A NEW NON-INVASIVE MONITOR TO MEASURE NOISE EXPOSURE FROM HEADSETS.

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1. INTRODUCTION.

For many years, it has been realised that no exact method is readily available to measure noise exposure of anyone wearing a headset of any type, be it for telephone or hi-fi type applications. With the ever-increasing number of headset wearers in working environments such as call centres, concerns about possible health hazards and compliance with Health and Safety at Work legislation led the U.K.'s Health and Safety Executive (HSE) to investigate typical noise exposures of headset wearers. As a result of this experience, a research project was proposed that would develop a simpler, quicker means of determining the noise exposure than the methods used in the initial investigations. The competitively tendered contract was awarded to A.V.I. Acoustic and Vibration Instruments Ltd (AVI) late in 2001, and this paper describes the development of a monitor to fulfil this role.

2. BASIC PRINCIPLES.

In order that the monitor be simple to install and operate, and not interfere with the tasks being undertaken by the headset wearer, it was decided that the only information available was the electrical signal sent to the earpiece of the headset. However, monitoring this signal alone will never give any accurate information regarding the noise levels experienced by the headset wearer. Furthermore, the frequency spectrum of the electrical signal is unlikely to be the same as would be experienced by the headset wearer. To be effective, the monitor must therefore take both these factors into account in some manner.

In addition to the monitoring of the signal to the earpiece, a knowledge of the acoustic conditions in which the headset wearer is working was also deemed relevant, and it was proposed that both the ambient noise in the vicinity of the headset wearer and the noise exposure due to the signals in the earpiece were measured and logged simultaneously. This is especially relevant for operators who wear headsets with only one earpiece, leaving the other ear exposed to the ambient noise.

2.1 Outline Specification.

To minimise installation difficulties and to avoid any safety issues, the monitor has to operate stand-alone, and therefore needs to be battery powered. Battery life therefore needs to be a minimum of about 12 hours to guarantee that any workshift period can be fully monitored. To avoid the possibility of any operator interference with the monitor, it was decided that it would have no controls or display fitted, and would be operated solely by plug-in connection to a computer to initiate measurement and collect measured data. A laptop PC is therefore ideally suited to this task, and a programme known as LOGGER brings together all the required functions for monitoring.

Enabling the monitoring process requires the headset to be disconnected from its normal connection socket, the monitor plugged into the vacated socket and the headset into the monitor unit. Briefly connecting the monitor to a PC would cause the commands necessary to start monitoring to be sent, and it can then be disconnected until data is required from the monitor. Reconnecting the PC enables the logging process to be terminated and data to be downloaded.

This outline specification forms the basis of the monitor unit delivered to the HSE in 2003.

3. HEADSET CHARACTERISTICS.

To measure the noise exposure in the ear of the headset wearer, the information required can be obtained by the combination of two components. The first is the electrical signal present on the cable to the earpiece, the second is a knowledge of how that signal is perceived by the wearer of the same earpiece. Whilst the first is easy to measure in real-time, the second is not; however, it is not necessary to measure it in real-time, as its characteristics are non time-variant.
What is required is the transfer function between the electrical input and the response of the wearer at all frequencies in the input bandwidth plus the correlation between magnitude of electrical input and the acoustic output of the earpiece. This could be measured on an artificial head and torso simulator (HATS), but does not really require the full attributes of such a device as the only section of interest is the ear canal.

AVI decided that a low-cost version of HATS, with just the relevant sections required to measure the headset-to-wearer transfer function, would be required and set about designing such a device. The full information on this is presented in the paper by Dr. Paul Darlington entitled “Practical measurement of Telecommunication Receiver Electro-Acoustics for the Computation of Acoustic Dose” presented at the same meeting as this paper (1). The final output of the system is a file of filter coefficients, and their use will be discussed later in this paper.

4 DESIGN OF THE HEADSET MONITOR UNIT.

The monitor unit was designed with the minimum of controls and indicators deemed possible. This was partly for simplicity and low cost and partly so that no obvious ways of influencing anything on the monitor could be deduced by the headset wearer. In order to achieve this approach, the functionality of the monitor had to be controlled from an external source, and a PC was deemed the most appropriate.

The monitor unit has no ON/OFF switch, to prevent any accidental turning off, and fitting batteries to it places the unit in a Sleep mode requiring little battery power. The power source was selected as two AA size batteries, and all internal voltages were kept as low as possible, so nothing greater than 3.3 volts is ever required. Simple RS-232 serial links were provided, and a PIC microcontroller used to operate the monitor internally. Connecting a cable between the RS232 port of the PC and the monitor was selected as the means of making the monitor wake up and be ready to operate, and a single LED was fitted to give a status indication. This finished with 6 indication states, and will be detailed later.

4.1 Monitoring Channels.

In order that both the headset and the ambient noise could be monitored, two analogue channels were designed in. One requires an electrical connection to the telephone line earpiece signal, is protected from excess voltages that may appear on the line, and has a dynamic range of approx. 80 dB, typically covering the range 40 – 120 dB SPL in the ear. The other channel is connected directly to a good quality electret microphone whose characteristics are well known and which is suitable for the measurement of noise over the full audio bandwidth. The microphone characteristics meet the requirements of a Type 1 sound level meter according to IEC60651, and therefore can be safely used as the data-gathering device for any ambient noise exposure measurement. (Type 2 characteristics, which have wider tolerances than Type 1, are acceptable for most noise at work measurements.). The microphone was mounted into the same enclosure as the rest of the electronics in such a way that the pick-up of noise was local to the headset wearer but not unduly influenced by close proximity of speech from the headset wearer or other local noises such as cable movement. This microphone can be calibrated using a standard acoustic calibrator to a level of 94.0 dB, and adjustment in the electronics is possible to achieve this setting. It is recommended that this is checked annually to remove any elements of drift in microphone sensitivity, but this should always be small. The microphone channel has a dynamic range in excess of 60 dB, covering the range <50 to 110 dB.

4.2 Frequency and Amplitude corrections.

The noise exposure from each source needs to be computed with a number of corrections and weightings applied. Taking the ambient microphone first, the A frequency weighting is applied as would be normal for all hearing related noise measurements, and then the noise energy is computed in one minute intervals and presented as one minute Leqs (equivalent-continuous sound pressure level) for storage in the monitor's non-volatile memory, ready for download as required.

The signal on the telephone line has two stages of frequency/amplitude correction applied. The first is the specific headset transfer characteristic as measured on the AVI dummy head, which relates the frequency spectrum and amplitude as perceived by a wearer to the frequency analysis of the input electrical signal. The second correction enables the levels measured in the ear to be related to the equivalent diffuse field sound pressure levels, for which the action levels were set, so that the noise exposure is equivalent to someone who does not have their ears enclosed by a device such as a headset. These two corrections are rolled together in the headset file, which is unique to each headset make and type. Using these frequency and amplitude adjustments produces the noise exposure details which allow the one minute Leqs for the headset earpiece to be computed and stored, exactly matching the data from the ambient monitoring microphone. Note that the A-weighting characteristic used to measure in free field conditions does not apply to these corrections and is not required in that form as the two measurements used effectively include the effects the A-weighting is designed to mimic.

The measurement of the transfer function for each type of headset, together with the diffuse field transfer function, which is similar for many different makes and models of headset, is the key to the monitor's operation. The processes for producing these measurements are covered in Dr. Paul Darlington's paper. (1).

All frequency and amplitude correction data are loaded into a Digital Signal Processing (DSP) circuit contained inside the monitor. All communication with this device is made via the PIC microcontroller using the serial interface with the PC, which is required each time a monitoring session is prepared.

In order to accommodate as many different headset types as possible, the monitor does not retain any information on the headset type in use except during actual data logging. The PC LOGGER programme allows the accumulation of as many headset types as is required by the user, and each time a monitor is set ready for measurement, the appropriate file is loaded into the monitor. The final section of loading this file sets the monitor logging, and it is not possible to stop and restart the monitor without the appropriate headset file being reloaded. This should ensure that the person initiating the logging process is prompted to check the headset type in use and therefore loads the appropriate data prior to monitoring starting. By this means, an organisation with many different types of headset in use can use the same monitor and PC to log any wearer under surveillance, with no changes to any of the procedures required to monitor and report the noise exposures.

The DSP circuit applies all the frequency and amplitude corrections in real time over the full bandwidth of the communications line. It computes the 1 minute Leq values and passes these to the microcontroller which in turn saves them in non-volatile memory. Each pair of 1 minute answers is saved following a header that defines the start time and date (taken from the PC initiating the measurements) and some setup information including the headset type and software version information.

4.2 Construction.

The monitor was designed with cost in mind, although not at the expense of performance in the dynamic range of signals that could be measured. It is accommodated on a single circuit board inside a housing measuring 110mm wide, 140 mm deep and just 35mm high. The ambient monitoring microphone is mounted flush with the top face of the monitor box. The front panel contains just the indicator LED, whilst the rear panel houses the battery compartment cover, cable entry point and the socket to connect to the PC. There is only one internal adjustment – for calibration of the ambient microphone. This is achieved by removing 1 retaining screw to release the top cover of the monitor, applying an acoustic calibrator to the now exposed microphone, monitoring the level reported on LOGGER using the continuous update mode, and adjusting the control to obtain the correct reading of the calibrator's level (if required). It is recommended that this calibration is undertaken at least annually, and can be done by AVI or by anyone with a suitable acoustic calibrator available.

5 USING THE MONITOR.

The number of operational steps required has been kept to a minimum to reduce time spent setting up and analysing data. Before contemplating monitoring a headset wearer, the transfer function of the headset type must previously have been measured. Details of this are in (1) and can be obtained quite straightforwardly either by the user owning an AVI dummy head and associated measurement system or by supplying AVI with a headset and having it measured for them. The file of data on the headset is then assembled into the HEADSET TYPE location of the LOGGER programme, either added automatically if the user owns an AVI dummy head, or downloaded from a supplied file. Once this file is in place, the monitoring process is ready to commence.

5.1 Preparation.

The monitor unit must be fitted with the correct cable assembly to suit the type of headset connector in use and have batteries fitted ready for use. The headset should be unplugged from the normal telephone line point, and the monitor unit should be inserted in series with the headset. The PC to be used to initiate monitoring should be connected to the serial port connector and the LOGGER programme run on the PC. (NOTE: this can be done before the monitor unit is connected to the headset, but may result in some spurious readings that get logged when the headset is eventually plugged in.)

The headset file matching the type in use needs to be selected as the file to be loaded into the monitor, and then needs to be loaded into the DSP chip in the monitor. This takes a few seconds. When complete, the monitor will return information that all is well to the PC and commence logging. The PC can now be disconnected and the unit left to monitor for as long as required, or left connected. An option to view the measured data in real time every second is available on the PC screen, along with the last complete minute's answer set that was saved to the monitor's memory. This feature could be useful for examining typical maximum and minimum levels at a wearer's location without the need to monitor for long periods of time.

5.2 Status Indicators.

To indicate the status of the monitor, a small LED is fitted to the front panel. This has a variety of displays as follows:-

1. LED off – monitor either has no batteries fitted or is asleep.
2. LED on all the time – monitor is ON, not logging, and has no data in its memory. It will also be on all the time when the DSP file is being loaded from the PC
3. LED on most of the time, flashing off briefly every 2 to 3 seconds. – Monitor is ON, not logging, but has data in its memory ready for downloading
4. LED off most of the time, flashing on briefly every 2 – 3 seconds. - monitor is logging OK
5. LED is flashing quickly, 5 times a second – Fault condition – the battery is running low, the memory is full or an error has occurred during monitoring.
6. LED is flashing evenly about once per second – Data is being downloaded from the monitor to the PC successfully.

For the wearer of the headset, there are really only two LED conditions that would be expected to occur – numbers 4 and 5. If all is well and the monitor is operating correctly, the occasional flash of the LED should show this to anyone observing it. If this changes to a rapid 5/second flashing, something is wrong and it needs attention from the appropriate person. If the unit is positioned such the the headset wearer can see the LED during use, the fault condition should be observed and reported without too much delay occurring. The other 4 states mainly confirm the monitor’s status to whoever is interested in measuring the headset.

5.3 Data retrieval.

When sufficient monitoring time has elapsed, the unit requires reconnection to the PC and the STOP LOGGING command needs to be sent. Once the monitor has acknowledged this, the data in its memory is available for downloading (but not until it has stopped logging). The data can then be downloaded in an EXCEL spreadsheet format and saved on the PC under any name given to it by the PC operator. As soon as the download is complete, the operator is given an option to view the whole file immediately and either to retain the data in the monitor or erase it. The monitor will retain the data (even if no batteries are fitted) almost indefinitely, and it can be downloaded as many times as required if the memory is not erased. To avoid any confusion with further uses of the monitor, the loading of a DSP file (required before every monitoring operation gets going) also erases the memory of any previous data, so no confusion between data sets is possible.

Once downloaded and saved on PC, the monitor can be restarted for monitoring another headset wearer. If the headset type is the same as previously monitored, the PC operator can go straight to the Loading stage without needing to reselect the headset type, as this will be prompted on screen automatically.

6 RESULTS

The data available on the PC immediately after a download gives the following parameters:-

Date and time of start of monitoring
The type of headset in use, and the issue of the programmes used to monitor it.

The 8 hour equivalent exposure for the ear(s) of the headset wearer.
The 8 hour equivalent exposure for the ambient conditions surrounding the headset wearer.
The individual 1 minute Leq’s comprising the 8 hour equivalent exposures.

All this data is saved in Excel spreadsheet format and can be further manipulated if required using the facilities provided in Excel.

Identification of the 8-hour exposure levels is crucial to showing whether the wearer is at risk from the noise levels presented to the ear. With the UK action level of 85 dB(A) for an 8 hour period, care must be taken to ensure the wearer is not exposed to levels greater than this figure. How this is achieved (if required) will need examination of the time history of the noise exposure, which the one-minute Leq values logged by the monitor can provide.

7 CONCLUSIONS

The development of the monitor and the associated dummy head has been completed successfully. The measured results have been verified at the Health and Safety Laboratory at Buxton, UK using their own methods and excellent correlation between their test results from the monitor and measurements made by HSL using other methods prior to the development of the new monitor has been obtained. The HSE is now using the monitor to check noise exposures when required.

Discussions are underway to make the monitor system commercially available to anyone requiring monitoring of headset wearer noise exposures. Further information is available from either the HSE or AVI Ltd.

8 REFERENCES

1) "Practical measurement of Telecommunication Receiver Electro-Acoustics for the Computation of Acoustic Dose" – Dr. Paul Darlington, - Proc. IOA one day meeting "Call Centres – A measurement headache" Liverpool, 5th June 2003.