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THE USE OF SHORT-TERM L_{Aeq} IN THE ASSESSMENT OF IMPULSIVE NOISE

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1 INTRODUCTION

The use of L_{Aeq} as a general descriptor of environmental noise is now widespread and is embodied in international standards such as ISO 1996 (1) and in national standards such as the revised BS 4142 (2). Both standards use the concept of a reference time interval, being the specified time interval to which an equivalent continuous A-weighted sound pressure level is referred. Generally such reference time intervals are long such as 8 or 12 hours. Sometimes hourly values of L_{Aeq} are specified but even this gives rather a broad picture of a given situation. At the other extreme we can record the complete noise signal for subsequent analysis back in the laboratory but this is inefficient in the use of data storage and often inconvenient. The advent of cheaper computer disc storage led to a proposal in 1979, in a report to the CEC by Komorn and Luquet (3), of a method of storing data called Short-Leq which compressed the data but ensured its integrity and yet stored a true representation of the original noise.

The method suggested was to integrate the sound level over a short period, typically under 1 second, and produce a non-time weighted Leq for this short period. This "Short Leq" would be stored and a further Leq taken, with no gap between them, continuing with successive Leq's for the duration of the whole measuring period. The advantage of the method is that the Leq is a true integral of the energy and thus accurately describes it for all statistical purposes.

Commins and others (4,5) went on to develop special instrumentation and showed that by varying the integration time and performing correlation analysis between pairs of simultaneous measurements it was possible to discriminate between sources and evaluate their relative importance. More recently Wallis and Luquet (6) have described an instrument which allows the full realisation of IEC Standard 804 (7) and is capable of storing over 100,000 separate L_{Aeq} values whilst at the same time giving conventional values of L_{Aeq}.

However there are situations when integration times of 1/8th of a second can be too long and even more detail is needed. In the course of work at NPL, supported by the Department of the Environment, on the evaluation of impulsive noise (8), a computer-based noise analysis system was programmed to implement an integration time of 10 ms and the subsequent time-series was further processed by various methods which gave good correlations with the results of subjective experiments on judged annoyance in laboratory conditions. More recently in the course of the Joint Project on Impulse Noise, funded by the CEC, this work has been taken further and a CRL 2.36 data acquisition integrating sound level meter made by Cirrus Research has been modified to take the short-term period down to 10 ms and further descriptors based on $L_{Aeq(10\ ms)}$ have been investigated.

This paper outlines the concept of short-term L_{Aeq} and discusses the associated instrumentation. Special rating methods based on processing the time-series of $L_{Aeq(10\ ms)}$ are introduced and their relationships with subjective data are discussed.

2 SHORT-TERM L_{Aeq}

Equivalent continuous A-weighted sound pressure level, $L_{Aeq,T}$, is the value of the A-weighted sound pressure level of a continuous steady sound that within a specified time interval, T, has the same mean-square sound pressure as a sound that varies with time. It is given by the equation:

$$L_{Aeq,T} = 10 \log[1/T \int_{t_1}^{t_2} (p_A^2(t)/p_o^2)dt]$$

where

$L_{Aeq,T}$ is the equivalent continuous A-weighted sound pressure level determined over an interval $T = t_2 - t_1$ (s)

p_o is the reference sound pressure (20 μPa)

$p_A(t)$ is the instantaneous A-weighted sound pressure (Pa).

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One can consider the value of $L_{Aeq,T}$ as a measure of the actual energy of the signal $p_A(t)$ between t and t + T. We can choose small values of T such as one second or less without giving any statistical significance to these values of $L_{Aeq,T}$ with respect to the $p_A(t)$ process. This integration process over successive periods leads to a time-series which can be analysed for itself. Each value of $L_{Aeq,T}$ is totally independent of previous and succeeding values. Figure 1 shows part of a 2 hour plot of the noise around an Air Force base in France using both a 10 minute and 10 second period for $L_{Aeq,T}$. The detail of events provided by the shorter time is readily apparent.

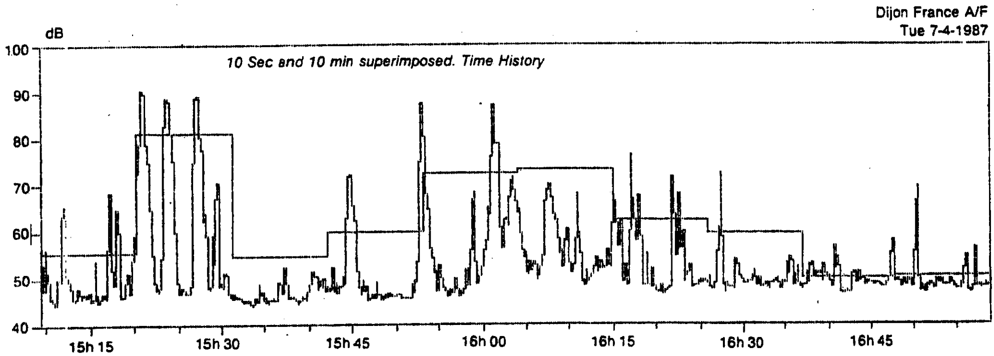

Figure 1. L_{Aeq} time histories

3 INSTRUMENTATION TECHNIQUES

The basic method is to calculate values of L_{Aeq} at intervals of either 125 ms, 1 second or 10 seconds and acquire the data into the non-volatile memory of the instrument where they are available to be used for subsequent analysis by a desktop or laptop computer. Each separate measurement session is identified in the memory by a data header and any number of separate sessions can be made, subject to the total memory limit of the instrument. Four code buttons fitted to the instrument allow particular noises to be identified and coded on-site. These codes are automatically transferred to the computer when the data are read over.

Details of the specific technique used in the CRL 2.36 were published by Wallis and Holding (9). The signal after filtering is passed to an analogue squarer to generate a current proportional to the energy reaching the microphone. This current is integrated in a totally analogue integrator. Only at this stage is it digitised and because there is no sampling done on the raw AC signal the problems of sampling rate error are designed out. The integrated signal is stored and converted to a digital value while the next period is being integrated thus the only lost time between periods is the sample and hold circuit acquisition time which is of the order of a few microseconds.

In the special instrument developed for NPL the basic period was reduced to 5 ms and the values concatenated to give $L_{Aeq(10\ ms)}$. With the decrease of acquisition time from 125 ms on the standard instrument to 5 ms, problems not considered in the original design showed themselves.

For example, the integrator feeds a 12 bit counter. If the instrument had 125 ms to fill this, the maximum speed of the integrator would be $125/4096 \times 10^3$ microseconds, about 30 microseconds. When this is speeded up to acquire in 5 msec, the fastest time is now just over a microsecond, which generates current supply demands that are impossible to meet in a battery unit. This was the limiting factor in the design. Thus, a trade off was made in the capacity of the counters, which reduced the dynamic span of the unit down to about 90 dB from the normal 120 dB, each 1 bit removed dropping the dynamic span by 3 dB. The final design is such that a single 20 kHz half sine wave, the fastest acoustic impulse we have considered can be acquired to the full system accuracy.

In the instrument we are reporting, the 5 ms elements are combined into a single 10 ms for storage. This approach was chosen as it was not clear at the start of the investigation what actual period would be required and it was felt that a single investigation to get down to 5 ms would leave some headroom for error. The standard CRL 2.36 has a capacity of 114,000 stored integrals which was not increased. With a 10 ms acquisition, this gives a total acquisition time of only 10 minutes although 125 ms and 1 s acquisition periods were included to give operating times of 4 and 30 hours respectively. Further development is in progress to increase the memory size to 1 Megabyte.

At any time after acquisition the data can be copied to a host computer, normally an IBM PC or compatible, via a RS232 port, and the data stored in permanent form on the disc. The software leads the user through a few simple steps, such as asking the name under which to file the data and the place and time of acquisition. Any one of a number of measurement sessions can be copied to the computer in this way leaving the original data retained in the memory of the instrument until the user chooses to discard it.

With a copy of the data safely stored on disc the measurement can take place. With short-term L_{Aeq} the acquisition and measurement phases are separated so that each of the two computers, the one in the instrument and the other in the host machine, can operate at full efficiency. The software allows any measurement to be made where peak levels are not involved, thus histograms and cumulative histograms can be plotted and percentile levels calculated. The simple time history of noise level between any two times can be plotted. Figure 2 shows the result for the noise of a pile driver with short term periods of 10 ms and 1 second. Note the detail provided of the individual impulses.

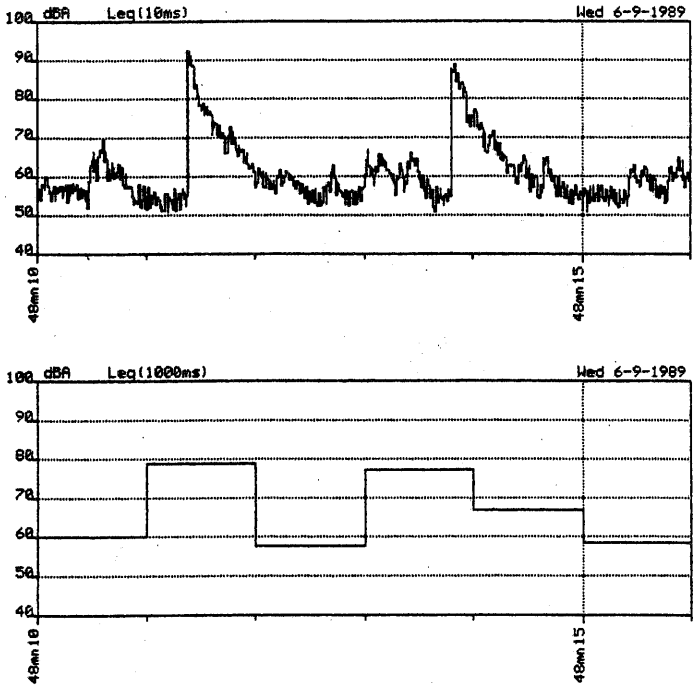

Figure 2. Time histories of pile driver noise, T = 10 ms and 1 second

In addition to the standard software, special routines have been written to analyse the time series and calculate special objective measures or descriptors of impulsiveness.

4 RATING METHODS FOR IMPULSIVE NOISE

The CEC Joint Project on Impulse Noise began in October 1987 with the aim of developing a physical objective method for quantifying impulsive noise. There are essentially two related parts to the project. Three laboratories - the Institute of Sound and Vibration Research, University of Southampton (ISVR), the Medical Institute for Environmental Hygiene, University of Düsseldorf (MIU) and the Institute of Acoustics (IDAC) in Rome - have been conducting listening tests under a common protocol on the subjective rating of impulsivity and annoyance of a wide range of noises.

NPL and the Institute for Medical Psychology (IMP), University of Düsseldorf have been studying the problem of physical quantification methods in order to derive an optimum objective rating.

Both NPL and IMP have focussed on methods based on processing the time-series of $L_{Aeq(10\ ms)}$, with NPL concentrating on time-domain methods and IMP on frequency domain methods.

Time domain

Three descriptors have been assessed - standard deviation, salience and increment. Standard deviation is obtained by taking each of the 100 values of $L_{Aeq(10\ ms)}$ in any one second interval and calculating according to the common formula

$$(\text{standard deviation})^2 = \frac{1}{100} \sum_{i=1}^{100} (L_{Aeq(i)} - \bar{L}_{Aeq(i)})^2$$

Salience is calculated from the difference between the maximum value of $L_{Aeq(10\ ms)}$ in a one-second interval and the overall value of L_{Aeq} for that interval. Increment is found by taking differences between successive values of $L_{Aeq(10\ ms)}$ and noting the maximum positive difference. The concepts of salience and increment are illustrated graphically below for a one-second segment of pile driver noise.

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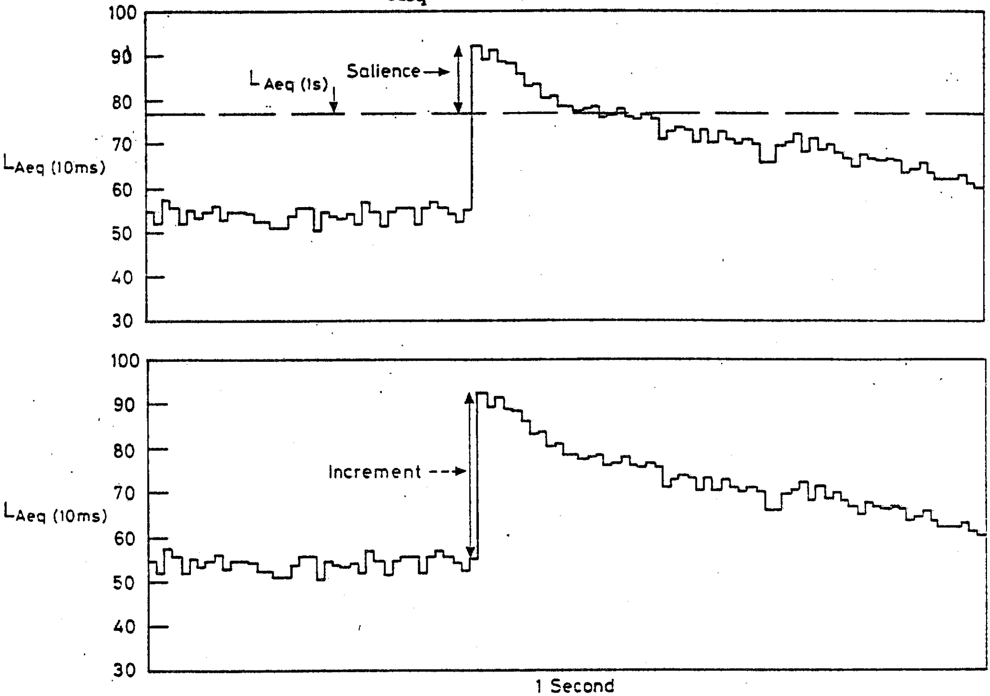

Figure 3. Concepts of salience and increment.

The individual values of $L_{Aeq(10\ ms)}$ making up the time series are evident in this "zoomed-in" view of the time-history provided by the standard software.

Frequency domain

We can regard the time-series or envelope function of the original signal as a "signal" in itself with frequency components from 0 to 100 Hz. Bisping (10,11) has shown how this signal can be analysed using Prony spectrum techniques. The powerful zooming capabilities of Prony compared to FFT techniques allow high resolution analysis of small bandwidth sinusoidal components embedded in noise. Early work simply considered qualitative effects such as the pronounced frequency spreading effect of impulsive noise compared to steady noise. Later however measures expressing the relevant information contained in the Prony spectra in one single number, such as spectral flatness (12), were investigated.

In Phase 1 of the project October 1987 to April 1988, ISVR, MIU and IDAC conducted experiments with 64 noises. These consisted of a common core of 40 used by all laboratories and a set of 24 noises specific to each laboratory. Each laboratory used 16 subjects who had to rate the 64 noises each presented for twenty seconds. Four questions were used in the questionnaire. NPL analysed all 40 common noises using salience, standard deviation and other methods such as crest factor and L_{AI} - L_{AS}. The results of the physical analyses were related to the subjective data for each laboratory. From the resulting correlation matrix it was concluded that the standard deviation was superior to the other methods (13).

In Phase 2 of the project, May 1988 to March 1989, the increment descriptor was included. When applied to the Phase 1 data it was found to be superior in its correlation with subjective data. The various noises used in separate further experiments by MIU, ISVR and IDAC were analysed and it was found that the increment descriptor performed best overall. Details were given at the 13th ICA in Belgrade (14). Also during this phase Bisping (11) found correlations of the order of 0.8 between subjective impulsiveness and the difference between the mean L_{Aeq} and the maximal amplitude of all the poles in the Prony spectrum between 0.3 and 25 Hz.

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