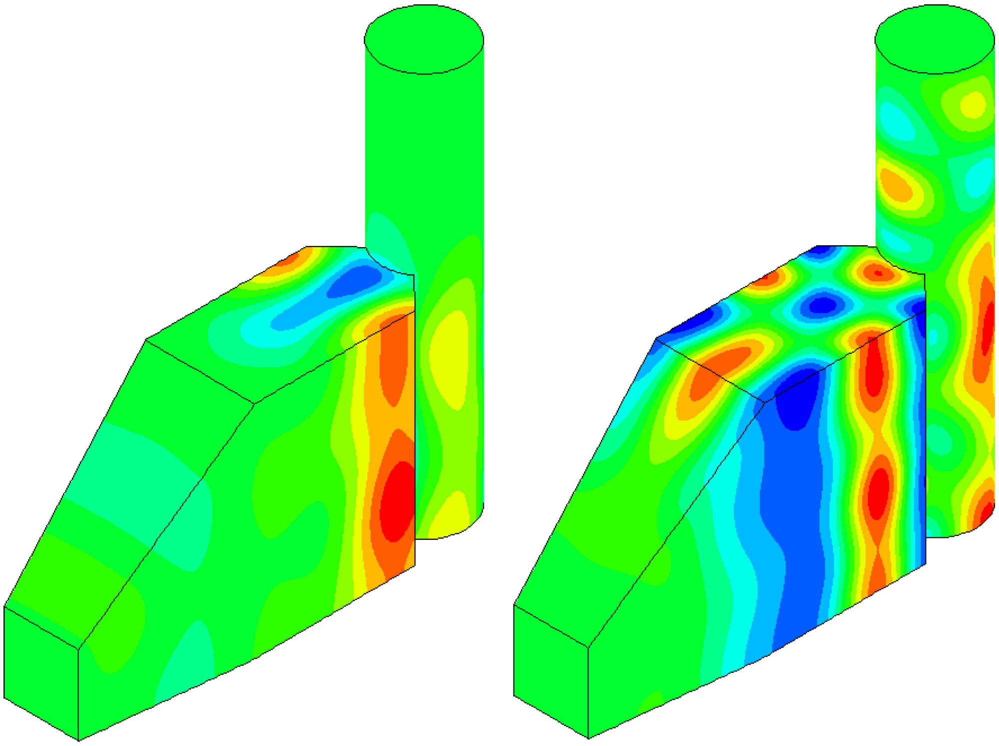

Figure 6: FEM sound pressure levels.