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ASSESSING TONAL NOISE FROM INDUSTRIAL SOURCES – SOME COMMENTS AND CASE STUDIES

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1. INTRODUCTION

This paper discusses some experiences gained in assessing mid-frequency tonal noise problems from industrial plant and advising on noise control measures. This paper does not seek to recommend formal assessment procedures or suggest standards or criteria. Indeed there is an argument that many tonal noise problems are in practice resolved informally and a flexible approach is often beneficial rather than rigidly adhering to a formal standard or assessment procedure. Some case studies are cited to illustrate the range of tonal noise problems that may be encountered. Also it is noted that whether or not a tonal noise emission will generate complaints is not just a matter of the frequency spectrum and magnitude of the tone. As with the majority of environmental noise issues, there are many non-acoustic factors involved which are not readily quantifiable.

2. SOURCES AND TYPES OF TONAL NOISE FROM INDUSTRIAL PLANT

There are many potential sources of tonal noise on industrial sites such as fans, pumps, motors, pipework, valves, compressors and generators etc. Some equipment will only generate localised noise. The worst offenders tend to be high velocity fans venting to atmosphere and 'ringing' of pipework particularly when located high up on factory buildings and processing plant installations.

Many papers have been written on the subject of low frequency tones however, in our day to day experience the majority of complaints about tonal noise relate to problems in the mid frequencies typically between 250 Hz to 1 kHz. Also research into the prominence of discrete tones (Ref 1) in terms of Tone-to-Noise Ratio (TNR) and Prominence Ration (PR) indicates that " low frequency tones appear to be less prominent than higher frequency tones of comparable TNR or PR"

A tonal noise emission may be steady and continual. This is usually the easiest type of tonal noise to deal with since it should be straightforward both to measure and resolve. Sometimes a tonal noise may be highly variable in amplitude or frequency or both (e.g. reciprocal machinery operating at variable speeds). Alternatively a tonal noise emission may be very intermittent or even occasional, which may result in difficulties in actually measuring the noise. Finally the tonal noise reported by a complainant may not be measurable at all. Case studies of these different types of tonal noise are described later.

3. MEASURING TONAL NOISE

In many cases the presence of a tonal noise can be confirmed and its source identified with the most readily available monitoring equipment – a pair of ears. From a regulatory point of view, this simple approach may be quite sufficient to enable an Environmental Health Officer, at least on an informal basis, to contact the premises causing the tonal noise to inform them of the problem and to request them to carry out the necessary investigations leading to measures to abate the problem.

However on complex industrial sites, tone matching techniques involving detailed frequency analysis may be necessary in order to trace the source of tonal noise (Ref. 2). Moreover, from a noise abatement view, spectral analysis will be necessary in any event in order to establish the

exact frequency and amplitude of the tone, thereby enabling the design of noise mitigation measures or as an aid to ranking priorities for noise control (Ref.3).

It is possible to use one-third octave frequency analysis for investigating some types of tonal noise emissions. Indeed a fairly basic but useful method of establishing the presence of a tonal component using one third octave analysis is contained in BS 7445 (Ref. 4). However, in many instances narrow band frequency analysis will be required and draft International Standards (Ref. 5) and national standards in some European countries (Ref. 6) appear to be heading down the route of requiring 'tonality' to be assessed only by narrow band frequency analysis.

In days gone by narrow band frequency analysis necessitated making calibrated tape recording of noise levels measured close to various items of plant on the site and then analysing the recordings back in the office using large filter networks. In more recent times the use of DAT recorders replaced the use of reel to reel tape recorders. This technique may still have its place (Ref. 3) in certain circumstances but is somewhat old fashioned. Today, modern instrumentation enables quick, simple frequency analysis to be carried out on the spot. Third octave and narrow-band spectral analysis in real time can now be carried out using hand-held instruments. This makes investigating tonal noise on industrial plant considerably easier.

4. CASE STUDIES

4.1 Case 1 - Steady Continuous Tonal Noise

We commissioned to assist with tracing and attenuating a tonal noise problem at a large industrial processing factory. The factory operates 24 hours a day, seven days a week. Between the factory and a housing estate which overlooks the site is a busy coast road and railway line, but at night the background noise climate is lower and it was found that a tone was clearly discernible outside the houses. However when walking around the processing plant area at the factory, it was not possible to hear the tone due to the masking effect of a myriad other plant noise sources nearby.

In order to trace the source of the noise, the approach adopted was to determine the frequency of the tone at the housing site by narrow band analysis, and then to repeat the narrow band analysis at various locations on the industrial site.

Outside the houses, the noise from the factory was characterised by a constant, and fairly broadband, background noise over which was superimposed a continual intrusive mid-frequency tone. Narrow band frequency analysis at 12Hz bandwidth enabled this tonal element to be identified at a frequency of 487 Hz.

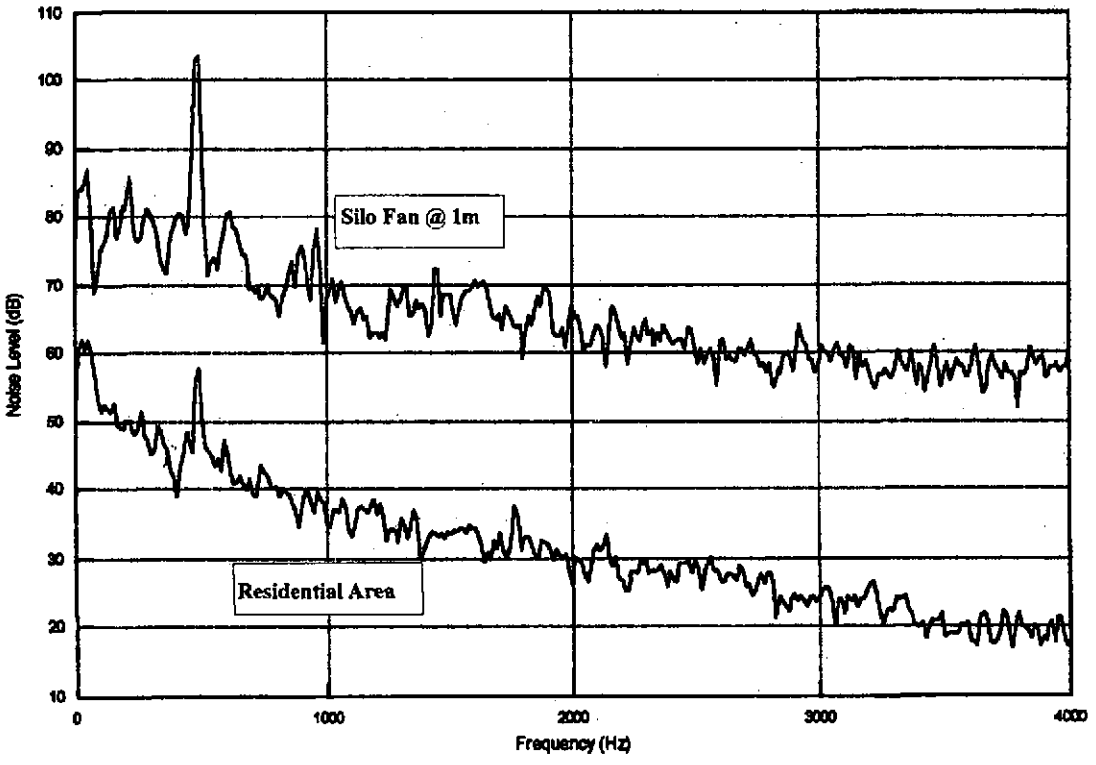
During the on-site noise survey the 487 Hz tone was picked up successfully in the south-western area of the plant. Following further investigation higher up the plant the source of the tone was found to be not the main processing plant buildings and associated maze of external fans, scrubbers, ductwork and piping, but the top of some very high storage silos - an area rarely visited by factory personnel. Each silo had a small exhaust fan on top and it was these fans that were generating the 487 Hz tone. Each fan unit was found to be emitting the tone at the same intensity.

The measured frequency spectrum at a distance of one metre from one of the silo fans, together with the spectrum measured at the nearest residential area, is shown in Fig. 1. The correlation of the peak at 487 Hz can clearly be seen. Displaced air from each of the silos is exhausted via a paddle blade fan located on top of the silo. There is a clear line of sight between the top of the silos and the residential area. The primary source of noise emission was found to be a gap between the fan outlet and the cowl of the ducting above. This gap enabled the exhaust noise from the fan to radiate freely into atmosphere. The net result is that there were five high intensity noise sources

located in an elevated position with no acoustic screening between the silos and the nearest residential area.

Once the source had been identified the tone was resolved by fitting appropriate silencers to the fan exhausts. During a follow-up survey it was found that the noise level on top of the silos had been adequately reduced.

Fig. 1: Narrow Band Spectra Measured Close to Fan and Outside Houses



In this example the use of narrow band frequency analysis was essential to enable us to trace the source of the tonal noise fairly quickly and conclusively.

4.2 Case 2 - Varying Tonal Noise

Hepworth Acoustics were commissioned by an aluminium extrusions factory to identify a source of a tonal noise emission from their factory and to advise on appropriate noise control measures. The Environmental Health Officer had investigated complaints from three local residents and had found that their complaints were justified. The EHO had contacted the factory requesting that steps were taken to resolve the problem.

The factory was part of a large industrial estate and was over 400 metres from the complainants' houses. However the EHO had identified the aluminium extrusions factory, and in particular a chimney at roof level, as the possible cause of the problem. The duct from the chimney was from a furnace fan inside the factory. The fan was understood to be a paddle blade fan but details on the number of blades and operating speed were sketchy. Furthermore the EHO reported that the tone varied over short time periods from being clearly audible and intrusive to being inaudible even in

stable wind conditions. Consequently the EHO stated that a BS 4142 type assessment might conclude that the noise was not excessive.

It was decided that further investigation was necessary to identify the source of the noise beyond all doubt and to determine the magnitude of sound reduction required to resolve the problem.

We arranged for a lifting platform to be hired by the factory so that we could measure noise levels actually on the roof close to the stack outlet. Narrow band frequency analysis was carried out. A distinct tone was measured at 270 Hz. However the magnitude of the tone was variable and reduced dramatically while we were there. This was found to be due to the effect of an automatic damping mechanism in the system.

In addition one-third octave band and narrow band frequency analysis was carried out late at night outside the house of one of the complainants in suitable weather conditions. Noise levels were measured with the fan on and with the hot jet exhaust fan switched off. With the fan on the 270 Hz tone was present although it varied by over 10 dB over very short time periods. The highest peaks @ 270 Hz measured are shown in Fig. 2 and Fig. 3.

It was then straightforward to specify an appropriate attenuator performance in order to resolve the problem. A follow-up test was carried out outside the houses and it was found that the silencer had eradicated the 270 Hz tone completely.

The tone was clearly intrusive and it is perhaps remarkable that so few residents had complained. It should be noted in this case that there was no need to carry out a BS 4142 assessment. Also, even though the magnitude of the tone varied, common sense dictated that the assessment should be based on the highest magnitude measured. It should also be noted that as the tone was so prominent, 1/3 octave analysis would have been quite adequate for assessment and noise control purposes.

Fig. 2: Noise Spectra Measured at Residential Location: 1/3 Octave

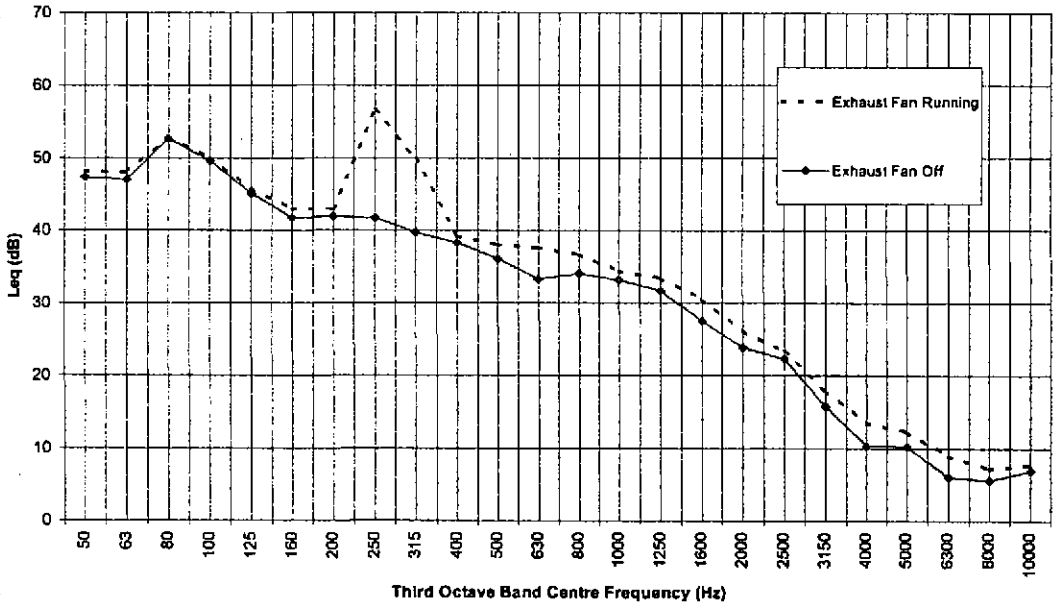
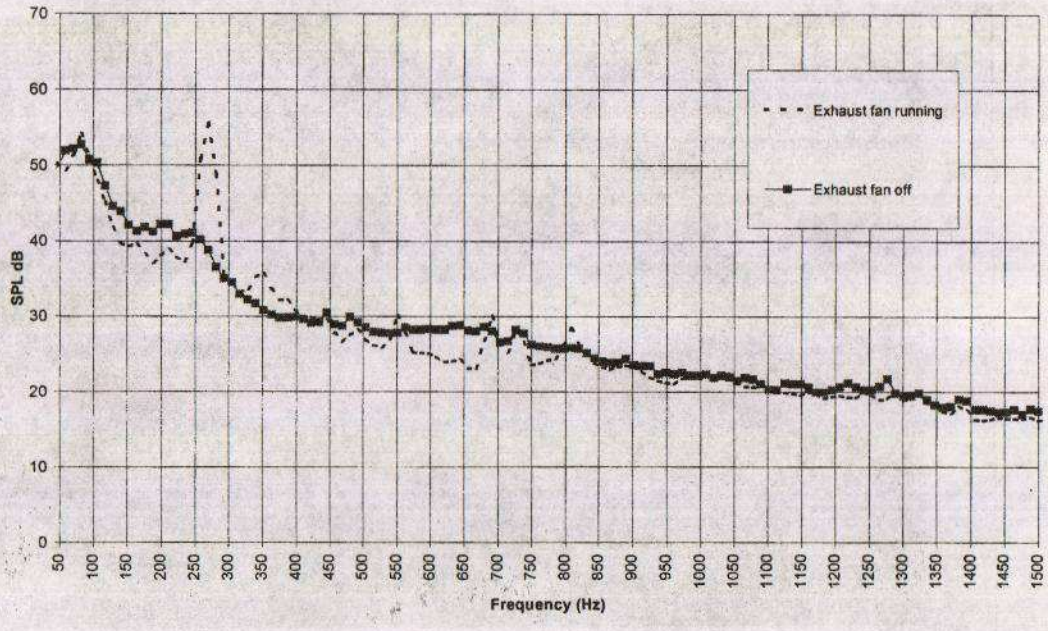


Fig. 3: Noise Spectra Measured at Residential Location: Narrow Band (12Hz)



4.3 Case 3 – Occasional Tonal Noise

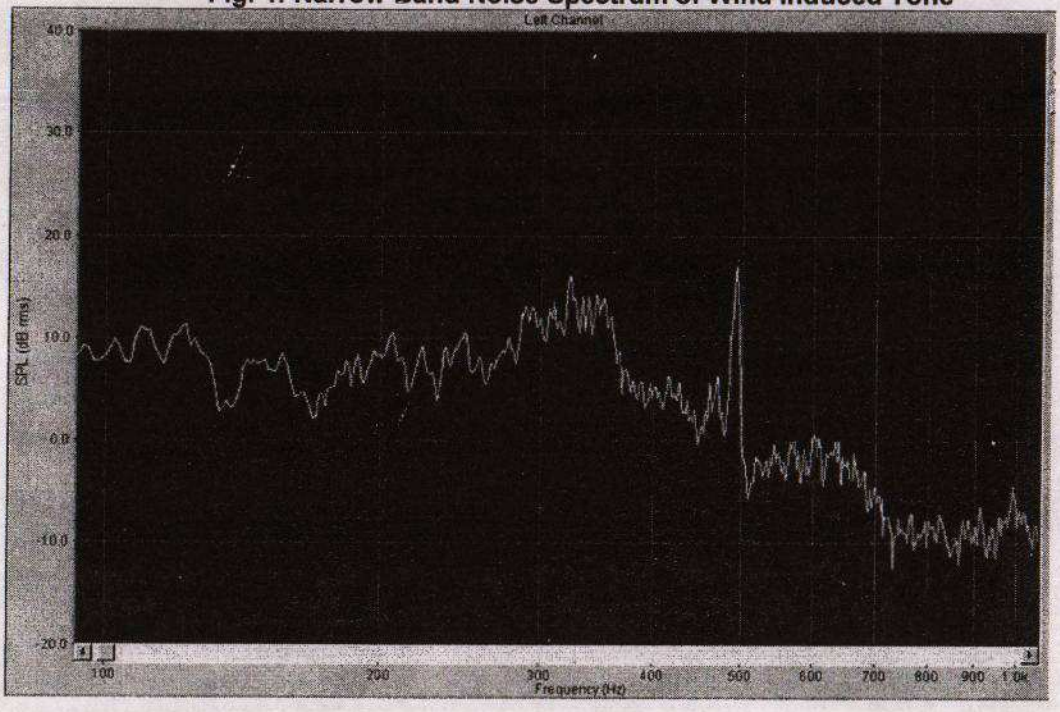
One of the more unusual cases we have been asked to investigate involved complaints associated with an alleged noise nuisance produced by a 100ft tall telecommunications mast. The mast is located on a coastal hillside in North Wales and, according to the complainants, was producing an intermittent intrusive tonal noise when the wind was blowing at a certain force and was from a particular direction. Furthermore the noise was alleged to have only begun following installation of four vertical rod antennae close to the top of the mast.

Although local Environmental Health Officers had been called out to witness the noise on several occasions they had only been able to confirm its presence briefly during one visit when suitable wind conditions persisted over several hours. Consequently the Council had not served an abatement notice but had requested that further investigations be carried out to locate the source of the noise.

Therefore, in order to try to capture a sample of the tonal noise we installed a DAT based recording system inside the nearest dwelling and instructed the occupant on how to operate it. The equipment was left in the dwelling for one month and a number of visits were made during this time in order to check its operation, and to hopefully witness the noise first hand. Relatively strong winds occurred during one of these visits winds and a faint tone could be tone could be heard from the direction of the tower although the exact location of its source could not be established.

Following narrowband frequency analyses of the recordings it was found that only two five minute recordings had been made which exhibited a strong tonal component at 490Hz. (see Fig. 4). The occupant of the dwelling explained that the intensity of the tone never reached its typical maximum whilst the recording equipment was installed – a phrase we are all too familiar with. Upon listening to the recordings it became evident that the recorded tone matched that which had been audible when we visited site to inspect the instrumentation.

Fig. 4: Narrow Band Noise Spectrum of Wind Induced Tone



Discussions with the antennae manufacturer drew a blank as they claimed to have never received any previous reports of wind generated tonal noise associated with their equipment. We therefore began to examine possible sources for the tone including pipe-tones occurring in various open ended structural elements of the tower and structural resonances.

We eventually concluded that the source of the noise was likely to be vortex shedding effects around the vertical arrays of rods forming the antennae's beam reflectors since the vortex shedding frequency corresponded to the diameter of the reflector rods and the estimated wind velocity at which the noise occurred. Another clue to this was that a complainant had mentioned the noise had reduced in intensity following removal of some beam reflectors' rods during recent engineering works.

Recommendations were given including removal of further beam reflector rods and spiralling cord around the reflector rods in order to disturb the flow of air around them. The latter measure was implemented and we have been informed that the tonal noise has not re-occurred.

Besides the infrequency with which the tone was found to occur, and the associated questions arising as to whether it could therefore represent a statutory nuisance, this investigation illustrated how difficult it can be to identify a highly intermittent and unpredictable tonal noise as well as its source.

4.4 Case 4 – Phantom Tonal Noise

There must be few Environmental Health Officers who have managed to avoid the complainant with a 'phantom' noise problem. These complainants usually come over as entirely reasonable, lucid people, often well educated, who are convinced that they are experiencing a terrible tonal noise

problem. The noise is mostly described as a whine, hum or drone. The complaint usually starts because there has been some new (often unwanted) development in the area.

The root cause may be a hearing problem (i.e. tinnitus) but it is very difficult to inform a complainant of this possibility without causing offence. Alternatively there may be more ulterior motives. It is a fact that many large companies, particularly the major utility firms, run the risk of claims for compensation whenever new facilities or plant installations are built in areas where there are dwellings nearby. Even if it is suspected that there is no noise problem, this type of complainant must be dealt with using tact and diplomacy. We have always found that the only successful way of investigating this type of noise complainant is to conduct an independent investigation as thoroughly and professionally as you would any other type of complaint. One such example of an investigation is described below.

We were commissioned by a Water Authority to investigate complaints made by three different residents who lived near to a newly built water pumping station. The complaints alleged a continual whine or hum that was more noticeable at night and this hum had only commenced since commissioning of the pumping station. The main complainant had sought compensation from the Water Company due to noise and dust during construction and noise and smells since the pumping station was built, and had enlisted the support of the two other residents as well as the local MP and the local press.

The pumps comprised 5 storm pumps and 3 dry weather pumps. As the noise was alleged to be continual the assessment focussed on the dry weather pumps rather than the storm pumps that operate only from time to time. The pumps are housed underground in a building with a thick concrete floor. The only noise escape was via ventilation louvres at the top of the stairwell from the pump room.

Noise monitoring was carried out on two separate nights (after midnight) using the following protocol:-

1/3 octave and narrow band frequency analysis was carried out inside the pump room; inside the top of the stairwell; outside the stairwell louvres; 100 metres away from the pumping station; outside the complainants' houses some 400 metres away; and inside the complainants' houses. Noise measurements were taken both with the pumps switched on and switched off, and for different combinations of pumps. We made a point of personally checking which pumps were on or off i.e. not just relying on our walkie-talkie instructions to the Water Company operative. In addition vibration measurements were undertaken in the pumping station and inside the dwellings. Our client was present during the surveys and he ascertained from the complainants that they were satisfied that their complaints were being thoroughly investigated.

The pump noise was found to be reasonably broad band inside the pumping station with no distinct tonal peaks. No noise (tonal or otherwise) from the pumps was measurable or audible at 100metres back from the building or outside the dwellings or inside the dwellings. There was no difference at these monitoring locations between 'pump on' and 'pump off' noise levels. On both nights the complainants stated that the noise was audible to them throughout the tests.

Our report concluded that during our surveys the operation of the dry weather pumps did not result in any measurable tonal noise inside or outside the complainants' properties.

5. CONCLUDING COMMENTS

In this paper a number of comments have been made on the measurement and assessment of tonal noise. Our main observations are as follows:-

- In residential areas close to long established industrial premises, and in industrial towns generally, we have found that residents are remarkably tolerant of noise from factories, including tonal noise emissions.

- In the case studies cited, all the companies were keen to investigate and resolve any tonal noise problems from their premises without the need for any formal enforcement action by the local environmental health department.

- In some cases 1/3 octave analysis is adequate for assessing tonal noise problems and specifying noise control measures.

- Narrow band analysis may be necessary to identify sources of tonal noise at some complex sites. For narrow band analysis we usually select a 12Hz bandwidth and a Hanning window.

- Where feasible, 'plant on - plant off' tests are a straightforward way of investigating sources of tonal noise.

- Once a tonal noise problem has been substantiated, wherever feasible the acoustic design goal should be to reduce the peak on the spectrum to the amplitude measured at neighbouring bandwidths. For mid to high frequency tones emissions from industrial plant this is usually fairly straightforward to achieve.

- Currently acoustic engineers enjoy a certain amount of flexibility in assessing tonal noise problems. However this may not be the case for much longer as we move towards increased standardisation of assessment procedures across Europe.

6. REFERENCES

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