Low Frequency Noise from Wind Turbines

With special reference to the GE 1.5 Turbines at Fenner Wind Farm

A Report Prepared

for

Noble Environmental Power

by

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1.0 Low Frequency Noise

A review of low frequency noise has been completed by the writer (Leventhall, 2003). In this, low frequency noise is defined as from about 10Hz to 200Hz, whilst Infrasound is from 20Hz down to a very low frequency, say 1Hz. In practice, it is normally only necessary to consider the range 10Hz to 200Hz .

1.1 Noise sources in Wind turbines. Wind turbines were not included in the above review of low frequency noise, as they were not considered to cause low frequency noise at problem levels.

There are several noise sources in wind turbines. .

- Turbulence from the blade tip, which is the highest frequency produced by the turbine and may be in the range 500 to 1000Hz.
- Gear and other mechanical noise, which may be in the range 20Hz to 100Hz or above
- Small pressure pulses caused when the blades interact with the wind flow at the tower. As these have a fundamental frequency of about 1Hz, analysis of their noise gives frequencies in the infrasound region, but at very low and inaudible levels.
- The swish – swish – swish noise, which is associated with wind turbines, is a low frequency modulation of higher frequency blade turbulence and does not contain low frequency noise. For example, compare an amplitude modulated radio signal, which contains only the carrier and sidebands. As some lay persons may be incorrectly referring to the low frequency modulation as low frequency noise, it is important to understand that it does not contain low frequencies**.**

There are several methods of reducing the low frequency noise of wind turbines.

- Placing rotors on the “upwind” side of the turbine tower reduces the low frequency pulses associated with the passage of the blades through the tower’s wind shadow, as occurs on “downwind” machines. In this way, the pressure pulses, which were produced by early versions of downwind machines over 20 year ago, are considerably reduced. It was these pressure pulses which led to the perception that significant infrasound is associated with wind turbines. Modern turbines are all upwind and have very low levels of infrasound.

- Gear noise is controlled by standard noise control procedures.
- Tubular towers and nacelles are streamlined, and produce little sound from the wind. If we consider a tower diameter of 2m and wind speed of 15m/s, the Strouhal frequency for turbulence shedding, f = 0.2(velocity/dimension) Hz, is then 1.5Hz and will be lost in the fluctuations which are inherent in the wind.
- As blade aerofoils have become more efficient, more of the wind is converted into rotational torque and less into noise.

Wind turbine noise at low frequencies is increased if the incoming air flow is very turbulent before it encounters the turbine blades.

1.2 Tonal Noise

In addition to wide band low frequency noise, tonal noise may also occur from wind turbines. The tonal noise may have both mechanical and aerodynamic origins. Tonal noise due to mechanical sources is typically associated with the rotation of mechanical equipment, and pure tones tend to be related to the rotational frequencies of shafts and generators and the meshing frequencies of the gears. Tonality differs between turbines and may also vary between tests of the same turbine model. However, the control of tonal noise from the mechanical systems is similar to that of noise control of any machinery noise and can be achieved by attention to gear teeth, adding baffles and acoustic insulation to the nacelle, using vibration isolators and vibration mounts for major components, and designing the turbine to limit noises from being transmitted into the overall structure. These steps are part of the normal design of modern wind turbines.

Aerodynamic tonal noise is from vortex shedding by the blades.

2.0 Perception of low frequency noise.

The ear is less sensitive to low frequency noise than it is to middle frequency noise. Table 1 shows hearing thresholds and is the compilation of two sets of results. One is the ISO Standard 226:2003 (ISO 2003) from 20Hz up to high frequencies and the other is Watanabe and Møller (Watanabe and Møller, 1990) from 4Hz to 125Hz. The hearing thresholds are median the levels, for which half the population of young people (18 to 25 year old) are more sensitive and half are less sensitive. Statistically, the standard deviation of threshold measurements is about 6dB, so that in the population as a whole, 68% of people are contained within about +6dB and – 6dB of the threshold. Half of the remaining (16%) are more sensitive than this limit. However, these statistics may not apply to small selections of the population of mixed age, as there is some reduction of hearing acuity with age, suggested as about 7dB for 50 – 60 year olds. (van den Berg & Passchier-Vermeer, 1999)

Freq Hz	4	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200
Level dB	107	100	97	92	88	79	69	60	51	44	38	32	27	22	18	14

Table 1 Threshold levels for young people

From Table 1 it can be seem that, for example, for a noise to be audible to half the young population at, say, 20Hz it has to be 79dB level.

3.0 General Spectrum of Wind Turbines

Many wind turbines, even though from different manufacturers, have similar spectra. This is because modern wind turbines are of similar construction. Some examples of noise from wind turbines are

1. Detailed measurements, using 1/24th octave band analysis in the range from 0.36Hz to 60Hz, of noise from a wind farm consisting of eleven 450kW turbines, the make of which was not stated (Snow, 1997). The measurement distance was 100m. It was shown that harmonics of the 1.5Hz blade frequency could be measured up to the tenth harmonic, and possibly higher. The levels of the lower harmonics were generally below 70dB and fell rapidly in level above 4Hz. All were well below their hearing threshold. (See Fig. 1)
2. A test report from Vestas on their V 52 – 850kW turbine gives many spectra under different operating conditions (Windtest, 2002) . A typical spectrum, taken at about 80m from the wind turbine, is shown in Fig 2. Here the analysis bandwidth is 2Hz.

Fig 2 shows a spectrum which rises up into the lower frequencies, reaching a maximum of about 70dB. There are peaks superimposed on the spectrum as follows:

Several peaks below 100Hz
A peak at nearly 200Hz
A peak at 600Hz

It is difficult to compare Figs 1 and 2 as the frequency ranges and analysis bandwidths are different. Fig 1 has a constant percentage bandwidth of about 3% and is plotted on a logarithmic frequency scale, whilst Fig 2 has a fixed bandwidth of 2Hz and is plotted on a linear frequency scale. However, the rapid spectrum fall off into the higher frequencies is shown on both Figures, whilst the constant percentage bandwidth of Fig 1 reduces the rate of fall off into higher frequencies as compared with the constant bandwidth of Fig 2.

3. A report from Bonus on their 1.3MW turbine gives spectrum details (DELTA, 2003). Measurements were made 100m from the turbine using a microphone ground board. Fig 3 is from this Noise Test Report . There are peaks on Figs 3 at 1450Hz, 850Hz, 485Hz and a dip at about 150Hz. As the frequency lowers there is a rise on which other peaks are superimposed. The final maximum is at about 11Hz. The fall off below 11Hz is likely to be an instrumentation effect. There are, in fact, large micro-fluctuations in air pressure (natural infrasound) occurring from very low frequencies of , say 0.001Hz up to about 2Hz, but these are not relevant to disturbance by noise.

It is clear that, although low frequency noise is produced by wind turbines, the low frequency noise levels from modern machines, for which we can take the Bonus 1.3MW and the Vestas V 52 850kW turbines as examples of previous measurements, are low and are very unlikely to be a problem at a few hundred meters from the turbines.

4.0 Measurements of noise of GE 1.5 Wind Turbines. A calibrated DAT tape was supplied for analysis. The tape, which contained about 17 minutes of recording, had been recorded by Tom Siener of Ecology and Environment on October 6th 2005 at the Fenner Wind Farm New York. Recording position was on the roadside between turbines #3 and #4. The distance of #4 to the west was 400ft and the distance of #3 to the east was 450ft. The sound level meter (B&K 2260) was tripod mounted at 4.5ft and connected to a Sony TCD-D100 DAT recorder. The two nearest turbines will have made similar contributions to the noise at the measurement point, which was 4.5ft above ground. The wind speeds at ground level ranged from 900 fpm to 1300 fpm. Listening to the tape showed slow variations in noise level over the recording time. Accordingly, analyses were made over approximately one minute durations, whilst avoiding periods of disturbing noise.

4.1 Measurement results These are shown in Fig 4 to 9, which are generally of the same form as each other and similar to Figs. 3 and 4. The spacing of frequency points in these figures is 2.5Hz.

In all the Figures, the rise into very low frequencies is unlikely to be wind turbine noise, but the general effects of wind as background noise and also wind acting on the microphone as wind shields lose their effectiveness at very low frequencies. The drop in level towards zero Hz is an instrumentation effect, as the recording system has lower limit of about 10Hz.

The sound corresponding to Fig. 4 was recognisable as from a wind turbine, but relatively low.

Fig 5 had a stronger sound and greater fluctuation. The difference between Figs. 4 and 5 is seen as a general increase in levels by around 5dB, including down to the lowest frequency, which indicates a greater wind speed.

Fig. 6 was for a quiet period, as shown in the analysis which, above 100Hz, drops below the 20dB limit of the sound level meter.

Fig. 7 follows a very similar slope to Fig. 4, but is a few dB higher in level throughout the spectrum.

Fig. 8 is of generally low level and, at higher frequencies, falls below the sound level meter 20dB limit.

Fig. 9 corresponded to a period of more pronounced swish than at other times. The levels are higher and two spectrum peaks occur between 150 and 200Hz. Comparison of Figs. 5 and 9 shows that the peaks are beginning to show in Fig 5, but not as developed as in Fig. 9.

5. Conclusions

Noise from the GE1.5 turbines is of similar form to that of other turbines.

Wind turbine noise fluctuates in level over short time periods, depending on fluctuations in the wind.

Under normal propagation conditions, wind turbine noise reduces by about 6dB for each doubling of distance. Thus the measured levels will be about 6dB lower at around 800 ft and 12dB lower at around 1600 ft , although non standard propagation effect may cause variations in these reductions.

At the measurement position, the median young persons hearing threshold was exceeded above 50Hz. Exceedance will not occur until higher frequencies at further distances.

The GE 1.5 turbines do not display any unusual low frequency noise characteristics.

References

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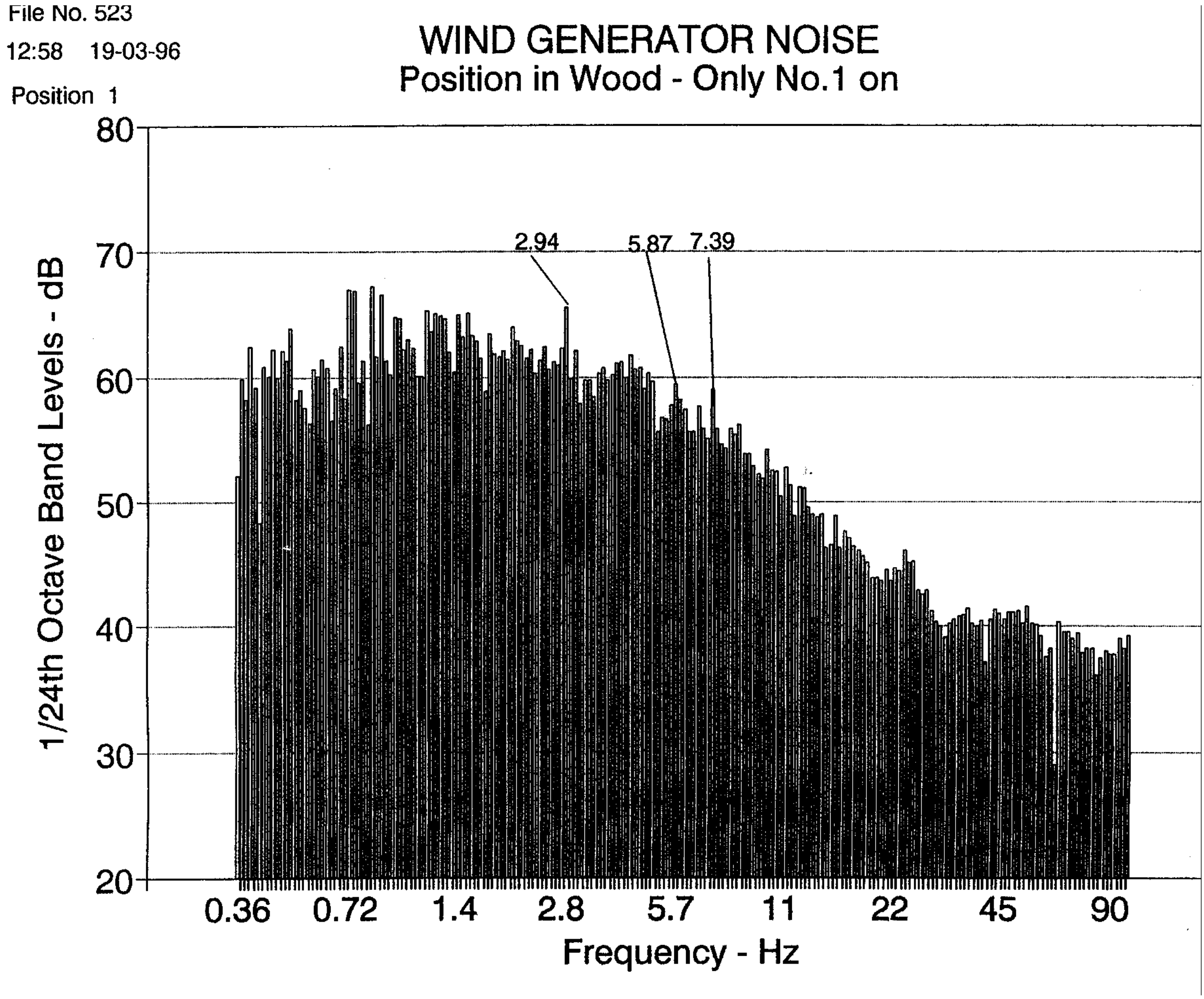

Fig 1. Low frequency noise from a wind turbine. 1/24 octave band analysis

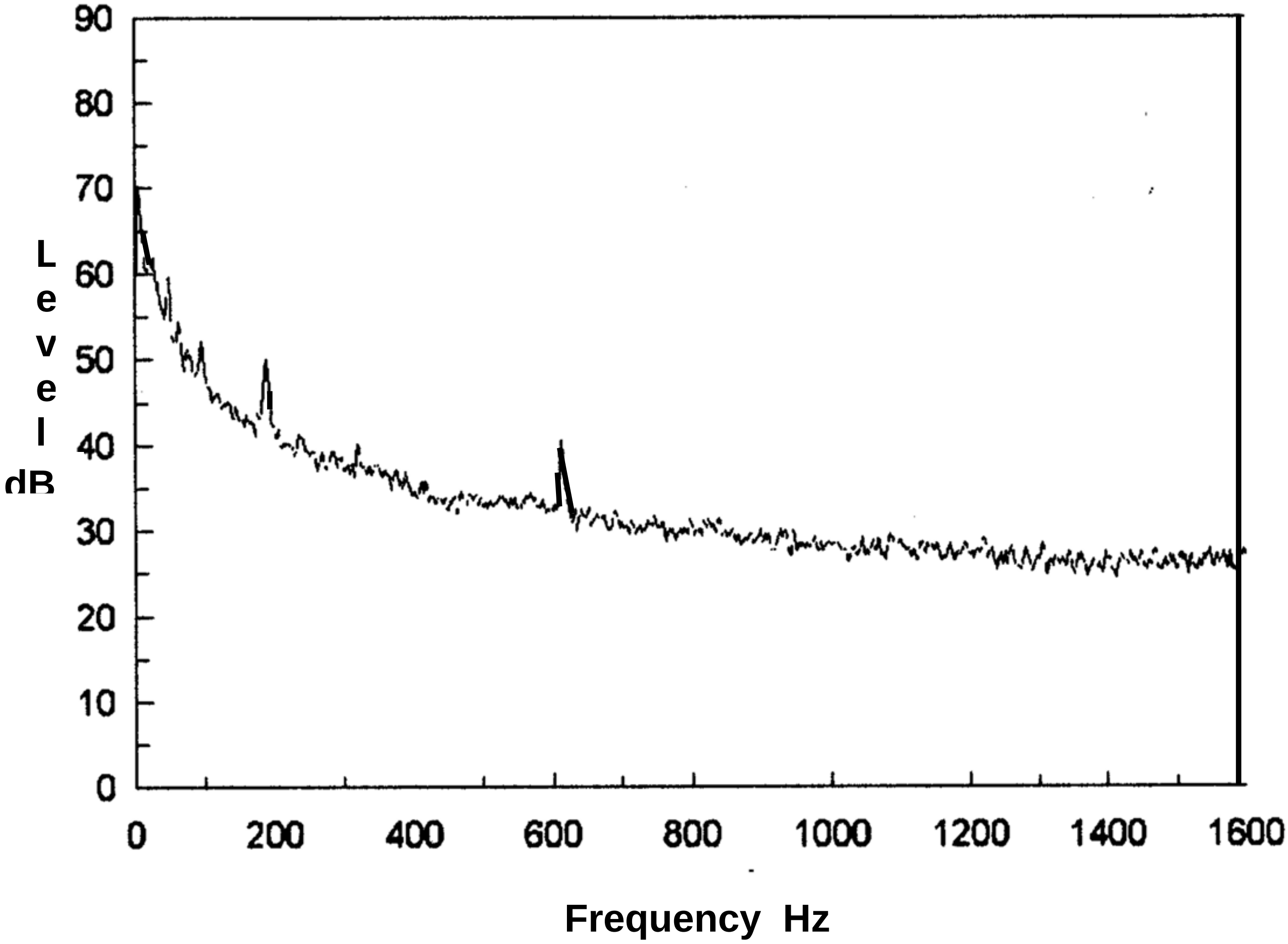

Fig 2 Vestas V52 - 850kW wind turbine. Typical noise at 10m/s wind speed

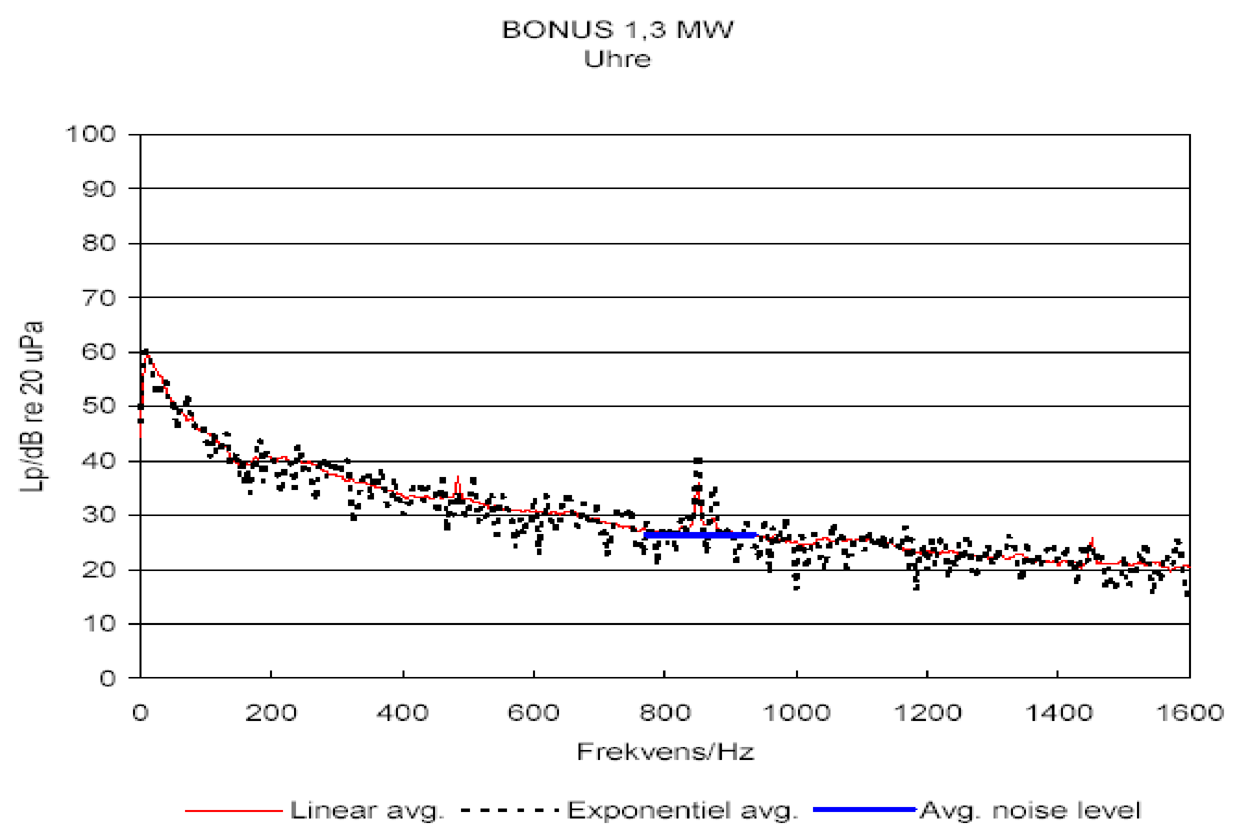

Fig 3. Analysis of noise from Bonus 1.3MW wind turbine.
(From report by DELTA to Bonus)

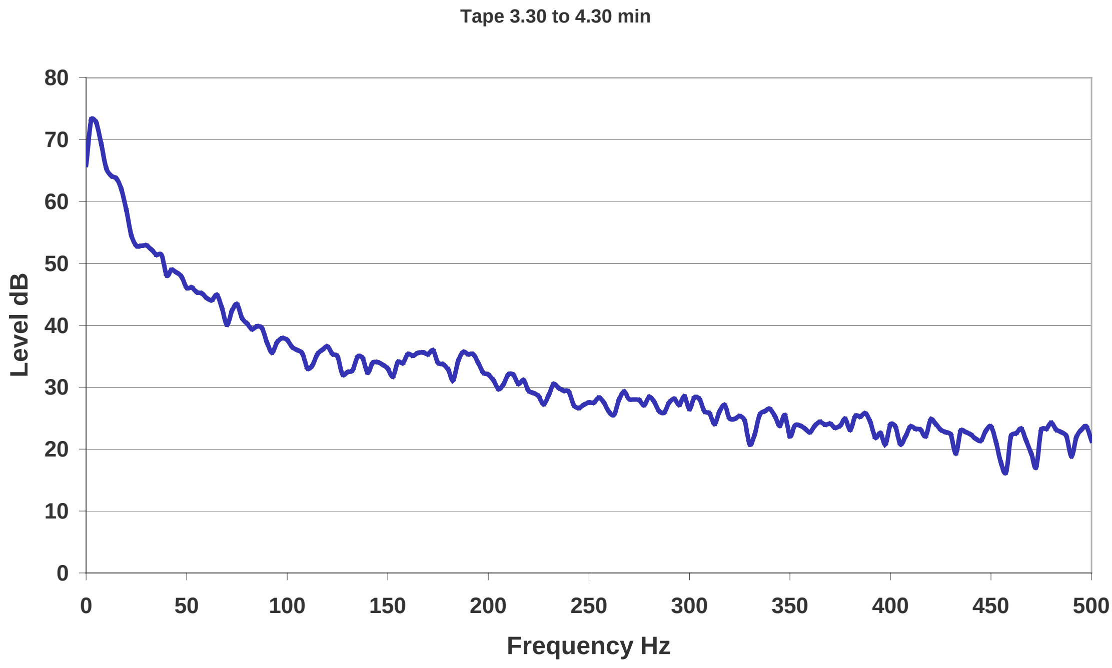

Fig. 4   Tape 3.30 to 4.30 minutes

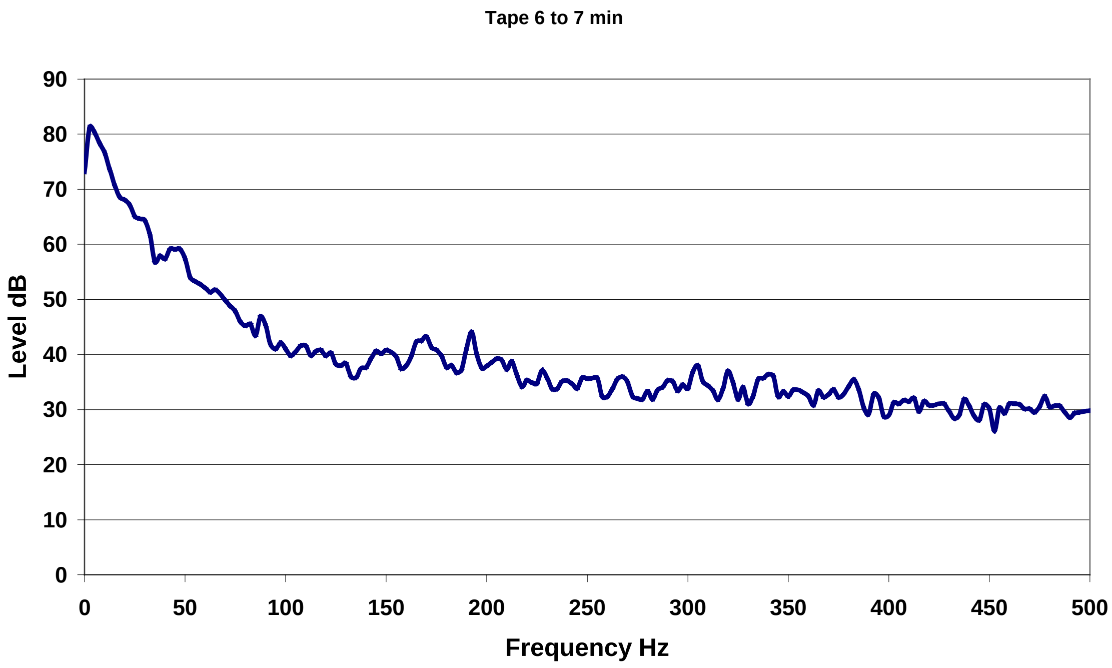

Fig. 5 Tape 6 to 7 minutes

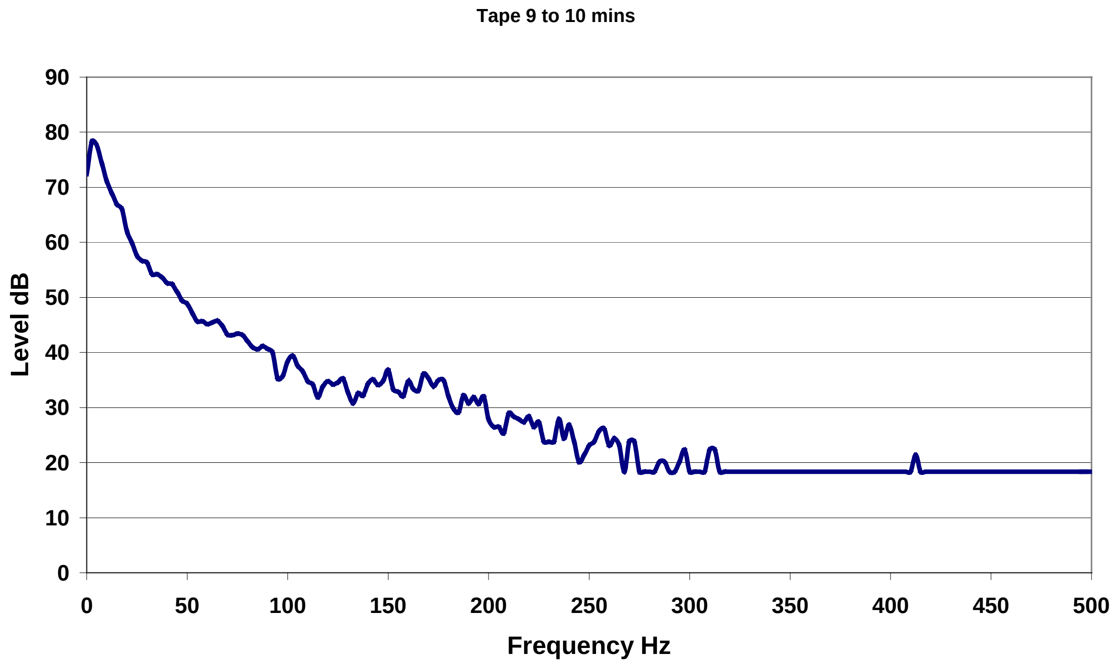

Fig. 6 Tape 9 to 10 minutes

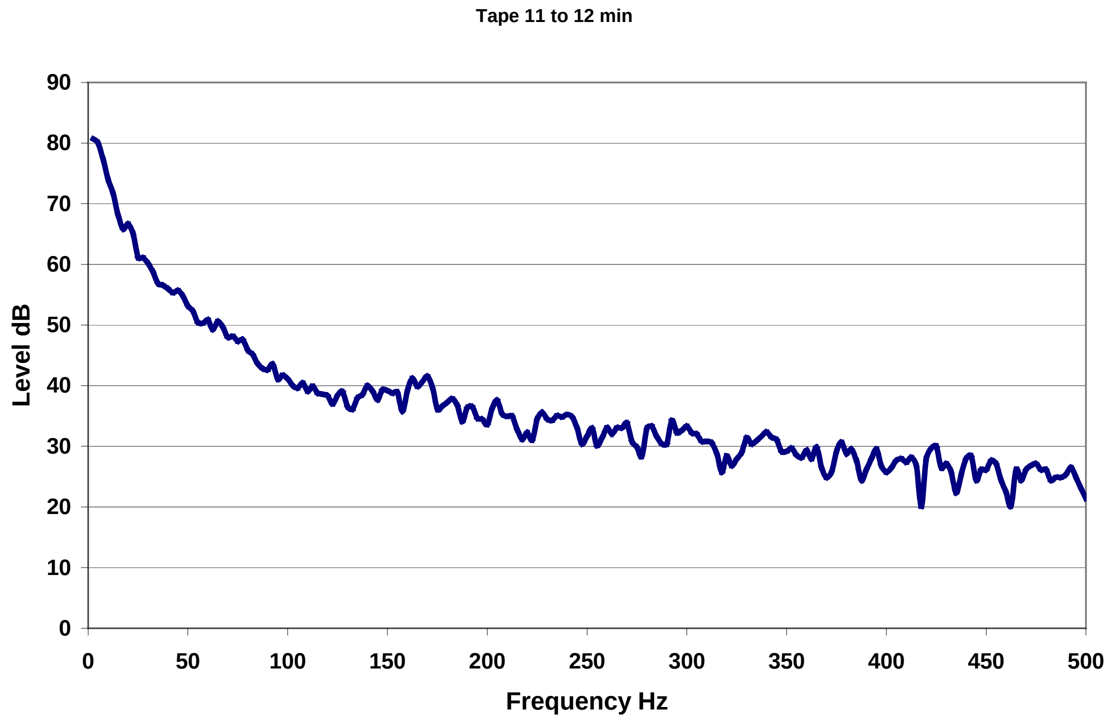

Fig. 7 Tape 11 to 12 minutes

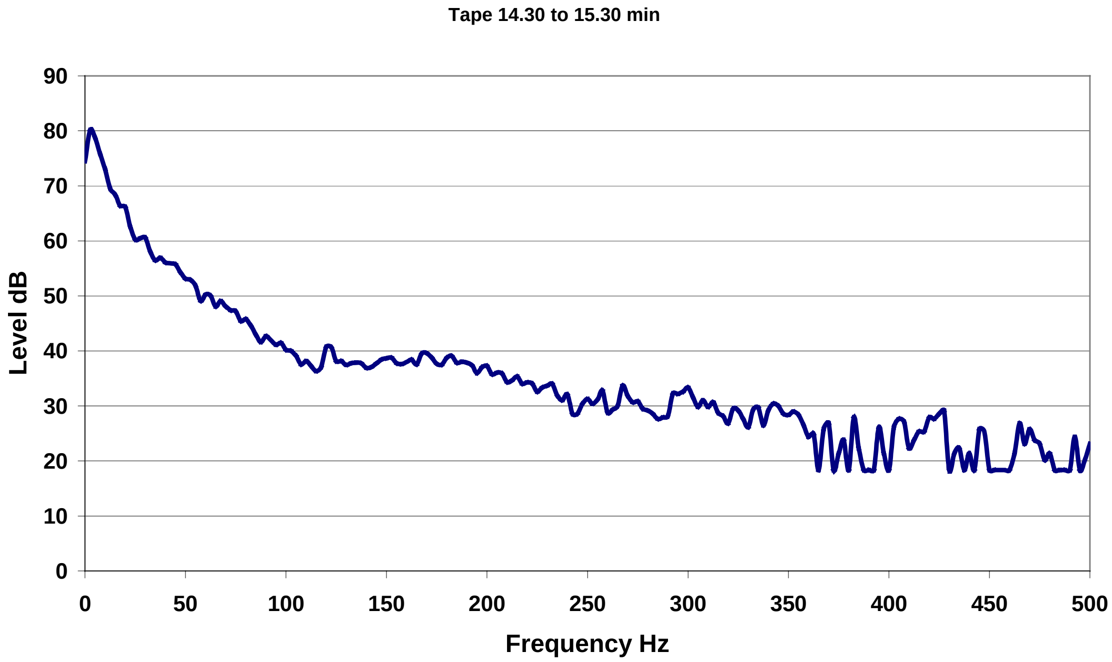

Fig. 8   Tape 14.30 to 15.30 minutes

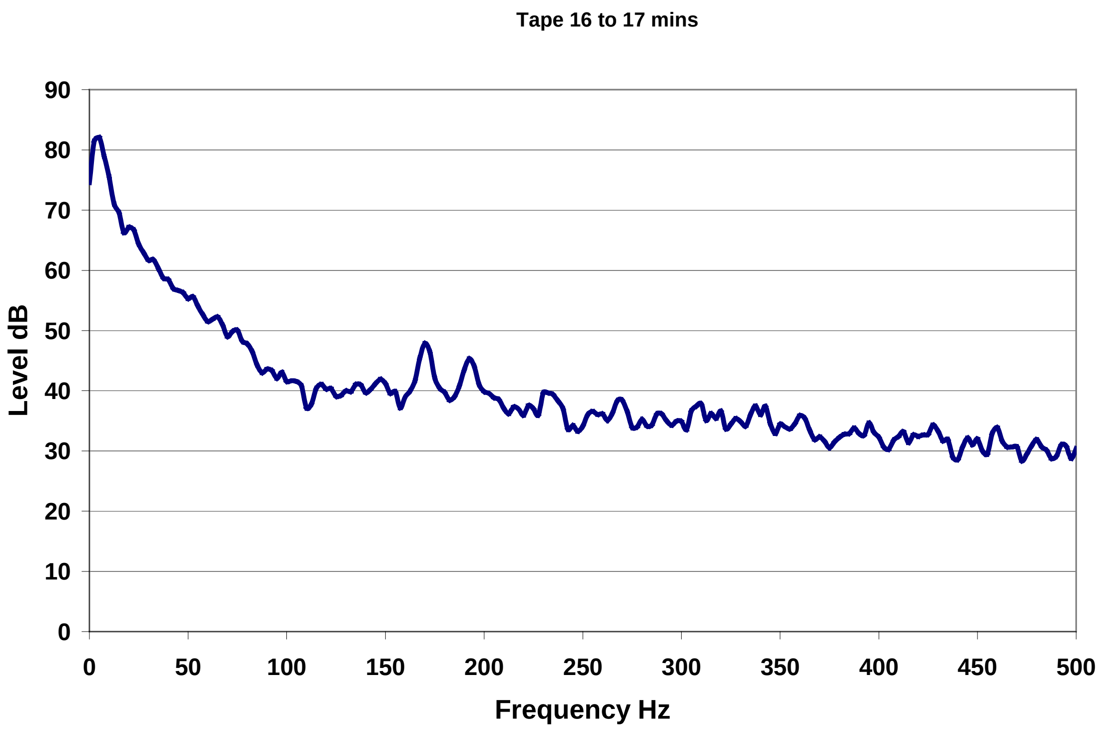

Fig. 9   Tape 16 to 17 minutes