Proceedings of the Institute of Acoustics

SOUND POWER MEASUREMENT AND CERTIFICATION OF WIND TURBINES

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1. INTRODUCTION

The European goal of supplying 10 per cent of its electricity demand from wind energy by the year 2030 is an ambitious one, and is largely dependent on the public acceptability of wind turbines. To date, in excess of 500 MW of capacity has been installed and the need for international agreement on environmental issues has been identified. One of the main, if not the most important of the environmental issues is noise.

This paper will seek to address some of the current issues related to the acoustical sound power measurement and certification of wind turbines. At the time of writing (February 1994) there are in the UK, essentially three documents used that specifically refer to acoustical measurements on wind turbines. These are the second edition of the International Energy Agency (IEA) acoustics document[1], the first edition of the International Electrotechnical Commission (IEC) Standard[2] and the Danish Statutory Order No 304 from the Ministry of the Environment, Denmark[3]. British Standard BS 4142[4] has been used on occasion for planning purposes, but is not normally considered when addressing the sound power issue.

It should be noted that where the IEC document is a formal international standard, the IEA document is a recommended practice, and as such is not subject to the lengthy timescale which is normally associated with the implementation of full standards. Throughout the discussion periods on both documents it was realised and agreed that there should be maximum commonality between them. There are some minor differences, but these are addressed as they occur later in the text.

2. OVERVIEW

2.1 Origin of the Current Documents

It is perhaps useful at the outset to briefly review the most recent history in terms of the acoustic issue as this will enable the progress made to date and current thinking to be viewed in context.

In 1984 the IEA published the first edition of a recommended practice on the noise emission from wind turbines. It was recognised at a very early stage in the document's development, that further discussion and collaboration would be required. This was primarily due to the complexity of the subject matter and that the committee comprised of members of a number of different countries, some of whom already had an acoustical document in place. This resulted in further meetings and the publication of a second edition in

1988[1]. Running almost in parallel with this European effort, the American Wind Energy Association (AWEA), was also addressing the acoustics issue and produced its own standard[5] in 1989.

As the exploitation of wind energy developed, so too did the need to meet more stringent environmental constraints and in particular, noise. With this accelerated growth arose a greater need for manufacturers and developers to provide acoustic data that was accurate, reliable and could be relatively easily obtained. This acoustic data was also required to be in a form that could be easily used and interpreted, particularly for planning purposes. It was recognised that the existing second edition of the IEA document was deficient in addressing some of these concerns. It was therefore recognised that a formal standard was required and an IEC Working Group was set up to develop it. It was also recognised that this Standard could take a considerable time to produce and it was agreed to set up a parallel committee to update the IEA document in the short term. Meetings of both committees took place until the present day where we have the third edition of the IEA document[6] which is due to be published in 1994 and the final draft of the IEC document which should be published in 1995.

The 1989 AWEA document[5] is still current, but as it is likely to be superseded by the IEC document, will not be addressed further in this paper.

A similar situation exists with the Danish Statutory Order[3] which is still occasionally called for in the UK but is also likely to be superseded.

2.2 Basic Approach to Acoustic Emission

The basic philosophy inherent in all of the documents is to make a measurement of a sound pressure level (SPL) on an acoustically hard reflecting board at some chosen point, and then use this SPL measurement, to derive an 'apparent sound power level' (SWL) at the hub of the machine. The turbine is assumed to be a point source located at the hub and generates spherically. This SPL is then correlated by a simple regression analysis to the measured wind speed.

All of the above documents address the acoustic issue in a broadly similar fashion although there are a number of differences between them. Most notably they all use or recommend a ground board measurement technique in order to try to alleviate the problems encountered with undertaking acoustic measurements in windy and topographically complex environments; references [7], [8], [9] and [10] give fuller details on this aspect. The main differen are not so much in the acoustic evaluation of the turbine, but in the additional non-acoustic data required to supplement and aid understanding of the acoustic data.

It has now been internationally agreed by those working in this field that acoustic data must be correlated with wind speed in order for it to be correctly interpreted and understood.

It is then possible to quote an SPL or SWL over a range of measured wind speeds, and also to report one SWL at a wind speed of 8 m/s measured at reference conditions. These calculated values can then be used as inputs to, for example, a propagation model for further detailed analysis and are particularly useful when seeking planning approval. This however is a rather simplistic overview, the actual practical measurement, analysis and verification being somewhat more complex.

3. TECHNICAL ISSUES

Wind turbines of necessity operate outdoors and often in extreme meteorological conditions, which makes the acoustical evaluation a rather onerous one.

Traditionally it has been good acoustical practice to avoid making measurements in high winds or in wet weather, and this together with the constraints on a wind turbines physical size (rotor diameters can be up to 90 m, with hub heights up to 80 m) compounds the problems for the acoustician, who is endeavouring to make good quality, reliable and repeatable measurements.

It has been agreed internationally that these constraints make the use of the ISO 3740 series of standards for measuring the sound power of machines impractical for most wind turbines and hence arose the need for a specific unique document as an aid to the evaluation of the emission characteristics of wind turbines and to further enhance the acceptability, exploitation and growth of wind energy.

The main technical issues can be divided into acoustic and non-acoustic considerations.

3.1 Acoustic Considerations

The first and perhaps most crucial of the acoustic considerations is the use of the microphone, its type, position, orientation and whether it should be at ground level on a reflecting board or at 1.2 m height in the absence of a ground board. General agreement has been reached on the use of a ½-inch free-field microphone mounted horizontally on an acoustically hard reflective board of minimum dimension 1 m diameter. Work carried out at NEL, reference [7], and at NPL, references [8] and [9], has shown this to be an effective means of reducing the effects of wind noise on the microphone diaphragm, in addition to reducing the effects of the surrounding ground.

As the reflection on the board causes the microphone to experience a pressure doubling on its diaphragm, the free field sound pressure level can be evaluated by subtracting 6 dB from the level measured with the board. The position of the microphone on the board is also a significant consideration to reduce the possible effect of standing waves and edge effects. The use of a primary and in extreme conditions, a secondary windshield is also recommended. Both the IEA and IEC documents discuss in detail these aspects and make the appropriate recommendations.

There is now general agreement that the equivalent continuous A-weighted sound pressure level, $L_{Aeq,T}$, over a minimum of generally one minute, will be used for conditions with the turbine operating, and with the turbine shut down for evaluation of the background sound. Under both of these conditions the acoustic data is synchronised with an averaged wind speed over the measurement period. Generally a minimum of at least 30 data pairs are required over a predetermined wind speed range (typically 6 to 10 m/s) to enable an accurate regression analysis to be performed.

Tonality is a major issue since it incurs a 5 dB penalty in most countries. The method for the determination of pure tones is generally based on that of ANSI S12.10 (1985)[11], and the guidelines for the measurement of noise from industrial plants published by the Nordic environmental agencies. There is however still some considerable discussion on the use of this as a final method.

The measurement positions have been chosen as shown on Fig. 1 where the reference distance R_0 is given by:

$$R_0 = H + D/2 \text{ (m)}$$

Measurements for correlation with wind speed are predominantly made at the reference position, 1, the data at measurement positions 2, 3 and 4 being used to derive the turbines directionality.

3.2 Non-acoustic Considerations

It can be shown that a turbines acoustic output is a function of a number of complex mechanisms both aerodynamic and mechanical. References [12], [13] and [14] give a more detailed treatment of these and in particular the aerodynamic mechanisms. However, in order to fully interpret the acoustic data it must be viewed in the light of some of these other considerations, the first and most important being the wind speed.

There are essentially three locations being considered at which the wind speed has to be measured

a) at 10 m height, a specified distance upwind of the turbine,
b) at hub height, a specified distance upwind of the turbine, or
c) derived from the turbine's electrical power output curve.

The IEA preferred method is a derivation from the power curve, as this would appear to give the best correlated data since it uses the best estimate of wind speed that the turbine experiences.

If the wind speed is being derived from the electrical power curve then we additionally must measure the temperature and barometric pressure as these will have a bearing on the power curve measurements.

The wind direction is another significant parameter since there may be times when our measurement anemometer will be in the wake of the turbine, and our wind speed will no longer be accurate and consequently may be invalid. Generally however, over a measurement period of for example one hour duration, the wind speed direction will remain relatively constant.

Since the wind speed and direction are such crucial parameters we must carefully consider where to position our meteorological mast for the optimum benefit.

There are a number of other data that should be considered and include the type of topography, ground cover, nearby reflecting structures and any additional noise sources.

Furthermore, it has been agreed that estimates of the turbulence intensity in the atmosphere and the presence of any temperature inversion should be noted. Although complex meteorological conditions in themselves, reasonable estimates can be made from measurements of temperature, barometric pressure and humidity with a subjective assessment of cloud cover, time of day and terrain type.

4. OBSERVATIONS ON THE METHODS

4.1 IEA Method

The 1994 third edition[6] of this document has a number of significant changes from the 1988 second edition[1]. The major changes have been to the location of the measurement positions, the positioning of the meteorological mast for wind speed evaluation and in the analysis and reporting.

These can be summarised as follows.

4.1.1 Measurement Position Locations. Fig. 1 details the exact nature of the measurement positions. The most significant change from the second edition is the removal of the need to measure at a distance of $2R_o$ in the downwind direction, and the relocation of positions 2 and 4 to the 120 degree downwind sector of the hub axis. This is as a result of concern over the potential null point which has been observed in the plane of the rotor.

4.1.2 Meteorological Mast Location. Considerable discussion has taken place over the influence of the wind speed on the acoustic signature and in particular how this should be measured. The third edition is very specific on the positioning of the mast and wind direction variation that can be tolerated. Figs 2 and 3 detail where this should be for the two cases where measurements are made at hub height (Fig. 2) and below hub height (Fig. 3). The document also details the equations to be used when converting wind speed measurements made at differing heights.

4.1.3 Reporting and Analysis. Two curves will be generated in the analysis. The first, noise versus wind speed, allows machines to be compared under comparable conditions, for example at a wind speed of 8 m/s and the second shows the variation of background sound with wind speed. The analysis additionally provides, through a simple derivation, an apparent sound power level that can be used with a propagation model to estimate immission levels at a remote location. Guidance is given on these derivations and on the instrumentation required to undertake the measurements. The SWL is reported in the downwind direction only (ie at position R_0) together with the directionality derived from measurements at the other three positions.

4.2 IEC Method

As stated previously the IEC document is to be the formal noise measurement standard for wind turbines and, although it is still in its final draft form, the indications are that it will agree generally with the technical approach of the IEA document. There are however some issues which will have to be resolved before this can be confirmed.

One major issue is the measurement and interpretation on tonality and there is some concern that the method being proposed has not been properly validated. It may be necessary to include this information in an appendix as a recommendation. Another major issue is the position of the meteorological mast which may seem a trivial issue but, with our variable topography and often hostile climate in the UK it could, if restricted, cause serious problems in obtaining adequate measurement conditions. One further topic which may ultimately differ from the present IEA document is the use of 'apparent sound power' to describe all the noise data. This will, if adopted, remove the present confusion on whether results have or have not had the 6 dB deducted for the board reflection.

All of these issues will be discussed at a forthcoming IEC meeting on 28 February 1994 and will hopefully enable the ratification and publication of the document by 1995.

4.3 Statutory Order No 304 Type Method

The Danish Statutory Order[3] has adopted a less complex approach to noise measurement than either of the two methods above, but none the less promotes a similar philosophy to that already discussed. Measurements are made at one downwind position only, a distance of 1 to 2 times the hub height and on a rectangular board with minimum dimensions 1.5 x 2 m. The wind speed is measured at 10 m height and a distance of approximately 1 times the hub height upwind of the turbine. At least 10 one minute $L_{Aeq,T}$ values should be made over a wind speed range of 6 to 10 m/s and a regression analysis performed to generate an appropriate noise verses wind speed curve. The background noise is measured in a similar fashion with the turbine parked.

5. FUTURE WORK

It is anticipated that many of the issues deemed critical, have now been addressed, some however to a greater extent than others. Only through time and the continued development of the technology can progress be made. There are still some outstanding issues which will require further work.

The first of these is in the understanding and development of propagation models that take into account the unique meteorological and topographical conditions under which wind turbines operate. NEL together with four other European partners is currently seeking to address this issue through a CEC funded JOULE II project. It will be sometime yet before the results of this study will be known.

Another area where researchers are active and further work is still required is in the modelling and prediction of both aerodynamic and mechanical mechanisms and sources. Work carried out by Professor Lowson[14], and others will improve the techniques available and ultimately enhance acceptability and the growth of wind energy.

6. CONCLUSIONS

Wind turbines have been proved to be a viable source of renewable energy. The development and growth of this new technology is highly dependent on the public acceptability of wind turbines, with the environmental issues and in particular noise to the fore. It is hoped that this paper has highlighted the areas of concern and shown through the brief overviews of the acoustical documents that much is being carried out to address this issue in particular and obviate it from being a hindrance to turbine growth. It is a difficult and complex issue, much has been achieved, but there is still much more to do.

7. REFERENCES

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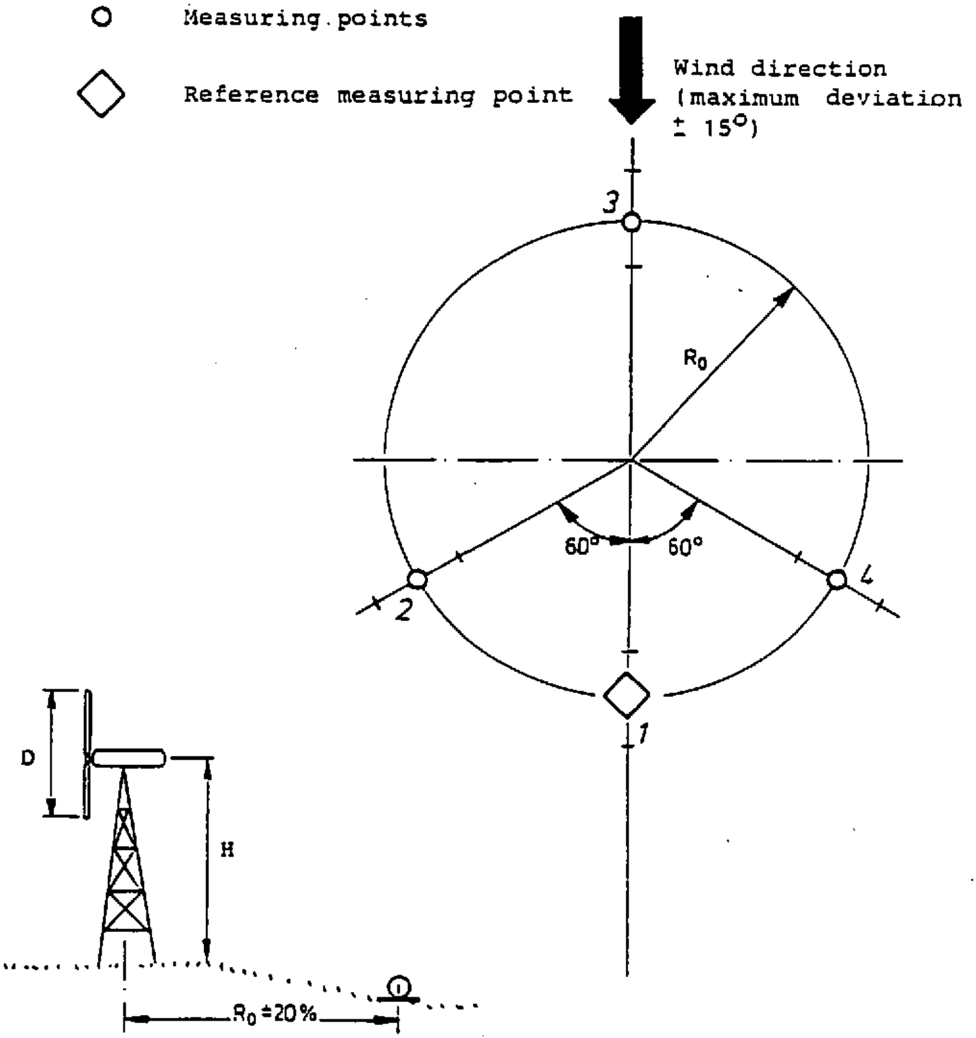

Figure 1. Recommended pattern for measuring points.

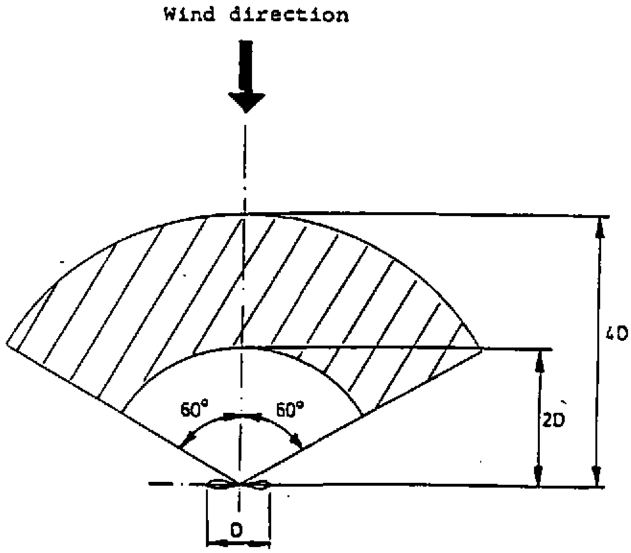

Figure 2. Recommended position of anemometer for horizontal axis wind turbines and for the case that the anemometer is positioned at hub height. D is rotor diameter.

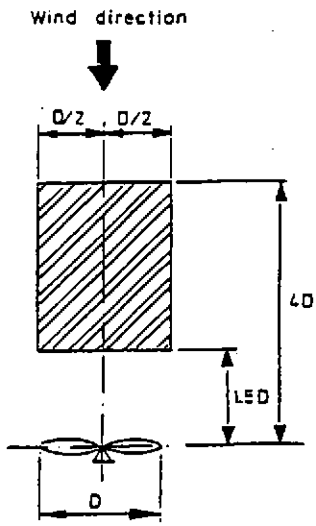

Figure 3. Recommended position of anemometer for horizontal axes wind turbines and for the case that the anemometer is positioned below hub height. D is rotor diameter.