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# DESIGN AND TEST CONSIDERATIONS IN THE OPERATION OF A LARGE HIGH INTENSITY ACOUSTIC REVERBERATION CHAMBER

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## 1. ABSTRACT

The provision of a large high intensity acoustic reverberation chamber requires that a considerable number of potentially conflicting design and test requirements are met. Design considerations include its size, location, safety, services required, access, ability to handle specimens, as well as optimising noise in the chamber while minimising undesirable noise and vibration elsewhere. Test considerations include how specified noise spectra can be produced, how to monitor noise in the chamber and the response of items exposed to the noise. Examples of the diversity of tests made in such a chamber are given with indications of the problems which have been overcome.

## 2. INTRODUCTION

In 1963, two of the six large $CO_2$ circulators, being commissioned at Hinkley Point Nuclear Power Station, had fatigue failures (see FIG.1). Details of the investigations which followed were reported by Rizk and Seymour [1] and it was concluded that the primary cause was acoustic excitation beyond the capability of some components.

As a result, the high intensity acoustic reverberation chamber at Whetstone was subsequently built (see FIG.2) and used for acoustic fatigue tests on specimens which reproduced essential design features involved in the circulator failures. The plates used for these tests incorporated welds and were hung just inside the mouth of the one exponential acoustic horn, then available, where they were exposed to pure tone noise (see FIG.3). The plates were 32 cm square and .64 cm thick over the central region which was fillet welded to a 5 cm wide by 5 cm thick rim, giving a resonant frequency of 609 to 630 Hz which was close to the blade passing frequency of the circulators. Data relating noise, stress and life was thus produced (see FIG.4) and reported by Yeh [2].

Increasing emphasis was made towards broad band noise excitation which was also important with the circulator failures and this has been the basis of most of the tests which have subsequently been made in the chamber.

From an original usage of one electro-pneumatic transducer with an acoustic output of 4000 W to one horn, the chamber was later uprated to be used, either with a number of similar transducers on up to four horns, or, just one large transducer producing an acoustic output just in excess of the others combined.

Some high intensity acoustic chambers can offer features such as a flow medium other than air, operation at high or low temperatures and mechanical excitation using hydraulic actuators to operate at frequencies below 100 Hz. Despite not having many of these features the Whetstone facility may still be considered to be typical in concept.

## 3. TYPICAL FACILITY

### 3.1 CHAMBER, HORNS AND LIGHTING

The acoustic reverberation chamber at the Engineering Research Centre, Whetstone, England is pentagon in shape, its sides are of length between 3 and 4.5 m, and it has an inclined roof giving a minimum height of 3.6 m and a maximum height of 4.8 m.

The weight of each test specimen can be shared between three monorails just below the lower roof level and an 'A' frame. The combined lifting capacity is 8t. A flexible suspension would be required, between the lifting points in the chamber and the test specimen, in order to avoid transmitting undesirable mechanical vibration. Alternatively, the test specimen can rest on a set of Metalastik isolation mounts.

At one end of the chamber there are two sets of sound-proofing doors in line with each other which allow access up to 3 m wide and 3.6 m high. All the doors are filled with sand in order to attenuate sound levels to the reception area. The inner set of doors swing open while the larger outer door slides open. With all the doors closed, the effective volume of the chamber is 93.4 $m^3$ but this can be increased by 50 per cent by leaving the inner doors open and using the additional exposed volume to the outer door.

A total of four acoustic horns are let into two adjacent walls at one end of the chamber. A 4.3 m long hybrid exponential horn 2.4 m square at its mouth occupies most of one wall and has a cut-off frequency about 25 Hz. The other horns are all exponential and attached to the adjacent wall. Two of these horns have an exponential section 1.8 m long, are 1.22 m square at the mouth and have a cut-off frequency of 50 Hz: the third has an exponential section 1.22 m long, is 1.8 m by 0.61 m at its mouth and has a cut-off frequency of 86 Hz.

The life of lightweight fluorescent light fixtures for operation in the chamber is relatively short and it has been found that fixtures, where the lamp is enclosed by heavy metal housings at the ends and elsewhere by glass, have had no problem of survival. Such fixtures were formerly in use for underwater applications.

### 3.2 NOISE SOURCES

Electro-pneumatic transducers produce high intensity acoustic energy using air which, after being modulated, can then pass via a transition section, encased in a box section filled with sand, and, in the case of the 86 Hz horn, a progressive wave tube, to the horn and chamber.

The two types of transducer used at the facility are the Ling Electronics Limited Model EPT-94B and the Wyle Laboratories Model WAS 3000 air stream modulator. Operated at gauge pressures of up to 2.76 bar, the respective maximum acoustic outputs for the transducers are 4000 and 30000 W, with air flow rates of 0.26 and 1.73 kg/s.

Modulation, in the transducer, is achieved by allowing the air to pass through two sets of slots, one set being stationary, the other moving as a result of the electrical input signal to a moving voice coil. Power amplifiers with outputs up to 600 VA are used to amplify the signals. To protect the coil, pressure switches cause the power supply to the transducers to trip if there is insufficient flow of air to cool the coil and displacement clippers help avoid overtravel.

The two main signal waveforms used are sinusoidal and random. For random excitation, filters are used to shape the frequency spectrum to the required specification. Where several transducers are involved, it is possible to group these so that each filter arrangement can concentrate its control over part of the frequency spectrum.

Supplementing the electro-pneumatic transducers at frequencies below 50 Hz and above 700 Hz are two noise boosters. For low frequencies, vortex noise generation is used. For high frequencies, noise levels can be increased by a series of organ pipes, which together cover the 8 kHz octave band.

### 3.3 COMPRESSED AIR SUPPLY

Air to generate the noise is normally supplied by two motor driven, two stage compressors, each delivering up to 1.16 kg/s. The compressors were built by J. Browett Lindley (1931) Ltd. at their Coburn Works, Letchworth, England and were installed, together with air receivers and inlet governors, etc., for Power Jets Ltd in 1942, for work on the development and testing of jet engines. The induction motors used with the compressors were made by

Metropolitan Vickers and, as each is rated at 400 hp, it requires a total of nearly 600 kW to run both compressors.

When major compressor repairs are to be made, or, if many hours of mainly unattended endurance testing are required, it is necessary to examine the available options. These include decisions on whether the air supplied by the compressor has to be oil free, whether to purchase or hire the compressors, whether to choose such as diesel compressors with the additional cost of fuel and labour costs for replenishing the fuel or use electric compressors with the additional costs of the supply of electricity.

In any case, the compressed air is piped several hundred feet to the horn room of the test facility, where the appropriate valves and air filters allow the air to pass, as required, to the transducers.

### 3.4 NOISE ATTENUATION AND VIBRATION ISOLATION

To reduce the noise levels outside the facility to an acceptable level, the air, exhausting from the chamber, passes through four 0.15 m diameter pipes, each of which is connected to a series of expansion chambers, then finally via two ducts, in which the air passes over perforated metal sheet, behind which lies packed mineral wool.

To isolate the adjacent ground from vibration produced in the chamber, the inner and outer walls, the floor, roof and lifting beams are all supported on a rubber carpet. The control room is completely separate.

### 3.5 NOISE LEVELS

In the reverberation chamber there is diffuse field sound. Maximum noise levels in the chamber can be achieved either by using the WAS 3000 transducer attached to the hybrid exponential horn or, for approximately the same rate of air flow, seven of the EPT-94B transducers. Four of the latter transducers would be attached to the hybrid exponential horn or to a horn with 50 Hz cut-off frequency, the other three similar transducers being attached in line with the horn with 86 Hz cut-off frequency. The maximum overall spatial average sound pressure level (SPL-referred to $2x10^{-5}$ $N/m^2$) which can be achieved in the chamber, by either transducer system, is 162 dB. In the chamber,immediately in front of the horns, levels of up to 165 dB can be achieved.

Running only the three transducers in line with the progressive wave tube allows specimens up to 0.53 m by 1.06 m to be subjected to grazing incidence noise at sound pressure levels of up to 170 dB.

## 3.6 SAFETY PRECAUTIONS

Safety arrangements include isolating push buttons in the chamber, key access to all hazard areas in the facility and, in the control room, key operation of the air control valve to the facility and an isolating toggle switch controlling the electrical circuit to the power amplifiers.

## 3.7 MONITORING, RECORDING AND ANALYSIS EQUIPMENT

Noise, vibration and stress are the three major measurements, which have been required for tests, at the Whetstone test facility. Apart from the noise, the degree to which the other two are required depends on the investigation or test.

Although new instrumentation has become available over the years, microphones can still be used to measure the noise, with accelerometers and strain gauges attached to the test specimen, in the required directions, to measure the corresponding vibration and stress response. Most of these require suitable amplifiers and analysers, with the means available for permanent signal capture in parallel or series. Items such as 14 channel FM tape recorders have fulfilled the latter role for many years but other data acquisition systems, which use computer disc storage, are taking their place.

The noise levels for high intensity tests has meant the use of ¼ inch Bruel and Kjaer condenser microphones at Whetstone. In the chamber, either several microphones can be placed around the test specimen or a single microphone on a rotating boom can be used, both methods allowing a spatial average to be obtained.

Calibration of each microphone circuit is done at a suitable amplifier gain setting against a standard calibrated noise level, such as a Bruel and Kjaer pistonphone. Test noise levels at other gain settings are then obtained by scaling.

Fast Fourier Transform analysers have been used for many years to handle the test signals and produce output in the form required. For noise, these include one third octave band and octave band analysis. For vibration, power spectral density is extensively used.

## 4. TYPICAL ACOUSTIC TESTS AT WHETSTONE

High intensity tests which have been made in the chamber include:

(a) insulation for nuclear power stations,

(b) missiles, stores, dispensers and weapons for high speed flight simulation

and (c) for space satellites, Skynet 2, carbon fibre honeycombe panels for SpaceLab, a gaiter assembly for Ariane, an X-ray imaging telescope for SpaceLab 2, transistorised power amplifiers for Marecs and various antennae for Intelsat 5 and Skynet 4.

FIG.5 shows a group of absorber pads attached to one side of the progressive wave tube for an acoustic endurance test.

Examples of tests in the chamber are given in 4.1 and 4.2, analysis of vibration in both cases being made in power spectral density ($g^2$/Hz).

### 4.1 SPACE TELESCOPE

In 1984, an acoustic test was carried out, for the Department of Space Research at the University of Birmingham. The telescope equipment tested (see FIG.6a), known as Experiment 7, was later to be used for X-Ray imaging of galaxies in space and formed part of the Spacelab Mission 2 due for launch on the American Space Shuttle in 1985.

The first step was to establish the control parameters for the noise with an empty chamber, then the equipment was moved into position in the chamber, fitted with its thermal blanket and supported on Metalastik isolation pads at three hard points on its rigid base (see FIG.6b). It was then exposed to the simulation of the noise levels which it would receive as the space shuttle was launched. The duration of the test was a total of 80 seconds. Analysis of the noise was in one third octave bands from 20 Hz to 10 kHz (see FIG.6c).

### 4.2 SKYNET 4 ANTENNA

Also in 1984 an acoustic test was carried out for Marconi Defence Systems on a Skynet 4 Spot Beam antenna.

In this case, the control parameters for the noise were established using a representative substitute for the real test item. The test item was then suspended on bungees (see FIG.7a) and tested for a duration of about 30 seconds. Analysis of the noise was made in both one third octave bands from 25 Hz to 10 kHz and in octave bands (see FIG.7b) from 31.5 Hz to 8 kHz.

## 5. ACKNOWLEDGEMENTS

The author wishes to acknowledge the contributions of all colleagues who have been involved in tests at the Engineering Research Centre test facility. Also the European Gas Turbine Company for permission to publish this paper.

## 6. REFERENCES

[1] W. Rizk and D.F. Seymour, 'Investigation into the failure of gas circulator and circuit components at Hinkley Point Nuclear Power Station', Proc., Inst. Mech. Eng., London, 179, Part 1 (21) (1965) 627-673.

[2] L. Yeh, 'High intensity acoustic testing to determine structural fatigue life and to improve reliability in nuclear reactor and aerospace structures', Materials Science and Engineering, 48 (1981) 167-179.

FIG. 1 ACOUSTIC FATIGUE FAILURE OF A CIRCULATOR

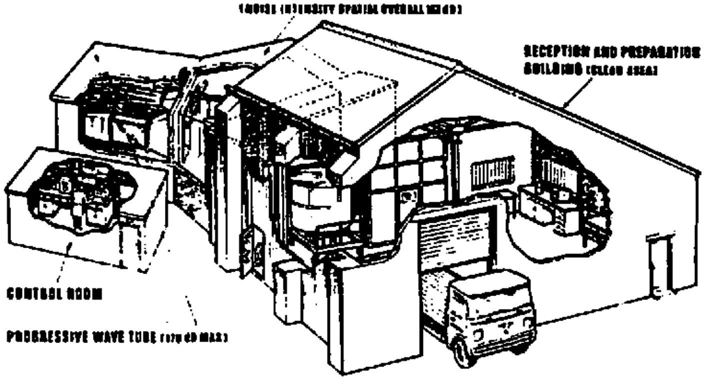



FIG.2 HIGH INTENSITY ACOUSTIC TESTING FACILITY

ENGINEERING RESEARCH CENTRE, WHETSTONE, LEICESTER

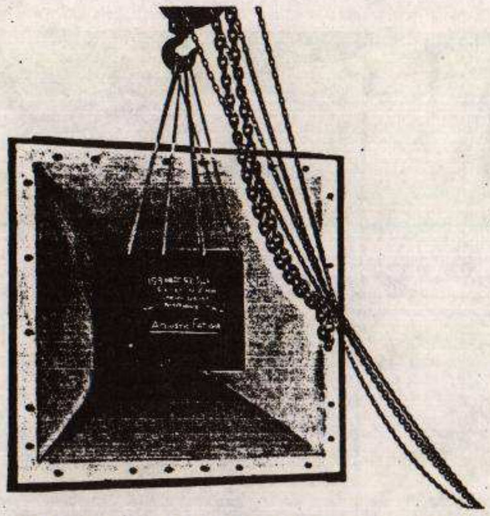


FIG. 3 ACOUSTIC FATIGUE TEST OF FILLET WELDS IN HORN MOUTH

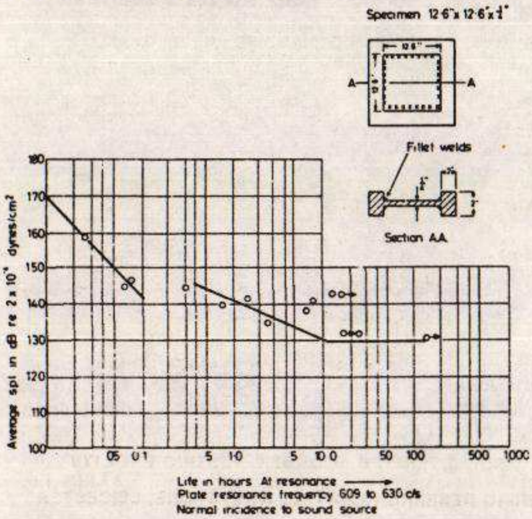



FIG.4 ACOUSTIC FATIGUE RESULTS OF FILLET WELDS DUE TO PURE TONE EXCITATION

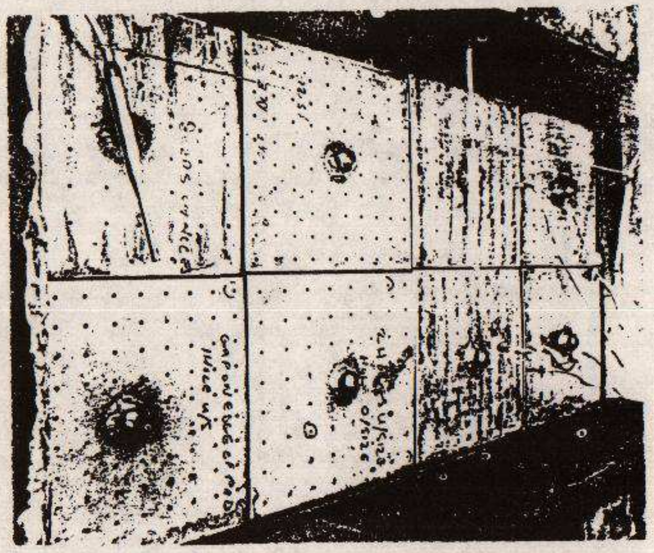
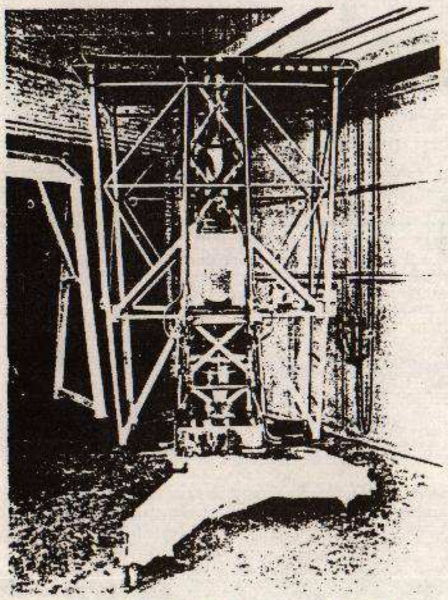
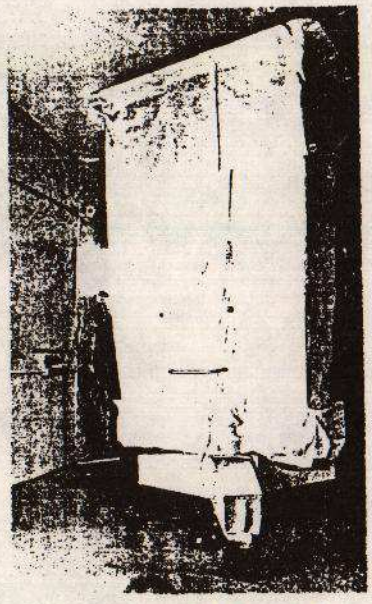


FIG.5 ABSORBER PADS IN PROGRESSIVE WAVE TUBE

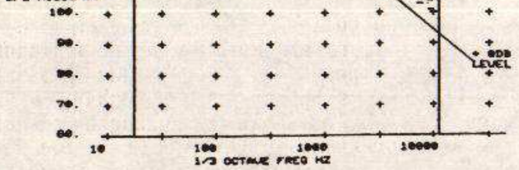
CONSIDERATIONS OF ACOUSTIC REVERBERATION CHAMBER



6a) WITHOUT THERMAL BLANKET

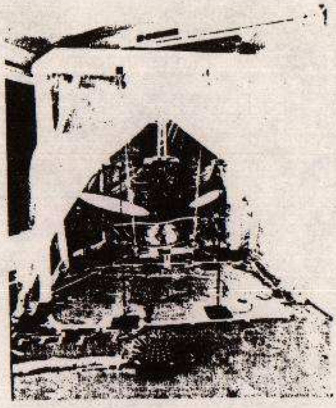


6b) WITH THERMAL BLANKET

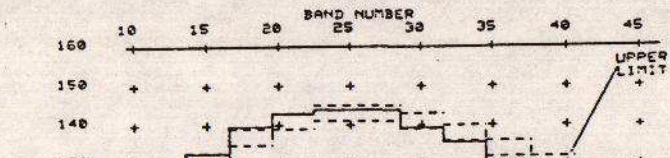



6c) ONE THIRD OCTANE BAND NOISE SPECTRUM SPL 141.5dB OVERALL

FIG. 6 SPACE TELESCOPE FOR X-RAY IMAGING FOR UNIVERSITY OF BIRMINGHAM



7a) TEST ARRANGEMENT




7b) OCTAVE BAND NOISE SPECTRUM - SPL 149.7dB OVERALL

FIG. 7 SPOT BEAM ANTENNA FOR MARCONI DEFENCE SYSTEMS