Vol 42 No 6 November/December 2017

ACOUSTICS BULLETIN

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and velocity, v(f) and * signifies the complex conjugate. It is plotted in dB in figure 5 along with the two idealised lumped-parameter impedances of $i\omega m$ and $\rho c_L S$. It can be seen that while peaks in the spectrum reach the upper $i\omega m$ curve, at most frequencies the curve is closer to the lower $\rho c_L S$.

Figure 6 shows the velocity transmissibility of the bearings along with the SDOF transmissibility curve. Figure 6 shows, in 1/3 octave bands, the velocity transmissibility relative to the base velocity of the building with the bearings in place, and Figure 7 is the velocity transmissibility relative to the base velocity of the building with rigid support so that it takes account of the effect of the bearings on the source below as well as the structure above. Of particular note is the absence of a peak at the SDOF bearing natural frequency, and the presence of two coupled peaks, one above and the other below the SDOF natural frequency, resulting from the coupling between the structure above the bearings and the foundations below. Comparison of Figure 7 with Figure 6 shows that when the change in the foundation velocity is taken into account, the actual transmissibility more closely resembles that predicted using the driving point impedance of an infinite column than a lumped mass.

Conclusions

It can be concluded the predicting the performance of a base-isolation system over the frequency range relevant to the reduction of groundborne noise using a SDOF model is likely to lead to an over-optimistic result is the base of large, tall or complex buildings. The reasons for this have been discussed and primarily relate to the dynamic response of such buildings which will limit the driving point impedance of the structure "seen" by the top of the bearings. The additional degrees of freedom of a lumped mass are only a partial explanation. Additionally, the use of a simple velocity transmissibility equation can be misleading, as the velocity of the base is affected by the insertion of the bearings. The SDOF model also fails to allow for coupling between the mass-on-a-spring of the building and its bearings and the mass and spring system which exists in the foundation.

Numerical modelling is capable of taking all these matters into account, and provides the most detailed method of predicting the performance of base isolation systems.

Rupert Thornely-Taylor *began working in acoustics in 1964 and has run his own practice since 1968. A former member of the Noise Advisory Council, he was also a member of the Scott Committee which drafted the basis of the noise section of the Control of Pollution Act 1974.*

References are available from the Editor at **ioa@ioa.org.uk**

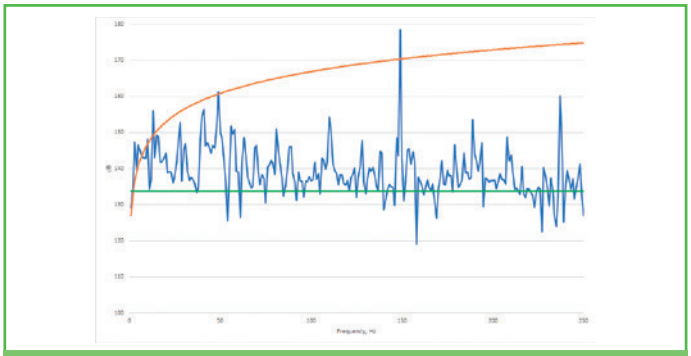

Figure 5. Driving point impedance of (1) column above bearing (middle curve) together with (2) an equivalent lumped mass (upper curve) and (3) an infinite column

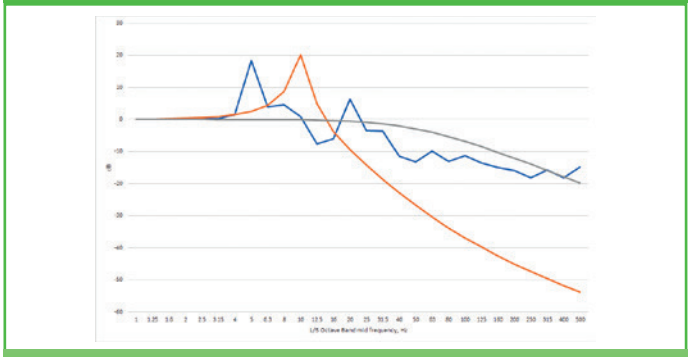

Figure 6. Velocity transmissibility of the 10Hz bearings (1) from the FDTD model (middle curve) together with (2) an equivalent lumped mass (lower curve) and (3) an infinite column (upper curve)

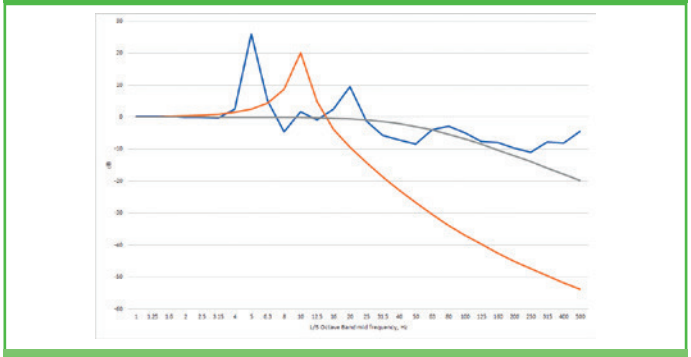

Figure 7. Velocity transmissibility of the 10Hz bearings relative to the base in the unisolated building(1) from the FDTD model (middle curve) together with (2) an equivalent lumped mass (lower curve) and (3) an infinite column (upper curve)

A planning condition for wind turbines

This article has been contributed to by Andy McKenzie, Matthew Cand, Dick Bowdler, Mark Jiggins, Gavin Irvine, Michael Reid, Richard Perkins, Michael Lotinga, Malcolm Hayes and Andrew Bullmore

Introduction

This article sets out a proposed wording for a planning condition on noise for wind farms or individual wind turbines.

Whilst local authorities and developers have waited for a planning condition that could be applied to newly consented wind farms, or to those already consented but with a suspensive condition, the report Wind Turbine AM Review (WTAMR) by WSP/Parsons Brinckerhoff for DECC arguably did not provide that. In addition there have been a number of comments on WTAMR that we consider should be addressed. The introductory sections and the conditions text represent the broad consensus view of those whose names appear below, following a period of discussion, compromise and agreement. This approach is proposed based on the current state of understanding, but may be subject to modification in light of new research and further robust information.

Copies of the condition only in Word format are available from the following websites:

- **www.hayesmckenzie.co.uk/uploads/A_Planning_Condition_for_Wind_Turbines_Sept_2017.docx**
- **www.dickbowdler.co.uk/content/publications/**

Proposed wording condition

The annex contains the condition wording which takes fairly typical wording for a planning condition on wind farm noise, including adjustments for tonal penalties if relevant, and adds a mechanism for adding a penalty for AM. Consistent with the recommendations of the WTAMR, the AM penalty is applied in addition to the tonality penalty. But how to calculate an AM penalty in practice is not clear from the WTAMR report.

WSP researchers in their subsequent *Acoustic Bulletin* article have discussed this aspect further: the penalty "should be applied to each

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individual 10-minute period assessed, and the rated levels separated into wind speed integer 'bins' for the purposes of comparison with the condition limits". They explain that to "aggregate the AM penalty" values would give an equivalent result to adding the penalty to each 10 minute period and then averaging the resulting "rated" levels, which is our experience in practice. In contrast, as they note, averaging the AM ratings and deriving an AM penalty on that basis would in many cases lead to different results.

The proposed condition has therefore been drafted on the basis of aggregating the AM penalties obtained, and applying this to the overall noise levels. This is considered to be a pragmatic way to represent the frequency/intensity of AM typically observed in relevant weather conditions. The condition explains that this averaging should only be done in relevant subsets of conditions which are determined in each case based on the observed complaints (if relevant), data analysis results or practitioner judgment. Analysis in wind direction bins, or plotting the amplitude modulation as a polar plot may be important in determining the appropriate subset. An example is shown in Fig 1 which is a polar plot of AM values as a function of wind direction and speed.

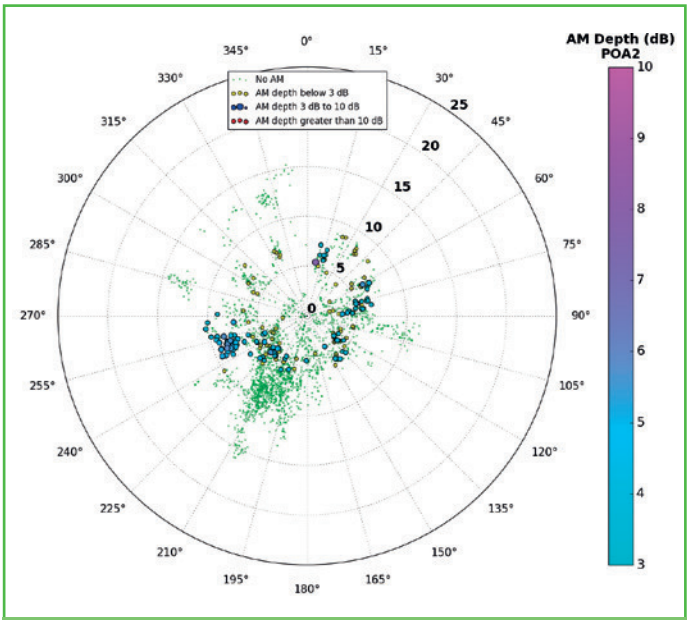

Fig 1 - plot of calculated AM ratings (dots) as a function of wind direction (circular direction) and wind speed (radial direction).

AM penalty – general aspects

As various people before us have discovered, the derivation of a penalty is not easy. There is not sufficient reliable research to be confident that a penalty system would always provide a fair indication of the impact of AM. However, to do nothing would be unfair on those wind farm neighbours adversely affected by AM and, in any case, there seems to be general agreement amongst many stakeholders on all sides of the debate that a robust condition including AM is required.

There are a significant number of people who have reservations about the penalty scheme proposed in the WTAMR report and this has been discussed in some detail by interested parties. The conclusion is that the penalty graph needs further research to establish whether it should be amended to take account of rotational speed and the difference between Leq and L90 (which increases as AM increases) and that this should be progressed as soon as possible. Meanwhile we have included the WTAMR graph in this condition. It is intended for medium to large scale turbines with a rotational speed up to 32 rpm.

A note on the night time limit

There has been criticism from some quarters of the method the WTAMR report proposed for an additional penalty to be applied at night to take account of the difference between the night-time and day-time limits; specifically where the night-time limits are higher. With a few exceptions (where suspensive conditions for AM have been applied, typically as a scheme to be agreed) the condition we are discussing here applies only to new consents. That means that, in the majority of cases, it will be applied as part of a complete set of noise limits. In such cases, the night-time and day-time limits can be set appropriately in accordance with the circumstances of the case. It should be noted that, if the night time limit is higher than the day time limit this could mean that an AM penalty would take the wind farm over the limit during the day but not at night. Where a suspensive condition for AM has been applied, the AM penalty would have to be tailored to the individual case unless an application were made to amend the conditions as a whole.

Annex

Proposed planning conditions on noise for ** Wind Farm**

The rating level of noise immissions from the combined effects of the wind turbines hereby permitted (including the application of any tonal penalty and amplitude modulation (AM) penalty), when determined in accordance with the attached guidance notes, shall not exceed the values for the relevant integer wind speed set out in or derived from Table 1 attached to these conditions and:

A) Within 21 days from receipt of a written request of the planning authority, following a complaint to it alleging noise disturbance at a dwelling, the wind farm operator shall, at its expense, employ an independent consultant and provide a written protocol to be approved by the planning authority. The protocol shall describe the procedure to assess the level and character of noise immissions from the wind farm at the complainant's property in accordance with the procedures described in the attached guidance notes. The written request from the planning authority shall set out as far as possible the time or meteorological conditions to which the complaint relates and time or conditions relating to tonal noise or AM if applicable. Measurements to assess compliance with the noise limits shall be undertaken in accordance with the assessment protocol which shall be approved in writing by the planning authority.

B) The wind farm operator shall provide to the planning authority the independent consultant's assessment of the rating level of noise immissions undertaken in accordance with the protocol within two months of the date of the approval of the protocol by the local authority unless otherwise agreed by the planning authority. The assessment shall include all data collected for the purposes of undertaking the compliance measurements and analysis, such data to be provided in a format to be agreed with the planning authority. Certificates of calibration of the equipment shall be submitted to the planning authority with the report.

C) Where a further assessment of the rating level of noise immissions from the wind farm is required pursuant to Guidance Note 5 of the attached Guidance Notes, the wind farm operator shall submit a copy of the further assessment within 21 days of submission of the independent consultant's initial assessment unless otherwise agreed by the Planning Authority.

[It is acknowledged that there may be other parts of the current IOAGPG conditions which require inclusion here, such as the clause discussing limits which apply at non named locations etc. The text included above aims to show how rating of AM scheme fits within the normal WF compliance approach.]

(Insert here the table or tables relevant to the specific planning condition)

Guidance notes for noise condition

These notes are to be read with and form part of the planning condition on noise. The measured data is to be split into bins as described below. The rating level in each bin is the arithmetic sum of the wind farm noise level, any tonal penalty applied in accordance with Note 3 and any AM penalty applied in accordance with Note 4. Reference to ETSU-R-97 refers to the publication entitled "The Assessment and Rating of Noise from Wind Farms" (1997) published by the Energy Technology Support unit (ETSU) for the Department of Trade and Industry (DTI). IOAGPG is "A Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise" or any update of that report current at the time of measurement. The IOA Metric is "A Method for Rating Amplitude Modulation in Wind Turbine Noise" dated 9th August 2016 or any update of that current at the time of measurement.

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Note 1 – Data collection

A) Values of the LA90,10-minute noise index should be measured in accordance with the IOAGPG. Measurements shall be undertaken in such a manner to enable a tonal penalty to be calculated and to allow an AM penalty to be calculated for selected periods where a tonal or AM assessment is required.

B) To enable compliance with the conditions to be evaluated, the wind farm operator shall continuously log arithmetic mean wind speed in metres per second (m/s) and arithmetic mean wind direction in degrees from north in each successive 10-minutes period in a manner to be agreed in writing with the planning authority. The wind speed at turbine hub height shall be "standardised" to a reference height of 10 metres as described in ETSU-R-97 at page 120 using a reference roughness length of 0.05 metres. It is this standardised 10 metre height wind speed data which are correlated with the noise measurements determined as valid. The wind farm operator shall continuously log arithmetic mean nacelle anemometer wind speed, arithmetic mean nacelle orientation, arithmetic mean wind direction as measured at the nacelle, arithmetic mean rotor RPM and whether each wind turbine is running normally during each successive 10-minutes period for each wind turbine on the wind farm. All 10-minute periods shall commence on the hour and in 10-minute increments thereafter synchronised with Universal Time (UT).

Note 2 – Data analysis

A) The independent consultant shall identify a sub set of data having had regard to:-
- the conditions (including time of day and corresponding wind directions and speeds) at times in which complaints were recorded;
- the nature/description recorded in the complaints if available;
- information contained in the written request from the local planning authority;
- likely propagation effects (downwind conditions or otherwise);
- the results of the tonality/AM analysis where relevant.

In cases where it is possible to identify patterns of clearly different conditions in which complaints have arisen additional sub sets may be considered provided this does not introduce unreasonable complexity in the analysis and can be justified by the independent consultant.

B) Within each of the sub set(s) of data identified, data shall be placed into separate 1 m/s wide wind speed bins.

Note 3 – Tonal penalty

A) Where, in accordance with the protocol, the noise contains or is likely to contain a tonal component, a tonal audibility shall be calculated for each ten-minute period using the following procedure.

B) For each 10-minute period for which a tonal assessment is required this shall be performed on noise immissions during two minutes of each 10-minute period. The two-minute periods should be spaced at 10-minute intervals provided that uninterrupted uncorrupted data are available ("the standard procedure").

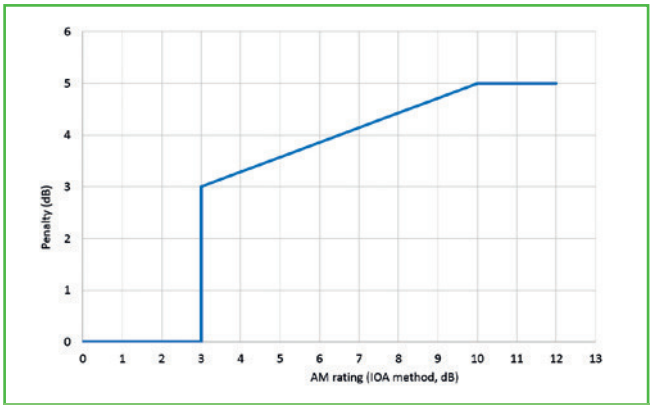
C) For each of the two-minute samples the tone level above audibility shall be calculated by comparison with the audibility criterion given in Section 2.1 on pages 104 -109 of ETSU-R-97. Samples for which the tones were below the audibility criterion or no tone was identified, a value of zero audibility shall be substituted. Where data for a ten-minute period are corrupted, that period shall be removed from the tonal analysis.

D) The tone level above audibility for each 10-minute period shall be placed in the appropriate data sub set and wind speed bin.

Note 4 – AM penalty

A) Where, in accordance with the protocol, the noise contains or is likely to contain AM, an AM penalty shall be calculated for each ten-minute period using the following procedure.

B) For each 10-minute interval for which an AM assessment is required this shall be performed in accordance with the IOA Metric. The value of AM for each ten-minute period shall be converted to a penalty in decibels in accordance with the graph below and the penalty shall be placed in the appropriate data sub set and wind speed bin. Where a penalty is zero it should be placed in the bin in the same way.



Penalty graph

Note 5 – Calculation of rating level

A) The LA90 sound pressure level for each data sub set and wind speed bin is the arithmetic mean of all the 10 minute sound pressure levels within that data sub set and wind speed bin except where data has been excluded for reasons which should be clearly identified by the independent consultant. The tonal penalty for each bin is the arithmetic mean of the separate 10 minute tonal audibility levels in the bin converted to a penalty in accordance with Fig 17 on page 104 of ETSU-R-97. The AM penalty for each bin is the arithmetic mean of the AM penalties in the bin. The assessment level in each bin is normally the arithmetic sum of the bin LA90, the bin tonal penalty and the bin AM penalty except where the AM penalty and the tonal penalty relate to the same characteristic (e.g. amplitude modulated tones) when the sum of both penalties may overly penalise the characteristics of the noise. Such cases should be identified and only the larger of the AM or tonal penalty should be applied.

B) If the assessment level in every bin lies at or below the values set out in the table(s) attached to the conditions then no further action is necessary. In the event that the assessment level is above the limit(s) set out in the tables attached to the noise conditions in any bin, the independent consultant shall undertake a further assessment of the rating level to correct for background noise so that the rating level relates to wind turbine noise immission only. Correction for background noise need only be undertaken for those wind speed bins where the assessment level is above the limit.

C) The wind farm operator shall ensure that all the wind turbines in the development are turned off for such periods as the independent consultant requires to undertake the further assessment. The further assessment shall be undertaken in accordance with the following steps:-

i. Repeating the steps in Note 1, with the wind farm switched off, and determining the background noise (L_3) in each bin as required in the protocol. At the discretion of the consultant and provided there is no reason to believe background noise would vary with wind direction, background noise in bins where there is insufficient data can be assumed to be the same as that in other bins at the same wind speed.

ii. The wind farm noise (L_1) in each bin shall then be calculated as follows where L_2 is the measured level with turbines running but without the addition of any tonal nor AM penalty:

$$L_1 = 10\log\left[10^{L_2/10} - 10^{L_3/10}\right]$$

iii. The rating level shall be calculated by adding the tonal and AM penalties to the derived wind farm noise L1 in that bin.

iv. If the rating level after adjustment for background noise contribution and adjustment for tonal and AM penalties in every bin lies at or below the values set out in the Tables attached to the condition at all wind speeds then no further action is necessary. If the rating level at any integer wind speed exceeds the values set out in the Table(s) attached to the condition then the development fails to comply with the planning condition in the circumstances represented by that bin.