Proceedings of The Institute of Acoustics

CHARACTERISATION AND SCALE MODELLING OF INDUSTRIAL NOISE SOURCES

M. HODGSON

I.S.V.R., UNIVERSITY OF SOUTHAMPTON

1. Introduction

Preparatory to scale modelling, the radiation of sound from industrial noise sources must be characterised and these characteristics measured. This having been done, sound sources can be developed which have the same (scaled) radiation characteristics. This paper discusses the characterisation and measurement of industrial sources. Specific reference is made to measurements made in a factory. Progress in the development of ultrasonic sound sources using crossing air-jets for use in the model factory built at the University of Cambridge |1| is reported. Clearly the sources must fit the planned use of the model. It should be kept in mind that in factories we are interested in the overall sound level distribution and in the levels at operator positions.

2. Characterisation of Industrial Sources

The sources of noise found in typical industrial environments are usually varied and complex. In general the radiation characteristics of an industrial source can be described by its spectrum, sound power output and the source distribution. Whether industrial sources can be grouped according to these characteristics is being investigated and will be discussed in the spoken paper.

The total output level of a source is normally described by its sound power level (PWL). Spectral information is obtained by measuring this in 1/3 or 1/1 octave bands. A dBA sound power level is often also used, as it relates to the subjective effect of the noise. Industrial noise usually is restricted to below 8 kHz but extends over the complete audio range if compressed air sources are present. The level and spectrum of noise in factories clearly are relevant to hearing damage and choice of noise reduction treatments.

By source distribution is meant the size of the source (relative to wavelength), its shape (compact, extended) as well as the degree of coherence between radiating regions of the source. A unit being treated as one source for the purpose of modelling may, in fact, consist of several coherent or incoherent sources. The source distribution determines the near and far-field radiation characteristics of the source. Near-field effects are important regarding levels at operator positions near the machines since large near-field pressures can occur which do not radiate into the far field. They also determine the rate of decay of pressure in the near field. Thus a knowledge of the extent of the near field is of importance. As near-field effects are often complex, not well understood and difficult to measure, they have not yet been considered in modelling. The far-field radiation from a source is best described by its directivity, the directional variation of the sound intensity radiated in free-field conditions. The directivity of a source in a factory enclosure is probably not important to overall sound levels but it can be of considerable importance to operator levels as well as to the effectiveness of local screening and absorbent treatments. The vertical-plane directivity of an industrial source is of interest since the roof is usually the main absorbing surface in a factory.

3. Measurement of Industrial Noise

For modelling it is necessary to know the free-field radiation characteristics of the source. However it is normally impossible to remove industrial sources to a free field environment and measurement must be made *in situ*. The source is usually in an enclosure, mounted on a hard reflecting plane (the floor) and often near walls, other machines or other scattering objects. Further, it is often impossible to operate the source on its own, so there is a high background noise level.

Sound power and directivity determination is based on measurement of the pressure or intensity at positions on a survey surface surrounding the source. According to the survey method or two-surface method, which relies on the surface's being in the far field, the pressure measured at the survey positions is averaged and the sound power determined from $PWL = \overline{SPL} + 10 \log S$ where $\overline{SPL}$ is the average surface sound pressure level and S the survey surface area. Under further assumptions, if the type of field in the enclosure (semi-anechoic, constant drop-rate) is known, a correction can be applied to obtain an approximate free-field sound power. Correction must also be made for background noise. Also, the presence of reflecting objects near the survey position will alter the pressure locally, leading to an incorrect average pressure and, therefore, sound power estimate.

The sound power output can be more accurately determined by measurement of the average normal component of the acoustic intensity over the survey surface. This is done using an intensity meter |2| which measures the time-averaged product of the acoustic pressure and particle velocity at a point. By this method problems due to background noise, the enclosure and nearby surfaces are significantly reduced.

The variation of pressure or intensity over the survey surface should give some estimate of the directivity of the source. However, neither method can accurately measure directivity in the presence of reflecting surfaces since these modify the pressure and intensity distribution over the survey surface.

Survey method estimates of the sound power and directivity of nine machines in a large, flat light bulb factory were made. The 1/3 octave band pressure level variation was from 3-10 dB for different machines, increasing with frequency. The estimated sound power of one machine was approximately 3 dB less using a two-surface method than using a single surface method. A theoretical investigation of the effect of a hard reflecting surface on the measured directivity of a source suggests that the effect is smaller than expected. Further details and comparison with intensity-meter results will be given in the spoken paper.

4. Air-Jet Sound Sources

In order to model the sound field using the 1:16 scale model factory built at Cambridge, one ideally requires a source to model each machine. These must produce continuous sound in the useable frequency range 1.4 kHz-72 kHz (125 Hz-4 kHz 1/3 octave bands at 1:16 scale) ideally with the scaled machine spectrum. High output levels are required since small, insensitive microphones are used in modelling to cover the high frequency range. The sources should be compact so as not to be too large at model scales. However, the sources should also model the scattering properties of the source they model, so it should be possible to surround the source by an appropriately shaped hard object. The sources should ideally have the same directivity as the sources they model. However, as was discussed above, the machine directivity is not accurately known, is relatively small (±5 dB or less 1/3 octave band variation) and is irregular. As a first approximation it was decided to work with omni-directional sources. Source size restrictions and the need for omni-directionality up to 72 kHz ruled out the use of loudspeakers or loudspeaker arrays. Veneklasen |3| found that crossing air-jets produce high levels of high frequency sound and radiate omni-directionally. Such sources were chosen for use in the model.

Investigations with crossing air-jet sources showed that their spectrum peaks in the 40 kHz 1/3 octave. The slope of the spectrum below this frequency increased with line pressure from 5 dB/octave at 5 p.s.i. to 12 dB/octave above 20 p.s.i. and decreased slightly with increasing jet diameter. As the spectrum was not similar to that of the machines being modelled, it was decided to measure in octave bands. This necessitates compensating for the non-flat output spectrum. For a 12 dB/octave slope this is simple to do electronically. The peak 1/3 octave output level was found to increase with line pressure by approximately 11 dB/pressure doubling and increased slightly with larger diameter jets. The jet configuration determines the source directivity. The planar arrangement of Veneklasen was found to give poor response above the jet where there is a strong air flow and thus a sound level reduction due to the cone of silence phenomenon. Two more spherically symmetric configurations (4 tetrahedrally arranged jets and 6 cubically arranged jets) were tested and were both found to give more omni-directional but mutually similar radiation. Since more jets require more air the 4-jet tetrahedral arrangement was chosen. As a trade-off between jet fragility and required air volumes, jets of 1.5 mm inside diameter were used. With the source operating at 20 p.s.i. the optimum spectrum and 1/3 octave levels of from 60-105 dB at 1 meter were obtained. The source was omni-directional to within 5 dB in all 1/3 octave bands. The jet sources were supplied with air from a compressor through a constant-pressure valve allowing continuous steady operation for over 6 minutes.

A 'linear' source was also developed to simulate radiation from the complete production lines found in the Philips factory. The source was required to radiate uniformly and incoherently along its length. A 2 x 3 inch tube with ten 2 mm diameter holes drilled at 20 cm spacing along one face and supplied with compressed air worked well. Suitable spectrum and output levels were obtained. The variation of sound pressure level along the length of the source was 9 dB at 10 cm from the tube, 5 dB at 30 cm and 3 dB at 1 m, approximately independent of frequency.

CHARACTERISATION AND SCALE MODELLING OF INDUSTRIAL NOISE SOURCES

References

1. Orlowski, R. Towards acoustic scale modelling of factories. Paper to be presented at this conference.

2. Fahy, F.J. A technique for measuring sound intensity with a sound level meter. Noise Control Engineering, 9 1977, 155-162.

3. Veneklasen, P.S. Model techniques in architectural acoustics. JASA 47 1970, 419.