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DEVELOPMENT OF PROBES TO MEASURE IN-DUCT SOUND PRESSURE LEVELS OF A GAS TURBINE EXHAUST

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1.0 Abstract

The ability to measure in-duct sound power levels at the exhaust flange of a gas turbine would allow in situ verification of gas turbine exhaust sound power levels and, in conjunction with other measurements, verification of silencer system dynamic insertion loss. The primary requirement for a measurement of sound power level is a procedure that will measure valid sound pressure levels in a high velocity, hot gas, highly turbulent turbine exhaust flow.

This paper describes the current state of development of specialized microphone probes to measure in-duct sound pressure levels. The mechanical and acoustical designs are described for two flush mounted wall probes: a perpendicular tube and a slit tube. The probes are calibrated for frequency response and turbulence rejection.

It is seen that both probes must be used at each measurement location in order to obtain a valid sound pressure level. The paper discusses the conditions under which valid and invalid sound pressure levels can be obtained and presents the results of applying the in-duct procedures to measure the dynamic insertion loss (DIL) of a gas turbine exhaust silencer system.

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2.0 Introduction

In general, a single microphone cannot distinguish between pressure fluctuations caused by sound waves and those caused by turbulence. Turbulence may be caused by flow over the microphone or may exist within the flow itself.

Early work established that specialized probes could be designed to desensitize microphones to turbulent pressure fluctuations relative to the desired acoustic pressure fluctuations; see for example references [1, 2].

These probes utilized a cylindrical tube terminated in a nose cone at one end and a microphone at the other. The probe is placed in the flow pointing upstream. The probe allows external sound to enter the interior over its length and impinge on the microphone.

As the means of admitting the external sound into the interior, the designs evolved into a long narrow slit parallel to the longitudinal axis of the tube and covered with a flow resistive cloth.

This type of device, called a slit tube or turbulence screen, is manufactured commercially [3] and provides turbulent noise suppression ranging from approximately 10 dB at 50 Hz to 20 dB at 1 kHz. It is utilized by an international standard, ISO 5136, to measure the sound power radiated into a duct by fans [4].

The commercially available turbulence screen is not a suitable probe for a gas turbine exhaust since the microphone would not survive the environment. A means must be found to remove the microphone from any contact with the hot exhaust gas.

To accomplish this we have initiated the development of two probes: a slit tube as described above and a second probe that we call a perpendicular tube. Both probe tubes are flush mounted to the internal exhaust duct wall. The probe tubes extend away from the duct wall. This allows a microphone to be inserted into the probe tube at a location remote from the hot exhaust gas. This approach is similar to that described in reference [5].

2.1 Requirement for Two Probe Designs

As indicated above, the reason for two different probe designs is that by itself, any single probe microphone cannot distinguish between the sound pressure we want to measure and the dynamic pressure fluctuations due to the turbulent flow from the gas turbine exhaust. These turbulent pressure fluctuations do not radiate any significant sound pressure levels.

Note that the self noise of either probe is eliminated by flush mounting with the inside wall of the duct. Even though this approach eliminates the local self noise of the probe, the probe still cannot separate the acoustic pressure fluctuations from inherent turbulent pressure fluctuations in the flow.

The perpendicular tube will measure the full value of both the acoustic and turbulent components of the dynamic pressure fluctuation.

The slit tube will measure the dynamic pressure fluctuation with the turbulent component reduced by an amount known from the turbulence rejection calibration.

If these two probes measure the same sound pressure level in a given frequency band, then the acoustic signal dominates the turbulent signal and a meaningful sound pressure level is measured.

If the perpendicular tube measures a sound pressure level that is higher than that from the slit tube by an amount equal to the turbulence rejection, then the turbulent signal dominates the acoustic signal and the measured sound pressure level is not meaningful.

Consequently, information from the two probes is required to establish if a valid sound pressure measurement has been obtained.

3.0 Test Set Up for In-Duct Probe Calibrations

Fig. 1 shows a schematic of the Silencer Test Facility at Higgott-Kane's location in Cambridge, Ontario. Test components are installed in the 0.6m x 0.6m (24" x 24") duct as shown in Fig. 2. Starting at a location closest to the fan and loudspeaker array, these components consist of a silencer, a plenum area and a sharp edged inlet to a 0.15m x 0.6m (6" x 24") test section. The test section contains the probes flush mounted to the outside wall of the duct. Downstream from the test section is a tapered silencer that acts both to reduce noise penetration from outdoors and as an anechoic termination.

4.0 In-Duct Probe Designs

Fig. 3 shows the measuring tube arrangement. This consists of a 2.5cm (1") inner diameter stainless steel tube terminated by 30m (100') of 2.5cm (1") inner diameter flexible clear plastic hose that is plugged at the far end. The microphone is flush mounted perpendicular to the stainless steel tube as shown in Fig. 3.

The flush mounted wall probes are terminated in a threaded pipe end and a ball valve as indicated in Fig. 3. With the ball valve closed, there can be no flow of hot gas from the turbine exhaust into the measuring tube. Consequently, a single measuring tube can be connected to any of the wall probes while the gas turbine is running.

Two types of flush mounted wall probes have been designed and tested: a perpendicular tube and a slit tube.

The perpendicular tube probe is shown in Fig. 4. The essential features are the tip and the thermal break. The flush mounted tip is covered with three layers of glass silk cloth and wire mesh screen.

The slit tube probe is shown in Figs. 5A and 5B. The essential features of this design are the 1 mm wide by 635 mm long slit and the thermal break. Ten layers of glass silk cloth are used behind the flush mounted slit.

5.0 Frequency Response Calibration

The frequency response calibration utilized the synchronous time averaging system, described in reference [6], to generate and measure an acoustic signal. The signal is also measured using a sound level meter. Referring to Fig. 1, the acoustic signal is produced by the loudspeakers; the fan is not used for these measurements.

The upstream silencer shown in Fig. 2 is removed and the computer generated signal is measured in three ways: using the perpendicular tube, the slit tube and a microphone flush mounted in the sidewall of the duct.

The flush mounted microphone measures the true sound pressure level. Consequently, the frequency response of either probe is the difference between measurements from the flush mounted microphone and the probe. This difference is the amount that must be added to the probe measurement to give the true sound pressure level.

The results for the flush mounted microphone are shown in Fig. 6A, for the perpendicular tube in Fig. 6B and for the slit tube in Fig. 6C. The sound pressure levels in these figures are averaged and subtracted as described above to produce the final frequency response calibration shown in Fig. 6D.

6.0 Turbulence Rejection Calibration

The turbulence rejection calibration utilized the complete test set up shown in Fig. 2. The purpose of this set up is to provide a quiet test section; both fan noise and external ambient noise are reduced by silencers on either side of the test section.

The flow from the fan across the sharp edged entry to the test section produces a high turbulence level, i.e., a turbulence intensity in the range of 15% to 25%, in the quiet test section. The turbulent pressure fluctuations dominate the dynamic pressure signal and the response of the probe tubes to this type of signal can be measured. The loudspeakers are not used for these measurements.

The fan is set to a constant RPM and the flow rate is varied by adjusting the variable inlet vanes. For a given flow rate, the resulting sound pressure level is measured using both the perpendicular tube and the slit tube. Measurements are obtained using both the computer system and a sound level meter.

The slit tube measures an attenuated version of the turbulent pressure fluctuation while the perpendicular tube measures the full value of the turbulent pressure fluctuation. Consequently, the turbulence rejection of the slit tube is the difference between measurements from the perpendicular tube and the slit tube, after correcting both for the frequency responses shown in Fig 6D.

The results for the two probes are shown in Figs. 7A and 7B for a flow velocity of 32.8 m/s (6460 fpm). The sound pressure levels in these figures are averaged and subtracted as described above to produce the final turbulence rejection calibration shown in Fig. 7C.

Due to the high slit tube attenuation at high frequencies as shown in Fig. 6D, the turbulence rejection calibration for the slit tube tested is valid for low frequencies only, i.e. at or below the 250 Hz or 500 Hz octave bands. Since the primary interest initially was in the lowest frequency octave bands, i.e. 31.5 Hz and 63 Hz, this situation presented no difficulty and no attempt was made to extend the frequency range of the slit tube.

7.0 In Situ Silencer Insertion Loss Measurements

Measurements were obtained for the exhaust of an operational 10 MW gas turbine as shown in Fig. 8. This exhaust duct contains two silencers, one on either side of the elbow. The perpendicular tube and slit tube microphone probes were attached at the end of the exhaust duct transition upstream of the first silencer as shown in Fig. 9.

The sound power at the turbine exhaust flange was calculated from the microphone probe measurements. The sound power radiated from the exhaust duct outlet was calculated from measurements obtained outside the duct in the plane of the outlet. The difference between these two sound powers is the dynamic insertion loss (DIL) of the silencer system and is shown in Fig. 10. We note that at frequencies above the 63 Hz octave band the external measurements were contaminated by other site noise sources. Consequently for frequencies above the 63 Hz octave band, the measured DIL is at best a lower limit of the actual DIL.

For comparison a static test (i.e. zero flow) was performed using loudspeakers at the base of the exhaust duct as a sound source. The results of this test, after correcting for temperature, are also shown in Fig. 10.

Fig. 10 also shows the DIL expected from the silencer design. Note that the design DIL values assume a flanking limit of 50 dB which, for this design, may be low by 5 dB to 10 dB based on the static test results. The flanking limit refers to the DIL produced by the silencer casing which becomes the controlling path when the air path DIL is higher.

There is good agreement between all three DIL curves in Fig. 10.

8.0 Conclusions

This study shows that useful in-duct measurements are both possible and practical to achieve and describes both the measurement procedures and the current state of the probe designs developed to conduct such measurements.

We are currently undertaking a more fundamental investigation with the objective of improving the technology associated with separating acoustic and turbulent pressure fluctuations.

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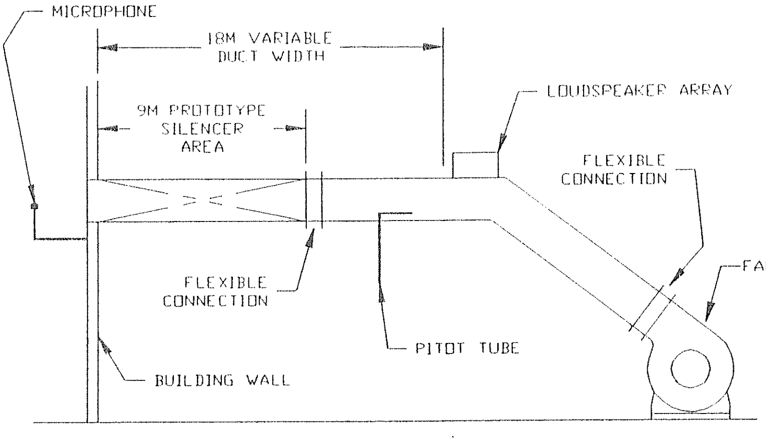
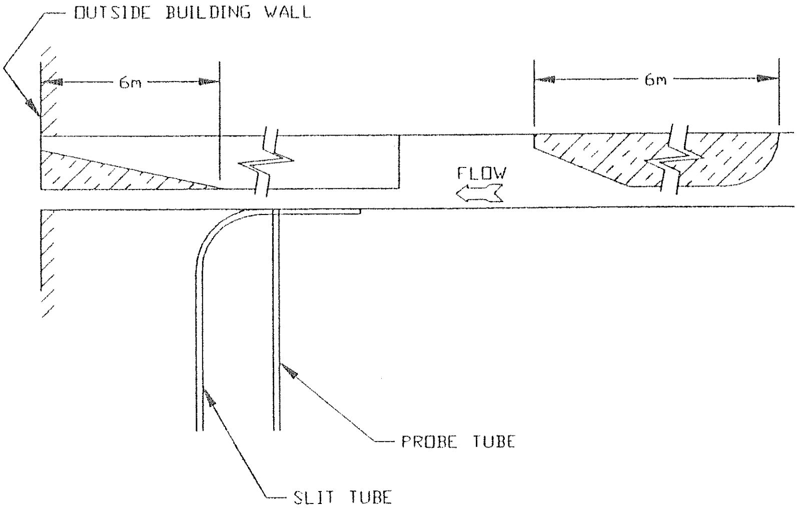


SILENCER TEST FACILITY

Fig. 1

H-K SILENCER TEST FACILITY



IN DUCT SOUND PRESSURE PROBE CALIBRATION

Fig. 2

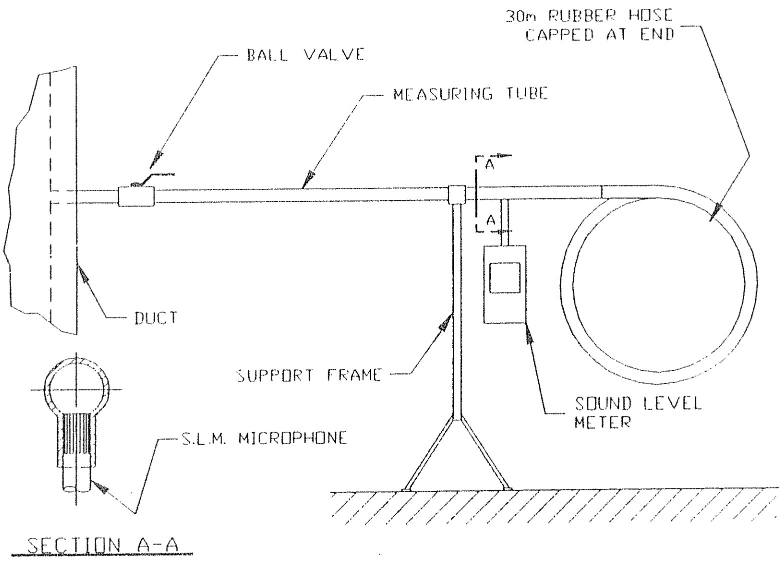


Fig. 3 Measuring Tube

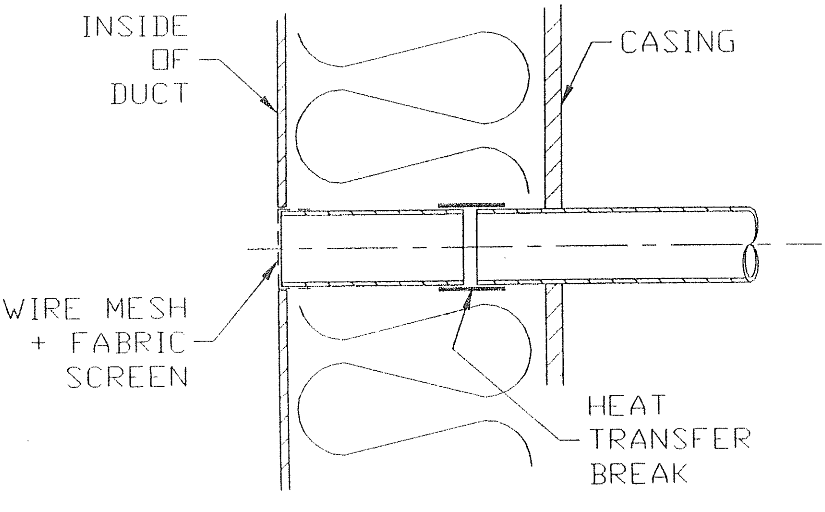


Fig. 4 Perpendicular Tube Probe

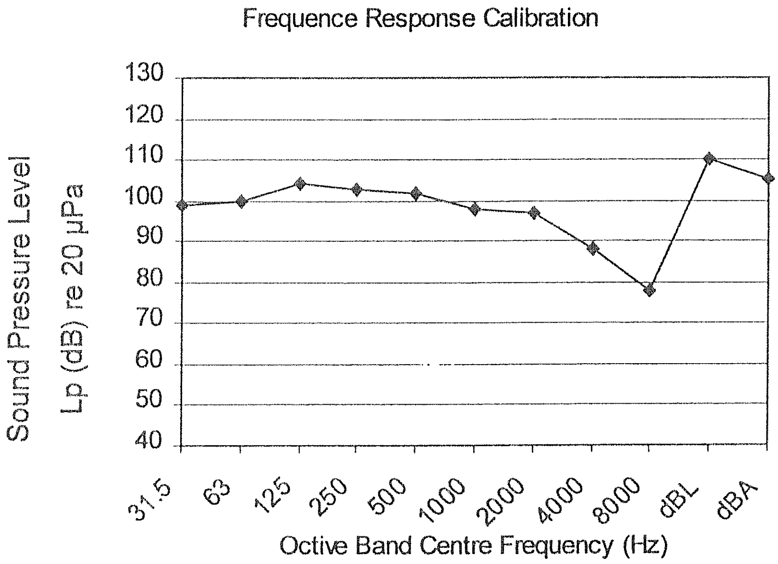


Fig. 6A Wall Port

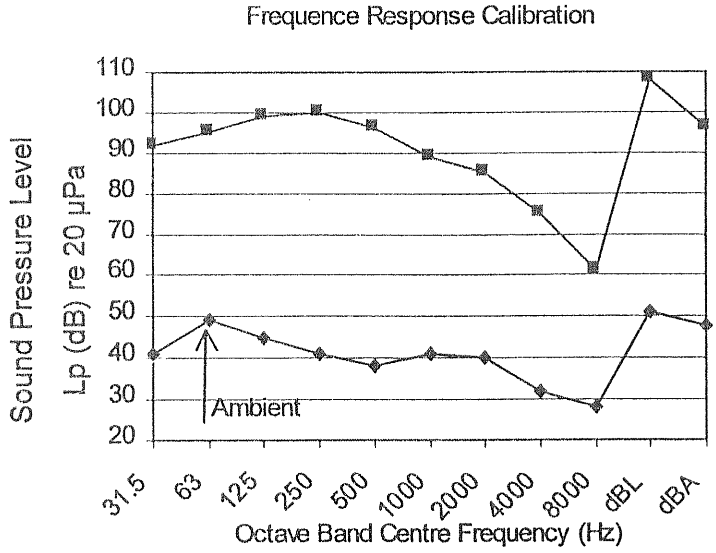


Fig. 6B Perpendicular Probe

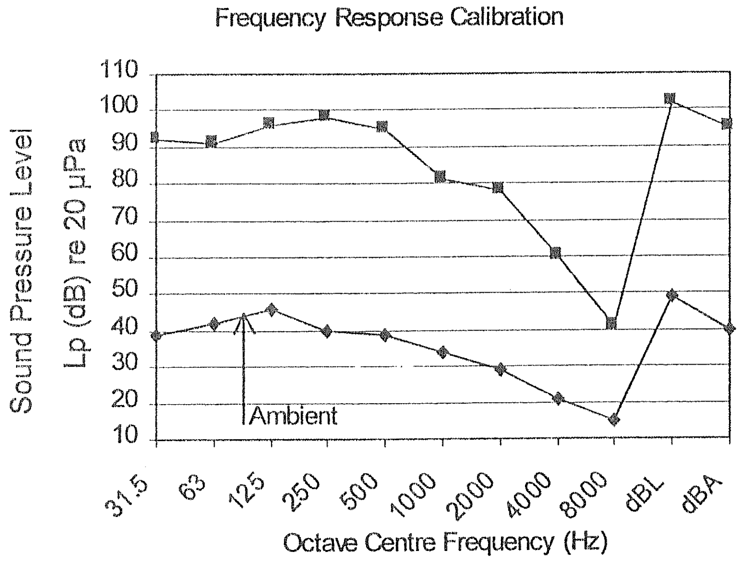


Fig. 6C Slit Tube Probe

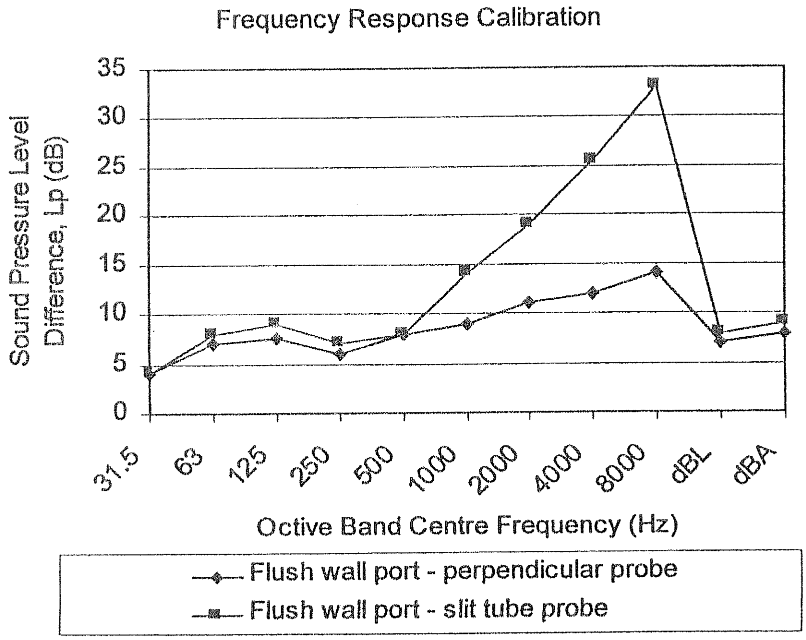


Fig. 6D Final Probe Calibrations For Frequency Response

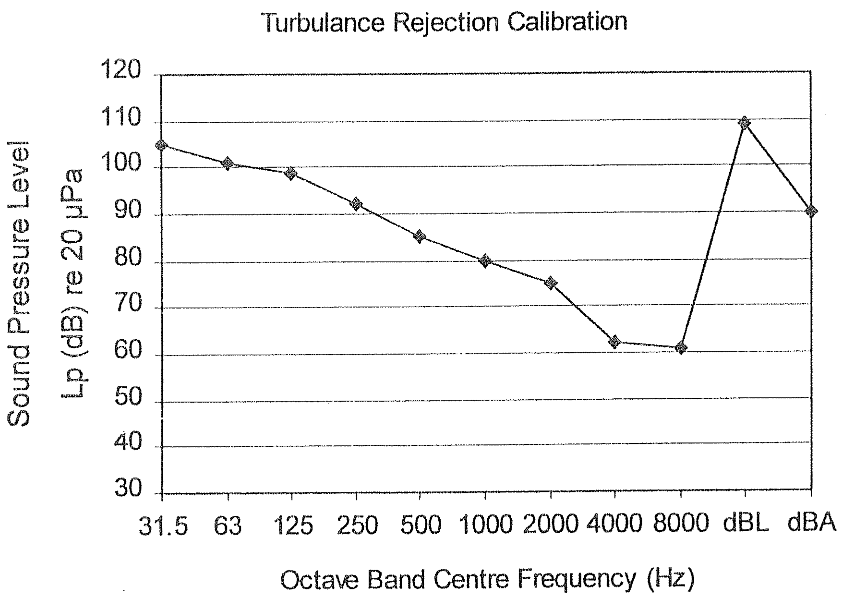


Fig. 7A Slit Tube 32.8 m/s

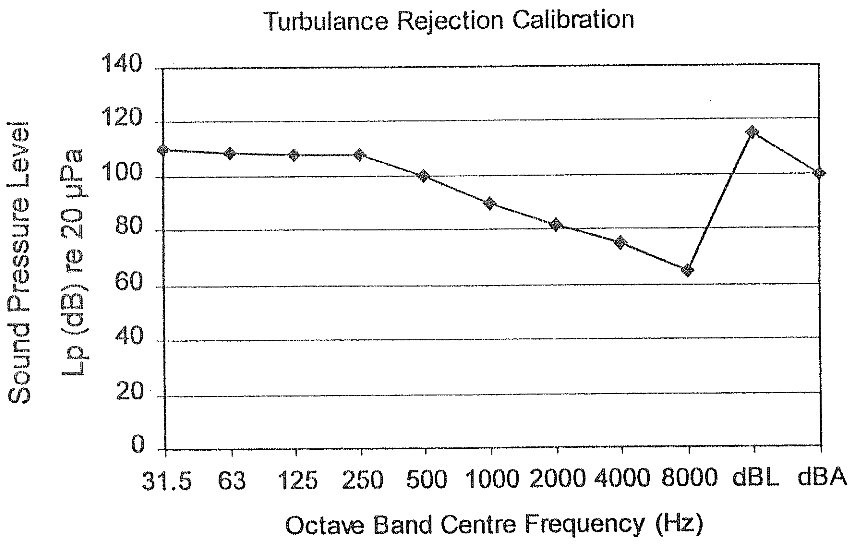


Fig. 7B Perpendicular Probe 32.8 m/s

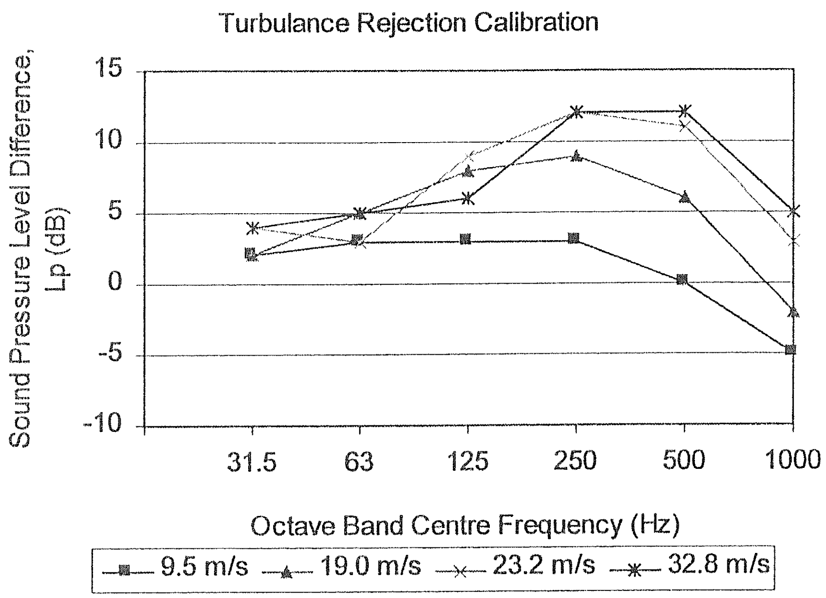


Fig. 7C Final probe Calibrations for Turbulence Rejections

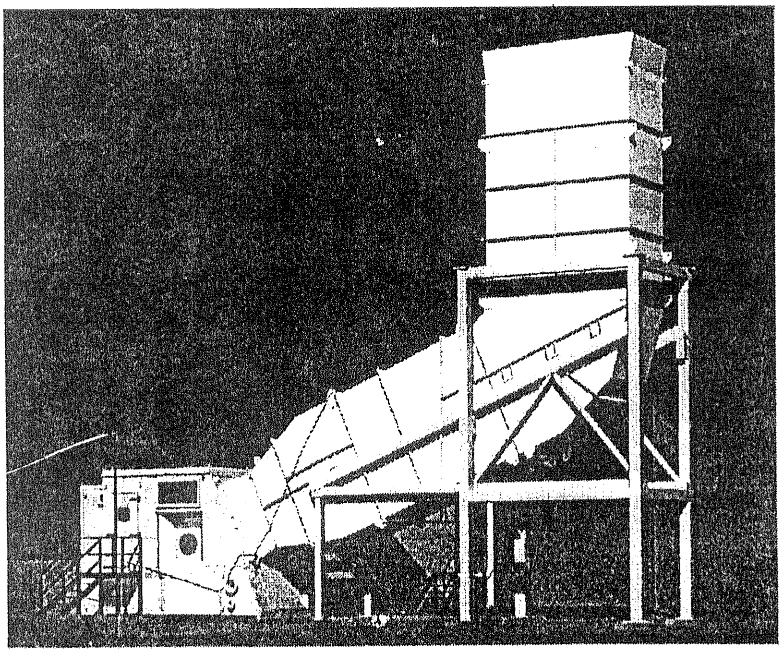


Fig. 8 10MW Gas Turbine Exhaust Duct

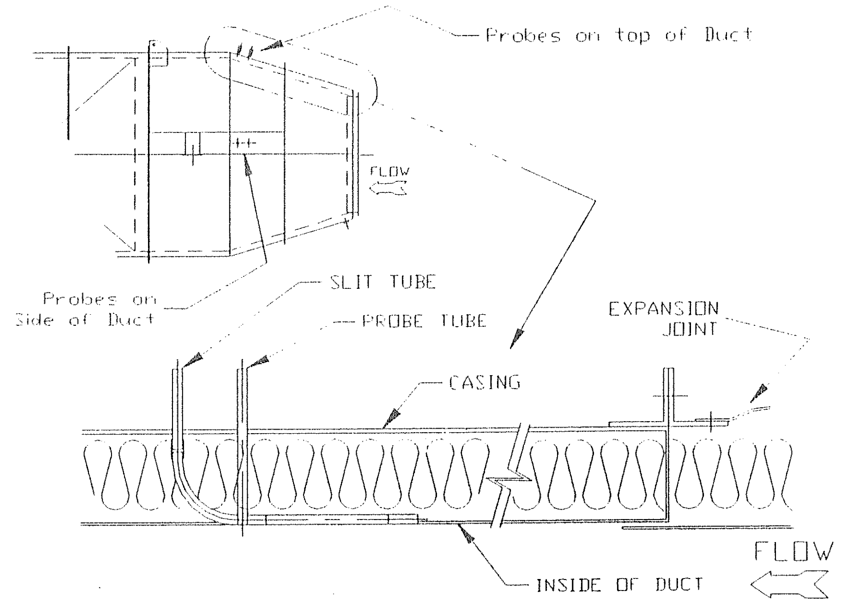


Fig. 9 In Situ Attachment of Probes

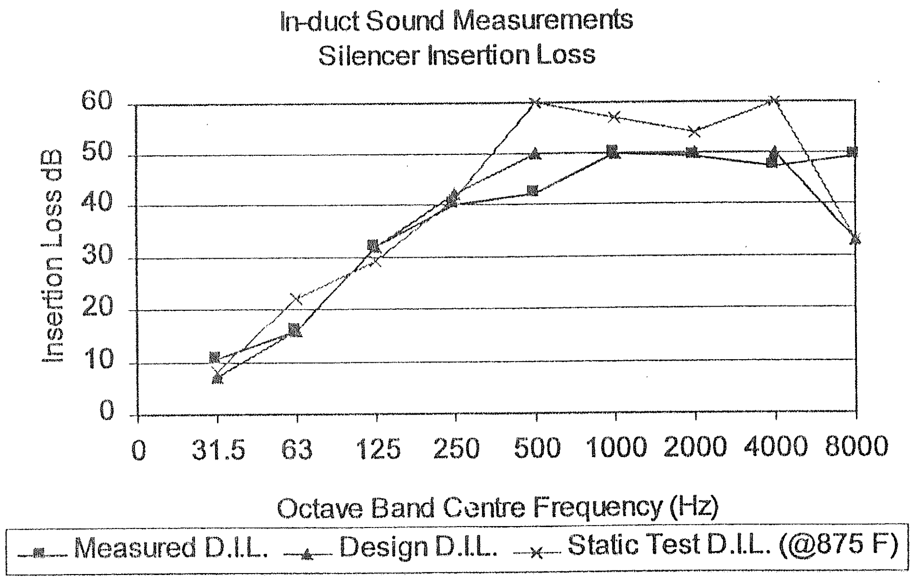


Fig. 10 Insertion Loss Comparisons