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# MICROPHONE PROBE FOR IN-DUCT MEASUREMENT OF GAS TURBINE EXHAUST NOISE

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## ABSTRACT

A new probe has been developed for Bruel & Kjaer 6.35 mm (1/4") microphones in order to allow in-duct measurements in high temperature gas turbine exhaust ducts without exposing the microphone to excessive temperatures. The motivation for this design was the need for a probe system that is easily transported and installed on site.

The new probe is made from readily available 6.35 mm (1/4”) o.d. tubing and compression fittings. It consists of a stem to sample the in-duct acoustic field, a shut off valve, a "T" connector to provide a microphone port remote from the hot gas and an anechoic termination.

The termination provides a true anechoic response down to 20 Hz. The probe provides a smooth, resonant free response between 20 Hz and 20 kHz allowing for accurate calibration and measurement.

This paper describes the probe design and installation details, probe frequency response calibration, probe flanking limit and performance of the anechoic termination. The paper also compares the probe response to theoretical predictions. Relative to other potential in-duct measurement probe systems the new design is seen to be lightweight, compact and inexpensive.

## INTRODUCTION

This paper describes a microphone probe that is intended to be flush mounted on a gas turbine exhaust duct wall. A primary requirement is that the distance between the microphone and a hot casing wall be sufficient to prevent the microphone and preamplifier from experiencing excessive temperatures. A microphone to wall distance of 500 mm would be considered adequate for this purpose in most instances.

A microphone probe design to accomplish this is shown in Figure 1. It consists of a stem to sample the in-duct acoustic field, a shut off valve, a "T" connector to provide a microphone port remote from the hot gas and an anechoic termination (not shown). The probe with the anechoic termination is shown in Figure 3.

Except for the stem, the probe is made from 6.35 mm o.d. flexible copper tubing and compression fittings. The stem is made from 6.35 mm o.d. steel tubing normally used in hydraulic brake lines. The anechoic termination consists of two 7.62 m (25 foot) coils of 6.35 mm o.d. flexible copper tubing in series and capped off at the far end. Different length stem pieces or other components could be used to suit specific measurement conditions.

With the shut off valve in the open position the acoustic path from the stem tip to the microphone connector is a continuous diameter with no gaps that could create standing waves within the probe. If this condition is not met the probe will likely generate strong resonances that can produce fluctuations in the frequency response curve of 30 dB or more. Under these conditions calibration of the probe would be essentially meaningless.

The acoustic design of the probe therefore requires a resonant free response and this is accomplished by careful machining and fitting of the components. The frequency response of the probe is then controlled by the attenuation of sound in the small diameter tubes. The acoustic path from the stem tip to the microphone is designed to prevent excessive tube attenuation at high frequencies. We have used an attenuation of approximately 10 dB at 10,000 Hz as a design limit. This requires a length to inner diameter ratio of approximately 100, e.g. see ref. [1]. This in turn requires a tube i.d. of approximately 5 mm which is consistent with 6.35 mm o.d. tubing (i.d. = 0.2 inches).

The anechoic termination must be designed to provide some minimum attenuation at the lowest frequency of interest. Our design requirement was a minimum attenuation of 5 dB at 20 Hz. This means that the sound wave reflected from the cap at the far end of the termination arrives at the microphone at least 10 dB lower than the incident waves from the stem tip. Therefore the effect of the reflected waves on the measured levels will be of the order of 0.5 dB or less. The performance of the termination will improve with increasing frequency. We describe below the operation and calibration of the probe.

## DESCRIPTION OF PROBE OPERATION

A sketch of the installed probe is shown in Figure 2. At each location to be measured, a 6.35 mm diameter hole is provided in the duct wall. A pipe coupling is centered on the hole, welded to the wall and closed off with a plug (not shown).

To prepare for measurements the engine is shut down, plugs removed and partial probe assemblies with supporting pipes installed as shown in Figure 2. Partial probe assemblies consist of the probe shown in Figure 1 without the anechoic termination or microphone. The supporting pipe threads into the pipe coupling at one end and supports and locates the stem tube at the other. The shut off valves are closed to prevent any escape of hot gas. The engine can then be restarted.

With the engine running microphones and anechoic terminations are installed on two of the probes. The shut off valves for these probes are opened and the pressure signals recorded. The shut off valves are then closed and the process repeated at two other locations. The probe locations are measured in pairs since two simultaneous measurements are required for cross spectrum analysis (e.g. ref. [2]).

## PROBE CALIBRATION PROCEDURE

The probes are calibrated for amplitude (sound pressure level) frequency response as shown in Figure 3. A Bruel & Kjaer HP1001 sound source provides a fixed reference location for the probe tip as shown in the figure, or for the 6.35 mm microphone and preamplifier by itself (not shown) called the "reference microphone". The HP1001 is driven by a Bruel & Kjaer 4205 random noise generator. A second loudspeaker driven by a pseudo random sound source is used to generate additional low frequency sound, primarily below 100 Hz, which the HP1001 does not produce.

A Bruel & Kjaer Nexus amplifier provides the functions of microphone power supply, signal amplifier and anti-aliasing filter. Signals are recorded on a computer as received by the mic/preamp installed in the probe and by the mic/preamp installed at the reference location of the HP1001. The difference between the two spectra obtained is the sound pressure level vs. frequency response of the probe.

In order to determine the performance of the anechoic termination, the microphone probe is removed from the "T" connector and replaced with a 7.62 or 15.24 m anechoic coil with the free end of the coil placed at the reference location of the HP1001; i.e. an anechoic coil is used in place of the probe.

Data was obtained at 44100 samples per second. Analysis utilized an FFT block size of 16384, Hanning window and 255 FFT block averages.

## CALIBRATION RESULTS AND DISCUSSION

Results of the probe calibration are shown in Figures 4 and 5. Figure 4 shows the octave band spectra as measured by the reference microphone and by the probe. As expected, the probe shows progressively higher attenuation with increasing frequency. Figure 5 shows the narrow band spectra that produced the octave band spectra in Figure 4. It is apparent that the probe reproduces the reference microphone spectrum with a gradually increasing attenuation at higher frequencies and no significant resonances.

Figure 6 shows the spectrum obtained with the shutoff valve closed compared to the spectra from Figure 4 and a typical ambient spectrum for reference. The spectrum obtained with the shutoff valve closed represents the flanking limit of the probe; i.e. the sound pressure level produced at the microphone by paths other than the intended open probe duct. It is apparent that the flanking octave band spectrum is typically 20 dB to 40 dB below the (valve open) probe spectrum and therefore will not have any effect on probe measurements. We note that the microphone preamplifier casing is sealed inside the "T" connector with plastic compression sleeves to minimize break-in noise at this point.

Figure 7 shows the spectra obtained when using 7.62 m (25 foot) and 15.24 m (50 foot) anechoic coils in place of the probe. The reference microphone, flanking and ambient spectra from Figure 6 are also shown in the figure.

We note that a 15.24 m "anechoic probe" corresponds to a 7.62 m anechoic termination since the sound waves in the 7.62 m termination must travel 15.24 m to return to the microphone location. The minimum attenuation provided by the 15.24 m coil, relative to the probe microphone, is 12.3 dB in the 31.5 Hz octave band. This corresponds to the sound pressure level of the reflected wave produced by the 7.62 m termination. This attenuation is sufficient to ensure that reflected sound wave produced by the termination would have no significant effect on the probe measurement.

It is apparent that for the lowest octave bands, where the flanking limit is not a significant factor, the 15.24 m coil produces approximately twice the attenuation of the 7.62 m coil, as would be expected from the theory [1]. Since these coils are relatively small and light, we have chosen to use a 15.24 m anechoic termination as standard in order to guarantee that even at the very lowest frequencies of interest, e.g. 20 Hz, the termination will be anechoic. A 15.24 m anechoic termination would be expected to produce a reflected wave attenuation of 24.6 dB in the 31.5 Hz octave band.

Figure 8 is the probe calibration curve for octave band data. It plots the difference between the two octave band spectra shown in Figure 4 and represents the amount, in decibels, that must be added to the levels measured by the probe in order to obtain the true levels.

Figure 8 also shows the expected theoretical probe attenuation [1] for comparison to the measured attenuation. We note that the calibration curve is measured for octave bands while the theoretical curve is calculated for the octave band centre frequencies. It is evident that the measured data follows the trend predicted by the theory but shows somewhat higher attenuation, by approximately 2 dB for the 8 kHz octave band. We note also that only plane waves can propagate within the probe at frequencies below 40,000 Hz; see ref. [3].

## CONCLUSIONS

1. The microphone probe has a smooth, resonant free frequency response consistent with expectations from theory.
2. This response allows accurate calibration and measurement.
3. The flanking paths are significantly (20 dB to 40 dB) below the probe duct path ensuring no degradation of the measurements.
4. The termination will provide an anechoic response down to frequencies of 20 Hz or less.
5. The performance of the microphone probe successfully met or exceeded all of its design objectives.
6. The microphone probe is a portable, lightweight system designed for on-site ease of use.

## ACKNOWLEDGMENTS

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## REFERENCES

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[2] M.P. Sacks, J.G. Kawall, R. Behboudi, J. Buttell, "In-Duct Measurement of Gas Turbine Noise Emissions Using a Cross Spectrum Method", ASME TURBO SHOW, Munich, May 2000.

[3] M.L.Munjal, "Acoustics of Ducts and Mufflers", Wiley-Interscience, 1987, p. 9-12.

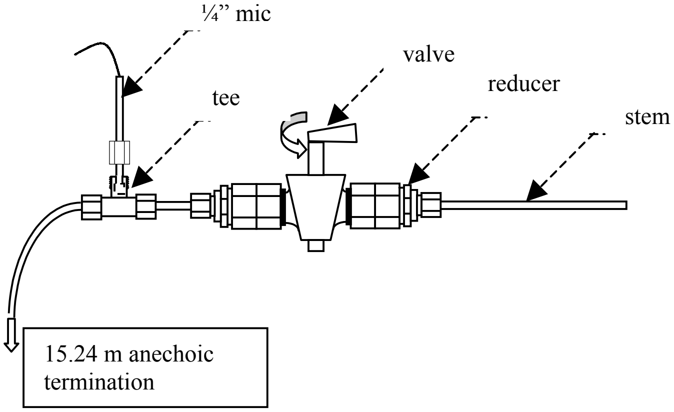

**Figure 1 – The Microphone Probe**

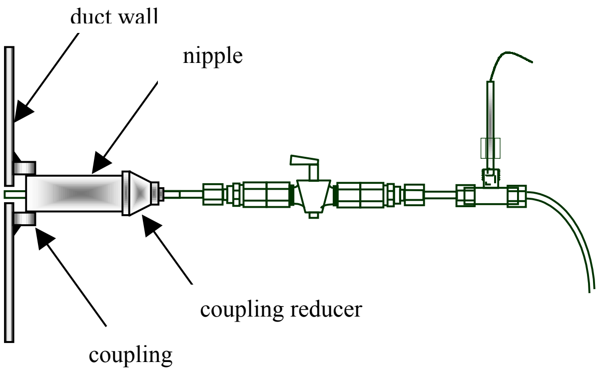

**Figure 2 – Installed Probe**

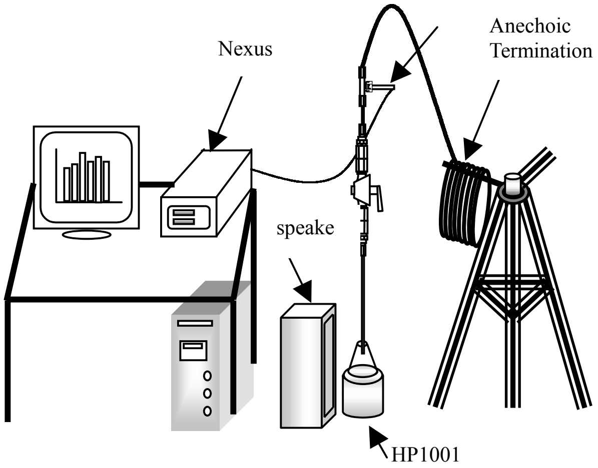

**Figure 3 – Calibration Setup**

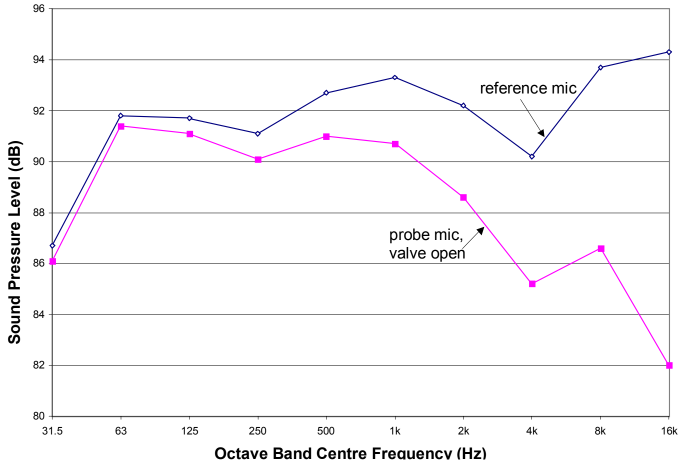

**Figure 4 – Octave Band Spectra as Measured by the Reference & the Probe microphones**

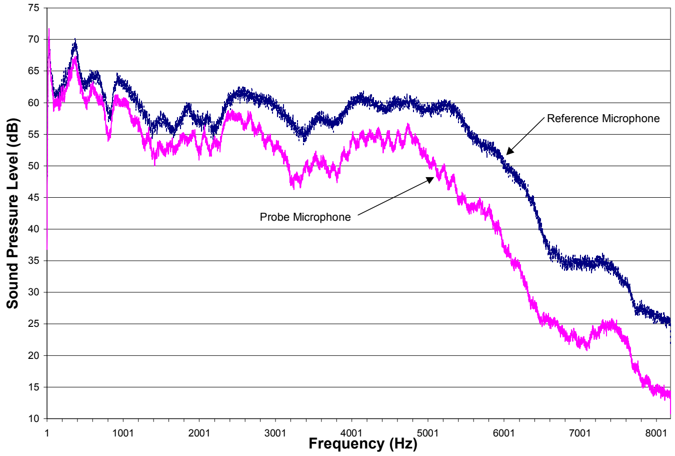

Figure 5 – Narrow Band Plot of the Spectra Presented in Figure 4

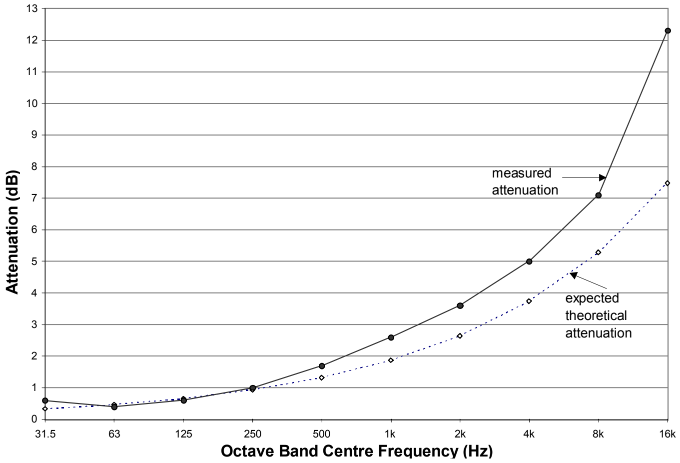

Figure 8 – Expected vs. Theoretical Sound Attenuation due to the Probe

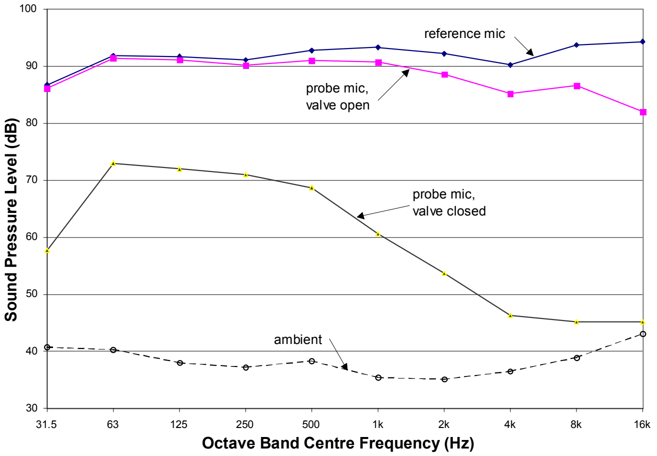

Figure 6 – Flanking Limit of the Probe

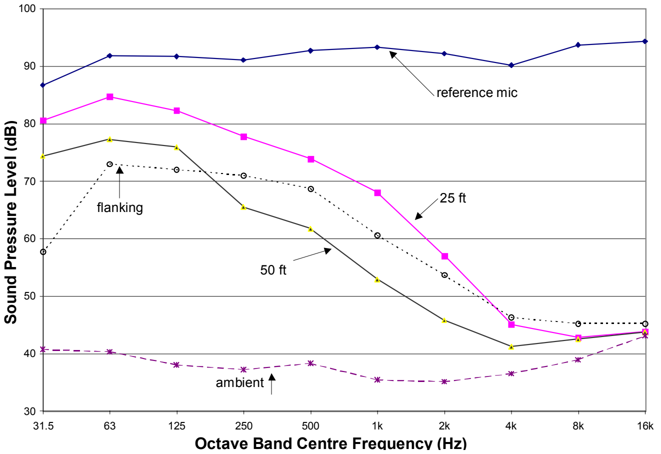

Figure 7 – Sound Attenuation in Anechoic Termination Coils