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MEASUREMENT OF ACOUSTIC INTENSITY IN DUCTS WITH HOT TURBULENT GAS FLOWS

Eva Persson

Siemens Industrial Turbomachinery AB
612 83 Finspong, Sweden
eva.m.persson@siemens.com

Abstract

The main sources of noise in an industrial gas turbine installation are the air intake and the exhaust. Big dissipative silencers are thus usually used to reduce the emitted noise. Duct measurements before the silencer and chimney measurements after the silencer usually do not agree well with the predicted sound insertion loss. This could be caused either by measuring problems or by actual lack of attenuation of the silencer. The environment in the duct, where the measurements are conducted, is usually very harsh. The temperature in the air-intake is equal to the ambient temperature, but for the exhaust system it is in the range of 5-600 ^{o}C with extremely turbulent flows. The number of possible measurement positions is usually very limited due to practical reasons.

To increase the knowledge of how to interpret the measurement results from the duct systems a study has been done on measurement technique in a scaled model duct with airflow in the duct.

Flush mounted pressure transducers on a man-hatch are usually the only way to mount a transducer on the exhaust side. Scanning of the duct cross-section was done in the model measurements to reveal how well the flush measurement position represents the total pressure in a duct with flow.

For low frequencies the flush mounting is overestimating the average sound pressure level of the duct cross-section. For the mid-frequency range the levels are well estimated while the overestimation reoccurs at higher frequencies. The variations are seen for approximately the same frequency bands for both laboratory scale model and real scale measurements. The duct dimensions and scaling of the ducts do not seem to have any influence on these differences in measurement results. The total sound pressure level is only exceeding the scanned value by a few dB.

INTRODUCTION

The main noise sources of a gas turbine installation are the air intake and exhaust. Big dissipative silencers are usually used to reduce the emitted noise. This paper discusses measuring problems and possible improvements of the measurement technique in the duct system of gas turbine installations.

To better determine the effect of silencers and to predict the emitted noise levels from new installations, more knowledge of the actual sound power level from the gas turbine itself is important. This is a matter of importance for the customer as well as the silencer manufacturer.

A plant up-and-running is in general supplied with dissipative silencers on both in-take side and exhaust side. The gas turbine sound power level can then be determined either by external measurements on air-intake, chimney top or duct measurement next to the gas turbine. External measurements will include the uncertain acoustic effect of silencers, boilers and difficult measurement situations close to high chimney tops.

The measurement environment in the duct is usually very harsh. For the air-intake the temperatures are normal but for the exhaust system the temperatures are about 5-600^{o}C with extremely turbulent flows. Usually only one or a few measurement positions are possible.

To increase the knowledge of how to interpret the measurement results from the duct systems a study has been done on measurement technique in a scaled model duct with airflow applied in the duct. The objectives of the measurement study were to evaluate different measurement positions and to investigate what influence the mounted silencer and reflections from this have on the measurement results. The background theory for flow in ducts used for this paper is mainly based on ref.[1].

For the real measurement situation the possible measurement positions are strongly limited on the hot gas turbine side. Flush mounting the pressure transducer on the man-hatch is usually the only way to mount a transducer on the exhaust side. Scanning of the duct cross-section was done in the model measurements to reveal how well the flush measurement position represents the total pressure in a duct with flow.

MEASUREMENT SET-UP

The duct used for the measurement set-up is seen in Figure 1. It consists of three duct sections of Plexiglas where the length of each duct section was 1 m. The cross-section area of the duct was 0.23x0.23 m^2, which gives the scale 1:10 to a real duct. Four loudspeakers were mounted in the duct in order to get a realistic acoustic field. White noise excitation was used. The duct was connected to a duct system with a pump introducing flow. The thickness of the Plexiglas was 10 mm to avoid major vibrations in the duct structure.

Two flush measurement points were used in the duct, positions A and B in Figure 2. In addition measurements were made with a 1/2" microphone mounted on a stick to allow scanning of the inner volume of the duct to detect pressure variations

Figure 1 The Plexiglas test duct used for measurements.

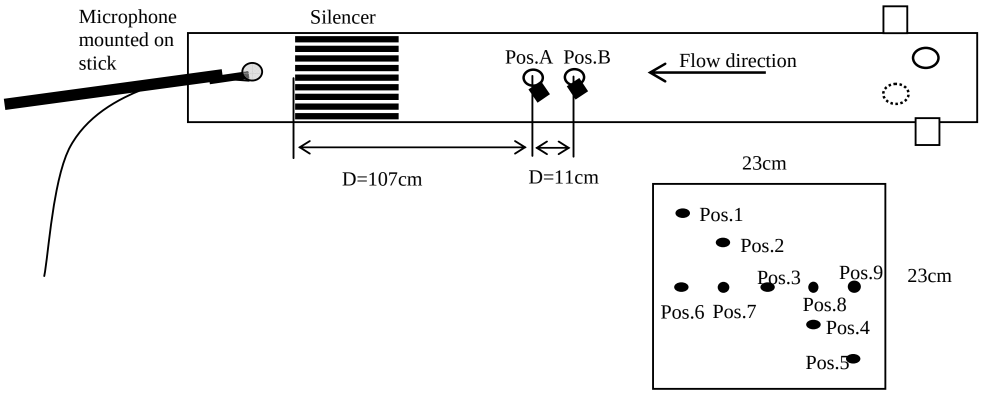

Figure 2 Measurement positions in duct cross-section with microphone mounted on a beam.

across the duct area.

Measurement position A, see Figure 2, was used as a reference measurement point using a ½" microphone connected to an analyser during all measurement set-ups. A wooden 9x10 bar silencer was used for the tests. The area of the cross-section of the bars was 14x14 mm^2 and the length was 0.19 m. The bars added no damping to the duct but self-induced noise and reflection due to the silencer were present.

MEASURED SOUND PRESSURE LEVELS IN DUCT

Measurements were conducted at the following flow speeds: 0 m/s, 16 m/s, 20 m/s and 30 m/s. White noise excitation from loudspeakers was used. The cut-on frequency for the test duct was 735 Hz. The Mach numbers in the duct used for the scale model measurements was 0.09, 0.06 and 0.04 for the flow speeds 30 m/s, 20 m/s and 16 m/s, respectively. For the measurement set-up used, the two-microphone method was valid for the frequency range f_{min}=154Hz and f_{top}=1236Hz.

The measured sound pressure levels in the duct were determined by the noise source and the boundary conditions of the duct.

Open end boundary conditions

This section includes discussions on the measured sound pressure level and its distribution over the duct cross-section for frequencies above cut-on and the difference in measured sound pressure level for different boundary conditions for the same noise source.

The difference in sound pressure levels measured in the same measurement position with isolated end versus open end shows that the silenced end gives higher sound pressure levels than the open end. This is due to reflections from the silencer. Figure 3 shows the end reflections, i.e. the difference in measured sound pressure levels for the silenced and the open duct end and predictions based on the two-microphone method with no flow.

The predictions as well as the measurements shows fluctuations of reflection influence for increasing frequencies agrees well with the reflection for the open end determined according to the two-microphone method using measurement results.

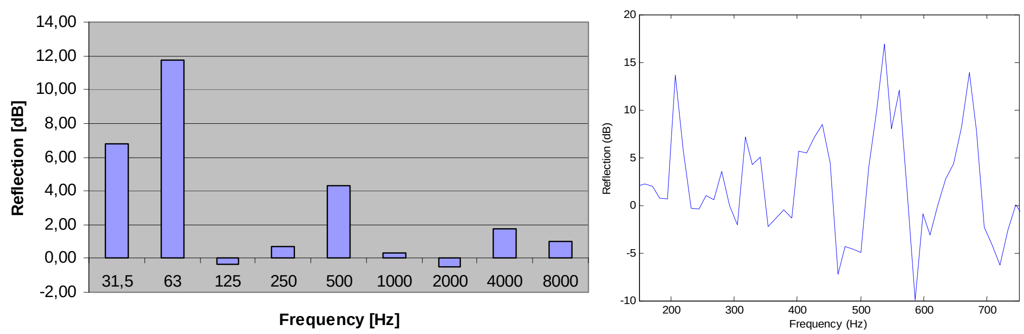

Figure 3 End reflections A) measured for isolated end contrary empty duct end. B) determined using the two microphone method during measurements in the duct with open duct en and flow velocity 0 m/s.

The reflections are of main concern and in-duct measurement results should be considered overestimated for low frequencies.

A silencer mounted in a duct induces self-generated noise and reflections.
The levels of the self-generated noise are to be assumed well below the incoming noise and self-generation is therefore neglected for this measurement set-up.

The noise reflected at the silencer end is investigated for different flow conditions. The measurements show that the sound pressure levels over the duct cross-section for the same noise source varies due to reflections at the duct end for different boundary conditions. For comparison the difference between the noise levels measured with the silencer mounted in the duct and the empty duct is plotted.

In Figure 4B, the difference in measured pressure levels in the exhaust duct with and without silencer is shown for two types of gas turbines. It is seen from the figure that the pressure levels measured in the silenced duct in general are higher than for the empty duct. From Figure 4 A, it is seen that the flow velocity has some influence on the frequency content of the reflection.

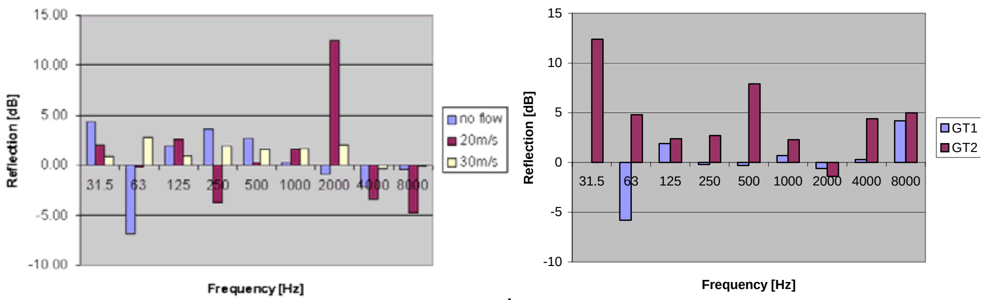

Figure 4 Difference in measured sound pressure level representing the reflection for silenced duct compared to empty duct. A) scale model with various flow speed. B) exhaust duct with and without silencer mounted for two different GT applications.

It is seen in Figure 4b for measurements on gas turbine applications that the reflection effect has a significant influence on some frequency bands. For the remaining frequency bands the influence is in general inside a margin of 5dB. The reflection should be kept in mind when analysing duct measurement results giving an uncertainty to the measurement results for low frequencies.

Pressure level variations over the duct cross section

To verify the pressure variations over the cross-section several measurement points were used over the surface shown in Figure 2.

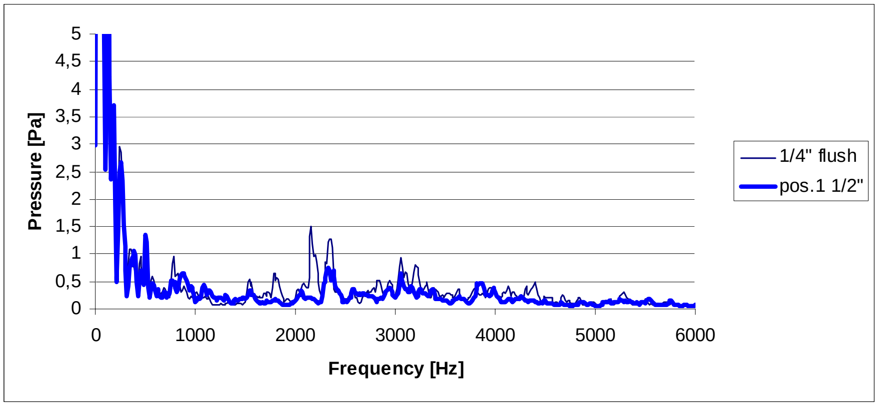

Figure 5 Frequency spectra for measurement position 1 compared to the stationary measurement point with flush mounted microphone with flow velocity 16m/s

Figure 5 shows a typical frequency spectrum for the duct scanning measurement positions, in this case position 1 and the flush mounted probe. The frequency content and the levels of the frequency tops show significant differences. In general using the flush mounted probe will overestimate the pressure levels for most frequencies. This could be due to the presence of the turbulent boundary layer caused by flow in the duct.

The differences for the mean value of the scanned levels as compared to the flush mounted values are rather big in the low frequency range. This reoccurs at 2 and 4 kHz. The behaviour varies a bit for the different measurement situations with different boundary conditions and flow conditions. Reducing the flow speeds seem to decrease the level differences, see Figure 7. The measuring results for the scanned positions will not detect the reflection contribution due to the type of microphones and the direction of the probe. The total levels agree by a few dB difference.

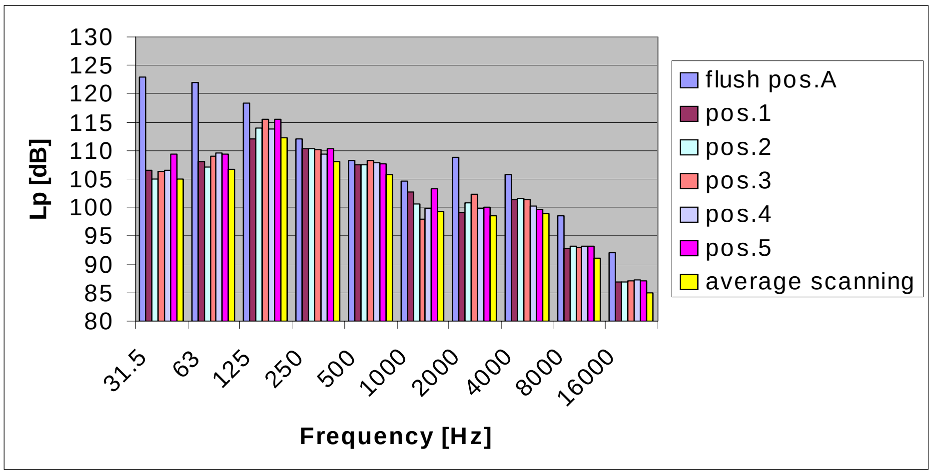

Figure 6 Measurement result when scanning the duct cross-section with 30m/s flow in the duct with silencer.

The conclusion is that the frequency content is difficult to determine exactly using flush mounting. The overestimation of pressure level by the flush mounting is seen in Figure 6 to be largest in the low frequency range and reoccurs for higher frequencies. The overestimation is increased by flow speed.

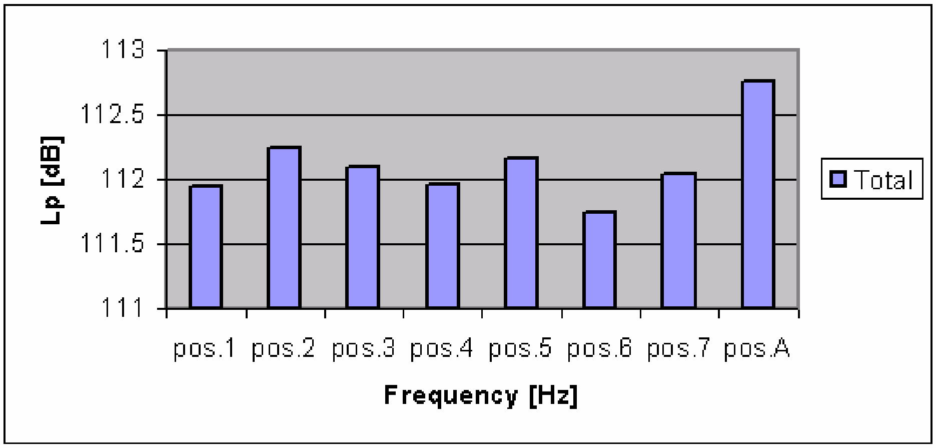

Figure 7 Total pressure level for no flow application with silencer mounted in the duct The plot shows that the pressure levels varies over the duct cross-section.

Agreement between duct measurements and L_w chimney measurements

Large discrepancies have been observed between measured sound power levels at a gas turbine chimney as compared to levels determined from duct measurements before or after silencers. Predictions, scale model measurements and hot gas turbine measurements have been made in order to determine the cause of the differences. The discrepancies found between the measurement results for the flush mounting and the scanning of the duct cross-section would explain the overestimation of the sound power level determined by duct measurements as compared to chimney measurements done according to ISO 10494 [2].

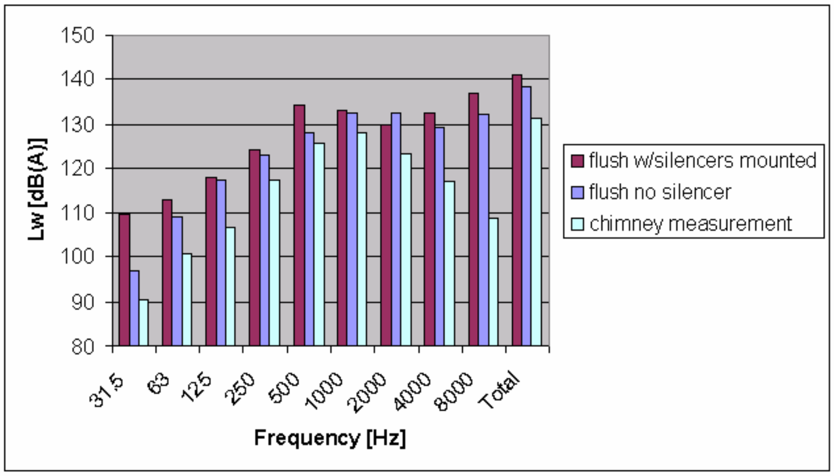

Figure 8 Sound power level determined by duct measurements using a high temperature pressure probe flush mounted in the gas turbine exhaust duct and chimney measurements.

The measurements in the gas turbine were performed in the duct with the measurement probe flush mounted and without a silencer mounted in the exhaust duct. The emitted sound power level was also determined by chimney measurements according to ISO 10494. The chimney measurement results would be influenced by directivity of the chimney top as compared to the sound power level determined in the duct after the gas turbine. The sound pressure measurements with the flush mounted pressure probe were made at two occasions at the same engine load. The measurements were made with and without the dissipative silencer mounted in the exhaust duct.

From Figure 8, it is seen that the duct measurements gave an overestimation of the levels in some frequency bands compared to the chimney measurements. The behaviour agrees well with the results found from the laboratory duct measurements. The reflection on the silencer presented in Figure 4 explains part of the differences in measured levels. The rest is explained by the influence of the flow. The duct scaling should be considered for all measurement results.

CONCLUSIONS

The measured levels are shown to depend on the choice of measuring position. For low frequencies the flush mounting is overestimating the average sound pressure level of the duct cross-section. For the mid-frequency range the levels are well estimated while the overestimation reoccurs at higher frequencies. The total sound pressure level is only exceeding the scanned value by a few dB. This is seen for real applications as well but the variations do not follow the scaling. The variations are seen for approximately the same frequency bands for both laboratory scale model and real scale measurements. This should therefore be assumed to be related to flow velocity and choice of probe and not to duct dimensions.

The duct end reflections for the measurement set-up were determined using the two-microphone method. For the isolated duct-end as compared to the entirely open end the reflections determined by one measurement probe in octave bands well agree with the reflection determined by measuring by the two-microphone method.

The silenced duct gives only small reflections as compared to the open duct end. The margin is within ± 4dB.

To go further in improving the understanding of flush mounted measurements in gas turbine ducts, measurements should be compared to sound pressure level predictions done in order to determine the various pressure levels over the duct cross section.

REFERENCES

[1] S.W. Rienstra & A. Hirschenberg: *An Introduction to Acoustics,* Eindhoven University of Technology, 2001

[2] ISO 10494:1993(E): *Gas turbines and gas turbine sets – Measurement of emitted airborne noise – Engineering/survey method*