Proceedings of The Institute of Acoustics

GENERATION OF HIGH INTENSITY NOISE IN HIGH PRESSURE GAS

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1. INTRODUCTION

About twelve years ago, the UKAEA and the nuclear power industry were concerned about possible damage by high intensity noise to components of gas cooled reactor circuits, particularly to insulation. Noise levels up to 165 dB were known to be produced in the coolant circuit using densities of about 40 Kg/m^3. The noise could have predominant frequencies arising from the blower blades, but in most designs was broad band. A large pressurised gas loop existed at Windscale and specimens could be put in various positions in this loop and subjected to high intensity noise. However, it was not practicable or economic to run the loop at full flow rates continuously and it was decided to build an independent test chamber.

This paper describes the development work carried out to provide this chamber. More details are given in references (1) and (2). Although a commercially available electro-pneumatic transducer which should in principle operate in high density gas, was used to generate the noise, it had not been used under these conditions and its operation was incompletely understood. The coupling of the transducer to the test chamber also had to be investigated.

2. THE NOISE GENERATOR

The Ling Altec electro-pneumatic transducer, type EPT94B, is essentially a sleeve valve modulating a gas flow. The valve has a stationary cyclinder with two rows of slots, each 1.52mm wide, around its circumference. A sleeve with a single row of slots can move outside this cylinder from a position where the slots are completely open to a position where they are completely closed. The sleeve also carried a current coil which can move between the pole pieces of a permanent magnet. It is suspended on a synthetic rubber compliance so that, when there is not current flowing in the coil, the slots are half open. Applying a current to the coil moves the sleeve and changes the flow area through the valve and hence the gas flow.

The complete test arrangement is shown diagramatically in Fig 1. The noise generator is represented by a plenum, supplied with high pressure gas, connected through the valve to a mixing chamber of approximately constant cross-sectional area of about three times the mean valve area. The exit throat of the generator is connected by a horn to a test chamber of much greater cross-section, about 25 times for the generator performance tests and about 700 times for the endurance tests.

The performance of the transducer had not been tested under pressurised conditions and the existing theoretical analysis was inadequate for the proposed operating conditions. It was therefore postulated in Reference 1 that:

$$U_4 = \bar{V}_4 \, M \, E \sin \omega t$$

where U_4 is the oscillating component of the gas velocity at the transducer throat

$\bar{V}_4$ is the mean gas velocity at the throat

$M \sin \omega t$ is the modulation or the oscillating component of valve flow area relative to the mean flow area

E is the overall efficiency of the process.

This will be converted into an oscillating pressure at the horn entry of:

$$p_4 = \rho_4 \, c_4 \, R \, \bar{V}_4 \, ME \sin \omega t$$

where R is the relative throat resistance of the horn

ρ_4 is the local gas density

c_4 is the local velocity of sound

To predict the sound output it is necessary to know R, M and E as functions of the frequency.

3. HORN PERFORANCE

It can be shown (e.g. see Ref 1) that the value of R falls to a very low value for frequencies below the "cut off frequency" given by the value of

$$\frac{c}{4\pi} \frac{\frac{\partial S}{\partial x}}{S}$$

at x = 0, the entry to the horn

where S is the horn cross-sectional area.

It is necessary to ensure that this is kept much lower than the lowest frequency that the horn is required to transmit. Above the "cut off frequency" the value of R will fluctuate around 1 with decreasing amplitude as the frequency increases. The fluctuations will be larger for an exponential horn, but for a given ratio of exit to throat area, an exponential horn is very much shorter than a conical horn. It is shown in Ref 1 that a conical horn is preferable for the generator performance tests, where the area ratio is small and relatively long horn can be used, because the output fluctuations are less. However, for a larger test chamber, an exponential horn is essential to give substantial output within practical length restrictions. The practical approximation, consisting of three concical horns in series, is shown in Fig 2. At all the higher frequencies, the value of R in both arrangements is close to 1.

4. VALVE MODULATION

The relationship between the fractional modulation, M, of the noise generator valve and the RMS value of the current applied to the coil at various frequencies was deduced from the variation of the overall flow resistance and from dynamic measurements. The two values deduced for the current required to give full modulation were in good agreement and significantly less than quoted by the manufacturers. However, when a replacement valve was fitted, it was found to have a different characteristic, showing that it is specific to a particular valve. The tests of the variation of flow resistance showed of one design defect. The valve is not balanced, that is the ends of the moving section are not subjected to the same pressure when there is a gas flow and it takes up a different mean position, not the half open position, for different flow conditions. This could lead to instabilities. The addition of a second row of slots to the sleeve would eliminate this.

5. EFFICIENCY OF FLOW MODULATION

Performance tests were carried out to determine the efficiency E, of the flow modulation process. The noise generator was connected by a conical horn to a test chamber 0.2 m diameter, 2.4 m long, with steel wool absorber at the end. The required flow of either air or carbon dioxide was provided by a compressor with aftercooler and filters. The modulating current was set to 1 amp at a frequency of 100 Hz generated by the automatic frequency sweep of a frequency analyser. The frequency was then raised steadily to 1100 Hz over 180 seconds whilst the current was maintained at 1 amp manually. This was repeated for higher values of current. Typical output spectra are shown in Fig 3. Some of the resonances shown arise from the reflections from the change of section at the end of the horn and imperfect absorption at the end of the vessel. With a poor termination, very large fluctuations in output were obtained (Fig 4). Knowing the gas properties, the flow rate, M from current and frequency, R from the horn theory, it is possible to calculate E from the noise levels measured near the horn exit and in the test chamber.

It was concluded that, for a wide range of modulating currents, frequencies and gas densities, E is approximately 0.2 This is only about a quarter of the value claimed by the makers.

6. ENDURANCE TESTING RIG

A large volume high intensity noise rig was built with a test chamber 0.9 diameter by 3 m long [2]. (Fig 2) The noise generator was coupled to the chamber by a three stage conical horn approximation to an exponential horn. A mean sound level of about 155 dB was achieved, in good agreement with the performance predicted from the measurements made with small test chamber.

7. CONCLUSIONS

The use of an electromagnetic transducer to generate high intensity noise in high pressure gas has been investigated theoretically and experimentally.

The mean gas flow through the transducer is subsonic with high density gas and the valve is assumed to modulate this flow. Theoretical consideration of the conversion of this modulated flow to noise in a test chamber by a connecting horn show that, for a small cross-section area test chamber, a conical horn is preferable, but for a large cross-section area test chamber an exponential horn is essential.

Performance tests in a small diameter chamber show that the efficiency of the modulation process is about 0.2, a quarter of the efficiency claimed by the manufacturer. As designed, the valve is unbalanced and this can lead to unstable operation.

A large test chamber, designed on the basis of the theory and performance tests, operated satisfactorily.

8. REFERENCES

1. RAPIER, A.C. and PARKIN, M.W. Generation of High intensity noise in high pressure gas ND-R-672(W)

2. PARKIN, M.W. The Windscale high intensity noise rig. TRG Report 2224 (W)

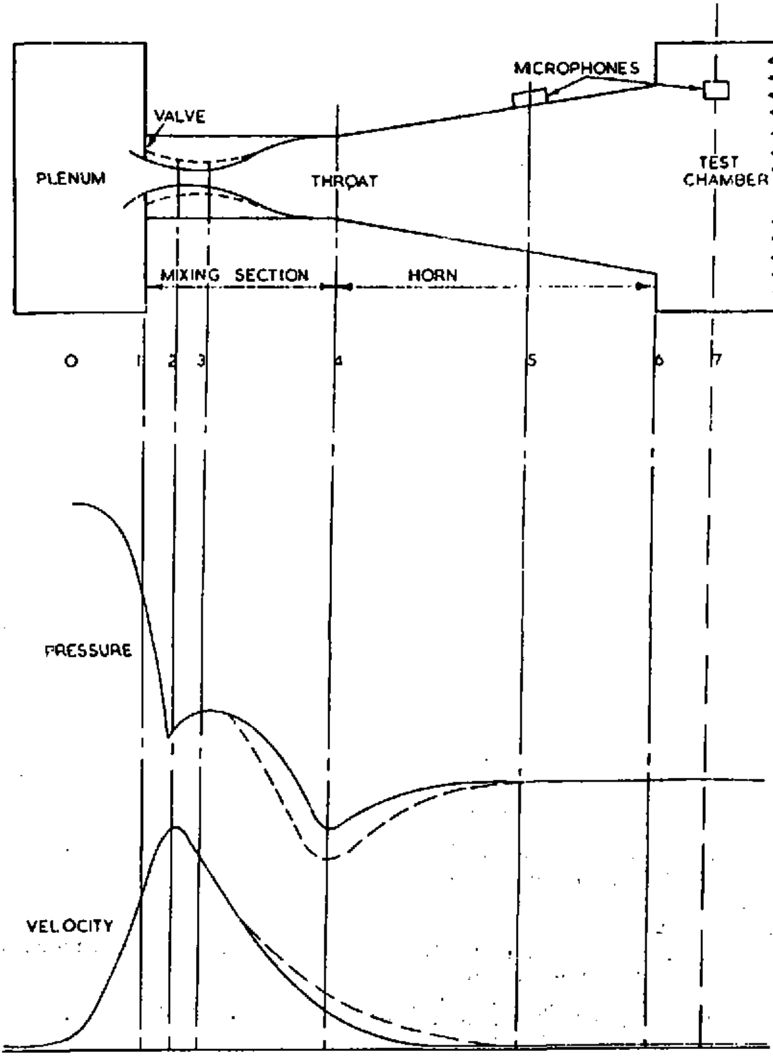

FIG 1 FLOW IN NOISE GENERATOR

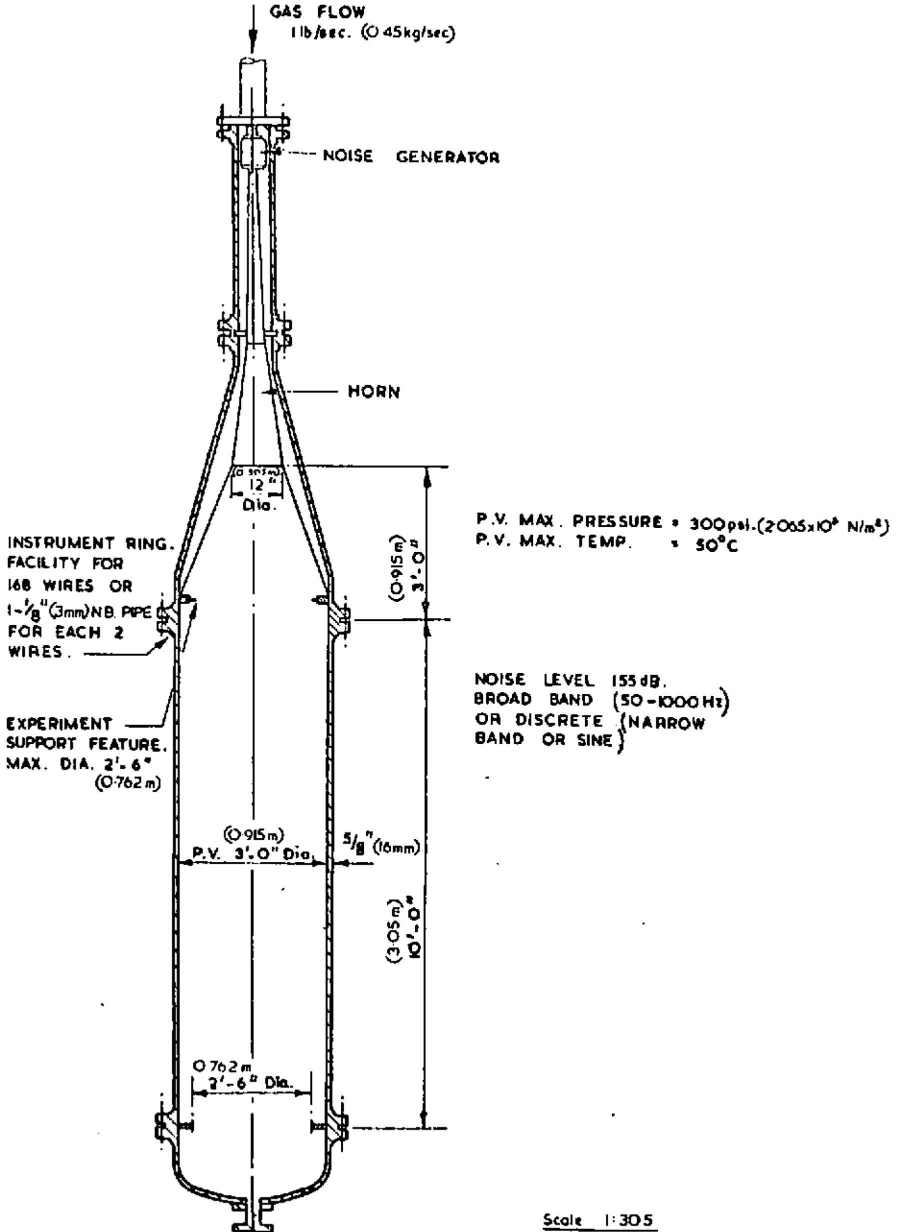

FIG2. ACOUSTIC TEST FACILITY AT WINDSCALE R.D.L.

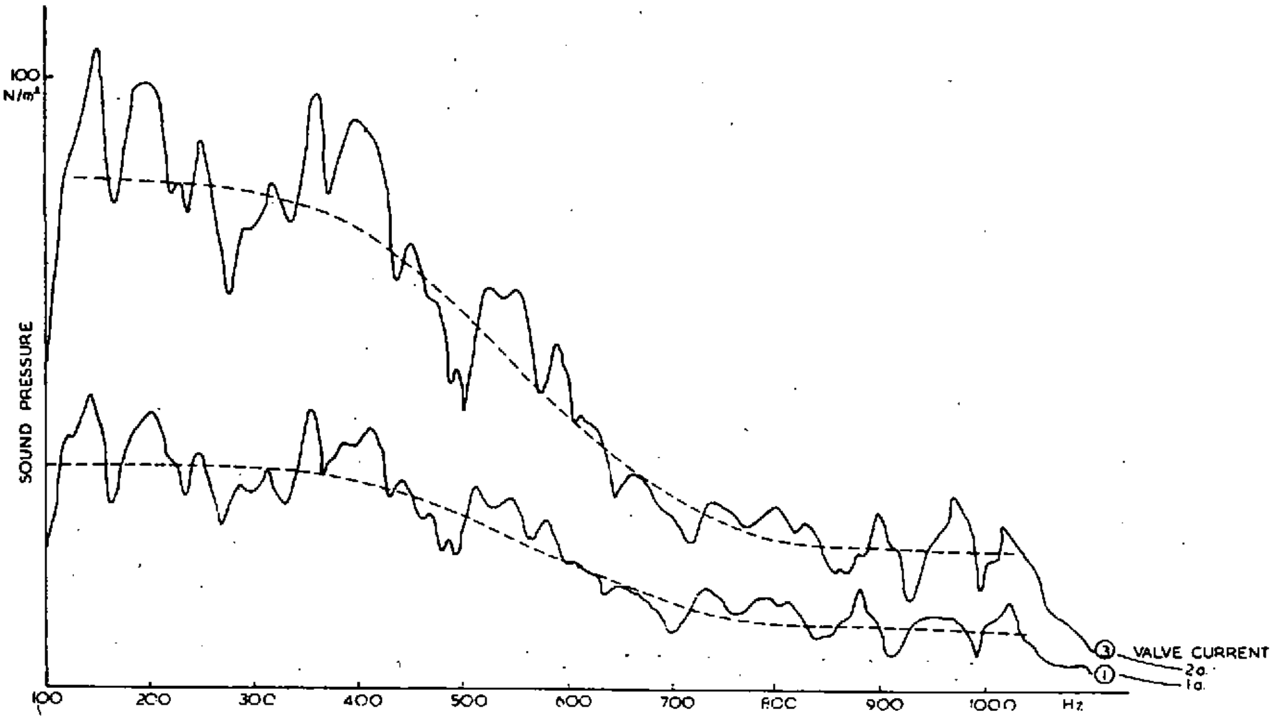

FIG. 3 TYPICAL OUTPUT SPECTRA

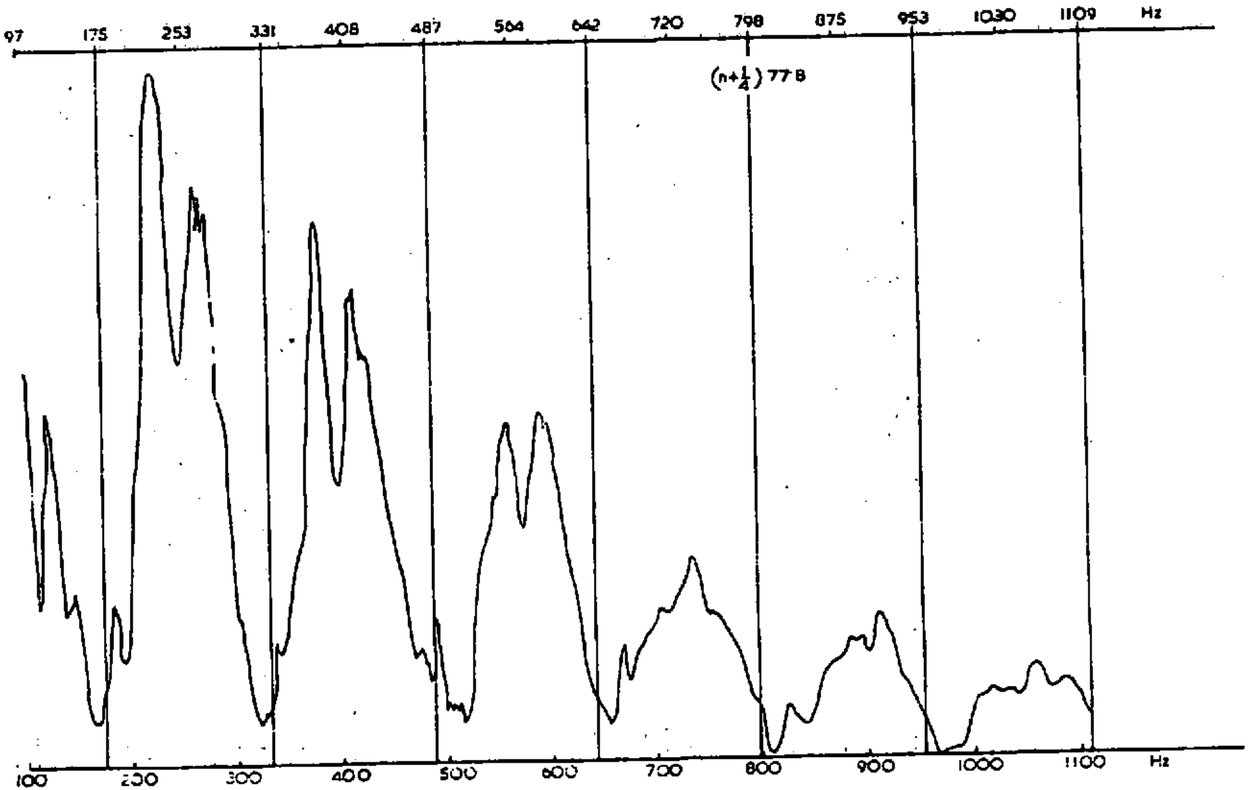

FIG 4 OUTPUT SPECTRUM FOR POOR HORN TERMINATION