NOISE MEASUREMENT OF WIND TURBINES

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1. INTRODUCTION

500 MW of wind power generating capacity has already been installed in Europe but the present goal, [1], is to expand this to 100 000 MW by the year 2030 and hence meet 10 per cent of the current European electricity demand. This is an ambitious but realistic target and, apart from technical and economic issues, it will depend largely on public acceptability for its success. One major environmental issue is noise and the lack of an agreed international standard on the subject is a serious potential hindrance to trade and the development of the industry.

Some countries have already developed and drafted their own measurement and certification requirements but there is general agreement on the need for an international standard which can be used and accepted by countries throughout the world. Unfortunately there are many technical issues which are affected by the different climate, wind regime, topography and national planning regulations in each country and a consensus procedure has been difficult to achieve. Despite this, extensive collaboration has taken place and substantial agreement has already been reached.

This paper will therefore outline the technical issues related to the source (emission), path (propagation) and receiver (immission) of wind turbine noise and will describe the past and future international collaboration which is intended to provide procedures which manufacturers, developers and planning authorities can readily accept and use throughout the world.

2. ACOUSTIC MEASUREMENT CONSIDERATIONS

2.1 General

Wind turbines generate mainly aerodynamic noise from the blades and mechanical noise from the drive train but the conditions under which they are measured tend to violate many of the accepted criteria of accurate and reliable results. Before assessing special measurement requirements however, it will be useful to discuss the nature of the noise generation and the non-standard issues which have to be considered.

2.2 Aerodynamic Noise

Work Carried by Grosveld, [2], Hubbard and Shepherd, [3] and Lowson [4] has shown methods of predicting broad band aerodynamic noise from wind turbines and has identified a number of generating mechanisms. The principal three are the Inflow Turbulence, Turbulent Boundary Layer/Blade Trailing Edge Interaction and the Blade Trailing Edge Bluntness. These mechanisms can be detected over the frequency range 63-4000 Hz and are therefore the primary sources of annoyance. Unfortunately the noise levels vary with rotor speed and wind speed and make the characteristics difficult to measure and quantify.

2.3 Mechanical Noise
The main source of mechanical noise is the main drive train and the gearbox in particular. The electrical generator is also an area of potential annoyance although experience shows this to be secondary to the gearbox. The frequency range of interest is dependent upon input and output shaft speeds but varies approximately from 100 Hz to 1 kHz. The levels vary with the power generation but the main problem is the tonal quality which is difficult to quantify for certification.

2.4 Physical Constraints
When we consider that a 60 kW wind turbine can have a tower height of 15 m and a rotor diameter of 17.5 m and that larger (2.5-4 MW) turbines have tower heights of the order of 80 m and rotor diameters up to 91 m, it is not difficult to appreciate the need for new unique measurement methods and practices. When evaluating the source emission or sound power level (SWL) of a turbine for use in propagation studies and immission calculations the traditional methods, namely the ISO 3740 series of standards, are inappropriate due the turbine's size, operating condition and environment.

2.5 Environmental Issues
Wind turbines by virtue of their nature operate outdoors, and as such are subject to extremes of weather. Best acoustic practice would advise against measuring in winds in excess of 5 m/s, however the vast majority of wind turbines will only start to turn at this wind speed and will normally operate in winds of up to and sometimes beyond 20 m/s. If we then assume that turbines will be operating continually all year round, then they will be subject to rain, snow, ice and extremes of temperature and the acoustic evaluation becomes a complex undertaking.

2.6 Wind Speed
Turbines are dependent on a good wind regime for successful operation both technically and economically. This creates a number of difficulties for the acoustician in the noise evaluation. Firstly, measurements must be carried out at high wind speeds and secondly, due to wind shear, the wind speed varies with the height from the ground. Different turbines, dependent on their size, number of blades and rotational speed operate at different wind speeds and thus acoustic measurements must bear this in mind when seeking to make comparisons between machines. It is generally accepted that wind turbine noise varies with wind speed at hub height and care must be taken when comparing acoustic performance to confirm whether the wind speed was measured at hub height or 10 m height. The level at which the turbine's noise exceeds the background is another important consideration and again this will vary with wind speed.

2.7 Ground Effects

To further complicate the issue the wind turbine is assumed to be represented as a point source located at hub height, in horizontal axis machines and the mid blade position in vertical axis machines. The turbine is then an elevated source and measurements made at the standard height of 1.2 m will be subject not only to the direct ray, but to a ground reflected ray as well. In order to minimse the effect of this, a ground reflecting board measurement technique has been developed which will reduce the interference effect of the reflected ray. The microphone is placed on an acoustically hard reflective board where it is subject to a pressure doubling on its diaphragm. By subtraction of 6 dB it is therefore possible to approximate the free field sound pressure. There are limitations on the method and experimental studies carried out at NEL, [5], and by Payne [6] and [7], detail the use of the technique.

3. ACOUSTIC MODEL

3.1 General

Wind turbine noise issues are important to manufacturers, developers and planners and regulators alike. Firstly, there is the identification of the source, the turbine itself. Secondly, there is the issue of the turbine's acoustic signature and how it propagates through the atmosphere, and lastly, there is the issue of the turbine's effect on remote locations. This follows the standard 'Source, Path, Receiver' acoustic model and is known as the turbine's emission, propagation and immission. At the time of writing a great deal of work has been carried out on the emission aspects, but less on the propagation and immission. This is due to the propagation and immission being very dependent on the location and meteorological conditions and the fact that considerable manpower and funding is required for effective research.

3.2 Emission

The acoustic strength or sound power of a source is required for input to propagation models to predict the effect of the source on an environment. The accuracy of the prediction is therefore dependent on the accuracy of the initial sound power evaluation. As regards wind turbines, the emission model is to assume an elevated point source, located at the hub and radiating spherically. The measurement procedure is then to evaluate the turbine's A-weighted source power level based on the greatest of four separate azimuthal sound pressure level measurements, located as shown in Fig. 1 below, using the ground board technique and referring these back to the SWL at hub height using equation (1).

$$SWL = SPL + 10 \log (4 \times \pi \times R^2) \qquad (1)$$

where SWL is the Sound Power Level at Hub Height in dB re 1 pW,

SPL is the Sound Pressure Level measured using the ground board measurement technique minus 6 dB in dB re 20 μPa, π is the constant = 3.1415, and

R is the distance from the hub to the microphone in metres.

The SPL is measured over the frequency range 50 Hz to 8 kHz and is time averaged in the form of an A-weighted L_{eq} and combined with a wind speed measurement over the same time period.

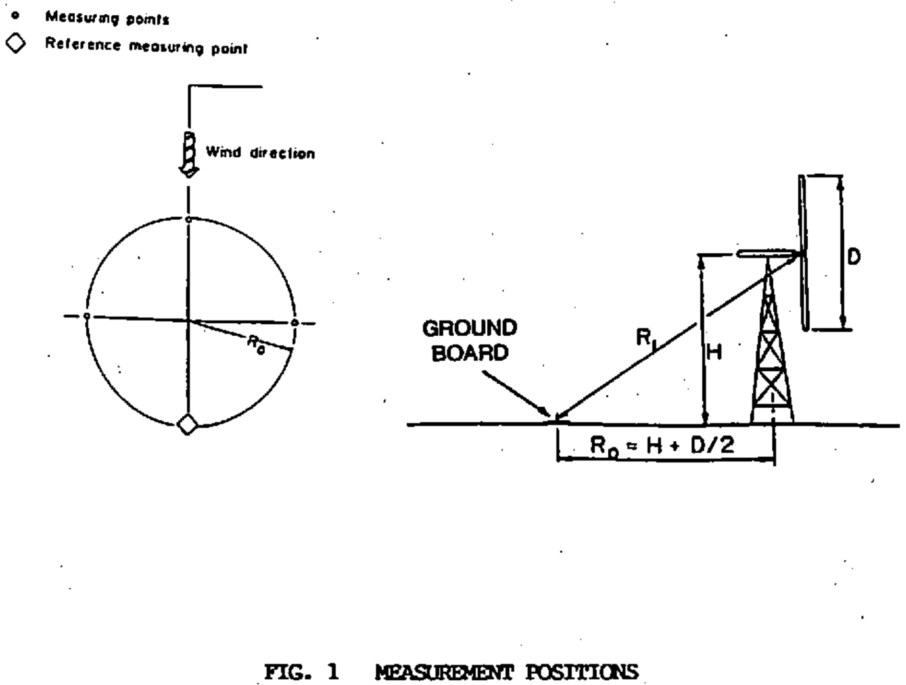

FIG. 1 MEASUREMENT POSITIONS

3.3 Propagation

The propagation models vary between simplistic and complex. The model commonly used is simplistic and based on spherical radiation and a 6 dB reduction in sound pressure level for each doubling of distance. Field tests to date have indicated that within about 200 m of the turbine, the model is sufficiently accurate despite its simplicity. Beyond this distance however the situation is more complex and a number of researchers are attempting to validate other models which include such things as topography, wind gradients, ground absorption and reflection and air absorption. A considerable amount of work has already been carried out but predominantly on either flat terrain, low wind conditions or where the source is at ground level. Wind turbines violate all these conditions and there is still no agreed formula which can cater for these eventualities.

3.4 Immission

Ultimately the acceptability of a wind turbine is dependent on the effects of the noise on the local environment and specifically on the extent to which it exceeds either the background noise or the permissible sound pressure levels which have been set for the location. In general the immission is the responsibility of the local authorities, but they have significant problems in setting these permissible levels, predicting the likely annoyance and in monitoring the final installation.

Sometimes the permissible levels are set nationally but often they are related to existing background levels. Unfortunately there is a lack of data on background levels with wind speed and it can be a lengthy process to obtain this information. Prediction of the annoyance requires reliable emission and propagation information, but it also involves an often complicated process of transferring sound power levels with hub height or 10 m wind speeds to sound pressure levels at 1.2 m at a remote distance. Monitoring the problem is also not straightforward since local measurements at 1.2 m height are sometimes difficult to correlate with the actual turbine operating conditions. Any International Standard would have to present data and guidelines to help alleviate the problem for planners.

4. INTERNATIONAL COLLABORATION

4.1 Background

In 1984 the International Energy Agency (IEA) published the first edition of a Recommended Practice on the Measurement of Noise Emission from Wind Turbines and, during its development, it was recognised that further discussion and collaboration was required. The IEA Standing Committee therefore arranged a special workshop in Stockholm later that year and this was attended by representatives from Sweden, Canada, Denmark, Germany, Great Britain and the Netherlands. In the Proceedings, it was recognised that the IEA document needed some revision but that it would serve as a useful guide to those working in the field.

In 1987 a report, [8], was prepared for the CEC following a joint study involving European National Test Stations. It presented recommendations for a preliminary noise measurement standard for EEC countries and was based on comparisons between the then latest draft versions of the American Wind Energy Association (AWEA) Standard and the second edition of the IEA Recommended Practice.

Following further international collaboration the IEA, [9], and AWEA, [10], produced final documents of their procedures in 1988 and 1989 respectively but unfortunately none of the three documents have been adopted as internationally agreed procedures.

Between 1989 and 1992 there was further cooperation among the European Community Wind Energy Test Stations (ECWETS) and it became clear that there were many common features in their test procedures which could form the basis of an acceptable standard. The IEA Standing Group for Recommeded Practices for Wind Turbine Testing and Evaluation then reconvened an Expert Working Group with the aim of producing a third edition of the document on Acoustic Measurement of Noise Emission from Wind Turbines. This working group met on 10 June 1992 and its members from Denmark, Netherlands, USA, UK, Germany and Sweden are currently considering future actions.

4.2 International Certification Policies

There is considerable confusion on the relationship between national regulations and certification procedures. In general the national regulations stipulate sound pressure levels at a particular location or distance from the wind turbine but, since these are immitted sound pressure levels, they are dependent not only on the emitted level from the turbine but on the propagation characteristics of the locality concerned. They cannot therefore be considered as a certifiable property of the wind turbine unless an agreed propagation formula is included in the certification process.

Despite this it is interesting to comment on the measurement and regulatory policies from different countries since they do have a bearing on the requirements for the acceptance of a standard measurement procedure.

Denmark has probably the most formal regulatory procedure which requires a number of acoustic L_{eq}(A) measurements on a reflecting board at the reference position to be paired with simultaneous wind speed measurements at 10 m height and, from the subsequent linear regression, a sound power level is determined at a mean speed of 8 m/s. A corresponding sound pressure level is then calculated from a propagation formula using spherical radiation, atmospheric absorption and a correction for measurement height. This sound pressure level is then compared with permissible levels for different locations and times.

The Netherlands too have a measurement procedure, which is accepted by the government and is similar to the Danish procedure. Sound power levels are determined at a mean wind speed of 7 m/s and are compared with a formula to determine whether the turbine is eligible for a national subsidy. There are also recommended permissible sound pressure level targets for different locations and times and their regulation is largely the responsibility of the local authorities.

Noise emission measurements in the UK have been carried out largely to the Second Edition of the IEA Recommended Practices but practical difficulties have required that concessions be made on reflecting board size, simultaneous measurements and other conditions. The regulations generally apply to permissible sound pressure levels which are set and controlled by local authorities.

Sweden is currently considering a Nordtest method which is similar to the IEA method but reports sound power levels, at a wind speed of 8 m/s and 10 m height, which have been determined by regression analysis from noise and wind speed data.

Germany have similar procedures and measure on a reflecting board for a range of wind speeds and report the sound power level at 8 m/s and 10 m height.

The USA use the AWEA First Tier Standard, [], and report the Standard Sound Level (a sound pressure level at a reference slant distance of 100 m) at a mean wind speed of 10 m/s at 10 m height. The reported level is an average of a number of combined noise and wind speed data points. The USA also have draft proposals for second tier procedures which are more detailed but are to be considered as Recommended Practices.

4.3 Agreed Principles

It is not possible to detail all aspects of the measurement standard in this paper but the following are some of the critical issues on which agreement has been or is likely to be reached.

a The acoustic model of an assumed point source radiating spherically seems to be adequate for the distances under consideration.

b Four measurement locations, at the distance of R0, in Fig. 1, are adequate although there may be some merit in concentrating the majority of measurements at one reference location.

c Ground reflecting boards are effective in minimising the effects of wind noise and ground reflections.

d Simultaneous noise and wind speed data should be collected over a selected wind speed range and some form of regression analysis be used to evaluate the characteristics.

e The results should be presented as a sound power level at one wind speed, say 8 m/s, at a 10 m height.

f Propagation and immission calculations should be included only as guidelines in the procedure.

4.4 Future Requirements

Despite the considerable measure of agreement there are still a number of issues which have to be addressed.

a The size of the reflecting board - 1 m diameter or 1.5 x 1.8 m?

b The value of percentiles, 1/3-octave and narrow band analysis.

c The measurement height of wind speed - hub height, 10 m height or from power curve?

d The value of some non-acoustic measurements - humidity, temperature, turbulence, barometric pressure.

e The estimated accuracy of the measurement method.

f Techniques to deal with impulsivity and tonality.

g Measurement methodology - a defined method for calibration, data capture and data reduction which is not necessarily specific to one set of instrumentation.

h The problems of measuring and compensating for background noise.

5. FUTURE ACTIVITIES

From the above there is a considerable number of issues which will have to be resolved and which will require further research and international collaboration.

The agreed standards strategy is to proceed on two fronts with the IEA Expert Study Group to produce a third edition of the Recommended Practices and with a parallel exercise for the International Electrotechnical Commision (IEC) to produce an agreed international standard. It should be possible for the IEA document to be updated in a relatively short time and, although it is only a Recommended Practice, it should serve as a useful input to the IEC Committee (IEC/TC/88/WG5) which has been set up to progress the full standard.

Proposals have also been submitted for further European collaborative research on aerodynamic noise and propagation in the forthcoming CEC Joule II Programme. This should not only help to reduce the overall noise signature from wind turbines but should provide an agreed propagation formula which can be included as guidelines in the emission measurement standard.

Progress on these two fronts will help certification, prevent trade barriers and assist local planning authorities in different countries to approve wind turbine developments.

6. CONCLUSIONS

This paper is an overview of the development of internationally agreed procedures in the measurement of wind turbine noise. It does not deal in detail with the technical issues but it does highlight the complexity of the problem and illustrates the special provisions which have to be made to produce a practical and reliable standard. It gives the history and current status of international collaboration on the subject and gives the scope and plans for future action.

7. REFERENCES

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