Aures – The Advanced Environment Noise Monitoring System – Leq(A) or new measurement technology?

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ABSTRACT

Noise has become one of the major environmental pollutions in urban areas. To ensure that the environmental noise requirements are fulfilled, the noise emission from industries must stay within allowable limits under normal operating conditions. APL Systems has developed an automatic noise surveillance system "Aures" in close cooperation with Wärtsilä Finland. The system includes Aures 2.0 -units and a server operating the Aures Analyzer -software. The possibility of long-term recording and analysing the surrounding noise in frequency domain has enabled this application to be one of the best available environmental noise surveillance systems in the market. The technology of frequency domain measurement and analysis has made it possible to understand better the components of certain noise source. With this feature, it is also possible to get more reliable measurement data when comparing to calculations. This paper questions present environmental legislation it's compatibility with the present needs of the different stakeholders including industry and public authorities. The paper also discusses presenting noise data in frequency domain instead of overall levels and especially why it should done so.

Keywords: Environmental, Monitor, Annoyance   I-INCE Classification of Subjects Number(s): 69.3

1. BACKGROUND

1.1 Development history

During the last decade, APL Systems has started the idea of developing a constant online noise monitoring system. Since then APL Systems has developed a state of art leading service platform for industrial customers. As one of the biggest heavy industry in Finland, Wärtsilä has been in cooperation with APL Systems and provided APL Systems probably the best methodology on how the system should be developed from expert point of view.

The first meeting was held in 2006 and the new noise monitoring system was dubbed "Aures" (ears in Latin). It has been well recognized since then that to monitor the environmental noise, especially for industrialized area or facilities, the software has to be able to analyze the recorded data at least in 1/3 octave band. Moreover, there should be triggers to dispatch alarms for each 1/3 octave frequency band noise level as well as for the total noise level. Thus, by knowing the basic characteristic of different noise sources and setting up different alarm triggers for different 1/3 octave bands, one may identify what noise source has caused the high noise level if an alarm is received.

After four years of development the first measurement device started collecting data in 2010 on the factory roofs. During that time the system was developed to be a leading industrial noise monitoring service platform thus enabling industrial customers to get only the essential data, analysis and sound signal they needed – data is only necessary, when it helps industry with environmental, process and maintenance optimization. There are currently four Aures devices situated at fixed locations, recording and analyzing each and every second of sound all year round. This system can now also be found at power plants, paper industries and wind power industries etc, wherever noise surveillance is needed. (1)

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1.2 The 1/3 octave band demands

There are several reasons why the triggers are demanded to be setup for 1/3 octave frequency bands instead of only total LAeq level.

First, normally for urban-localized industrial areas, various noise sources expose. Inside the facility it may have various machinery noise, ventilation noise or low frequency noise from relevant mechanism. Outside the company, the noise can be from the traffic, wind gust or other natural sources. To distinguish the noise that an industry should take responsibility for, the recorded noise must be analyzed in frequency domain to investigate the components. To achieve this goal, the 1/3 octave band is considered as a must if narrower band is yet to be available.

Moreover, although a plant's facility may easily fulfill the regulatory environmental noise limits under normal operation by law, the low frequency noise may still irritate neighborhoods to complain if that exists. In most cases, the low frequency noise is completely ignored if only the total LAeq level is taken into account because of the A-weighting curve. Thus, it is as important to analyze the 1/3 octave noise spectra in a linear scale so that the low frequency part can be emphasized.

As mentioned, while monitoring the factory or whatever environment noise events, the monitors also measure all of the sound from the surrounding neighborhood. Figure 1 shows examples of a medium-speed engine exhaust noise event and a bird noise event.

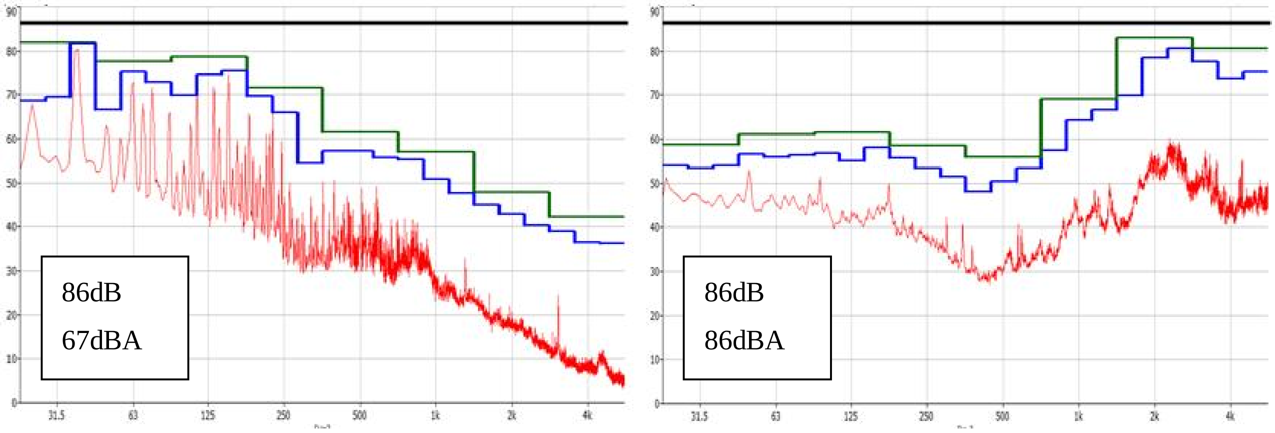

Figure 1 – Left, Example of an medium-speed engine exhaust noise spectra displayed in narrow band, 1/3 octave band, octave band and as total level; Right, Example of bird sound spectra displayed in narrow band, 1/3 octave band, octave band and as total level

As can be seen, even though the total level of the two sounds are both about 86dB, but the frequency components are completely different. The narrower the frequency band is, the easier one can identify the component of the noise. The wider the band is, the more information that will be missed. In this case, the engine exhaust noise dominates 40 Hz in 1/3 octave band, while bird noise dominates 2.5 kHz in 1/3 octave band.

Moreover, as can be seen from the figure, the exhaust noise linear level is 86dB and A-weighted level is only 67dB. This is because most of the noise components are at low frequency range for the exhaust noise. If only the A-weighted level is reported, i.e. 67dBA, it is actually as quiet as in a test run control room, so that no attention will be awakened. Thus, only when the linear level is reported and analyzed in 1/3 octave band, one may know the real cause for a certain exhaust noise complaint.

2. AURES

2.1 The Aures measurement system

The Aures noise surveillance system provides constant sound recording and noise level data together with reporting features. The system consists of four Aures 2.0 measurement units set at fixed locations on the factory roofs, and a dedicated server with Aures Analyzer software for storing and analyzing the data. The locations of the measurement units A2…A5 and a functional diagram of the measurement system are shown in Figure 2.

The Aures 2.0 measurement units have been designed to comply with IEC 61672:2003 specifications and have a measurement range of 35–125 dB. The weatherproof casing and electrical design have been tested for extended periods of time in the intensely varying conditions provided by the Scandinavian climate, e.g. -35°C cold condition. Each measurement unit feeds a constant stream of audio data to the server via a local area network. The Aures Analyzer server software is based on a Linux platform to provide rugged and reliable operation. The server software stores the audio signal streams from a number of Aures 2.0 measurement units, and is used to compute the various noise parameters provided for noise analysis. In addition, the software provides triggers, automatic reporting services and a web user interface. In essence the Aures measurement devices are live microphones that send PCM coded audio signal to the server over the LAN network.

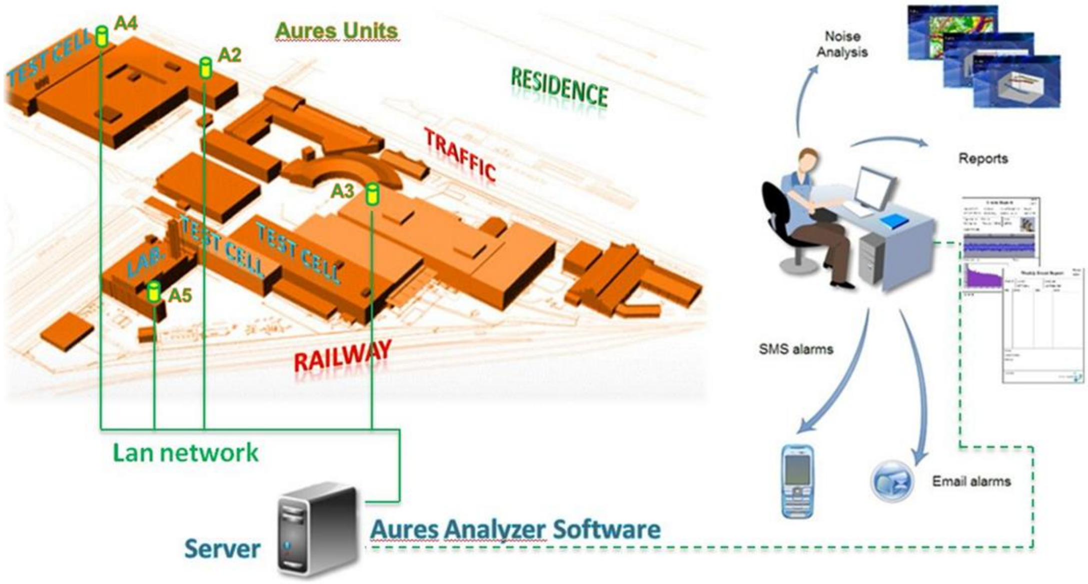

Figure 2 – Left, A map of the Wärtsilä production plant located in the middle of the Vaasa city area. The factory is surrounded by city streets and a railway. The plant noise monitor locations are marked with A2…A5; Right, A functional diagram of the Aures noise surveillance system (2) (3)

2.2 Triggers, data filtering and user interface

The Aures Analyzer software provides a trigger mechanism that can be used for automated tracking of abnormal noise events. Triggers are independent filters or optional modules, that filter abnormal noise events in real-time from measurement data flowing into the system. Triggers are defined by two key parameters with several options attached to each: trigger level (A, C, Z –weighting, octave or 1/3 octave bands) and time (integration time and persistence setting – i.e. how long does the noise incident have to last in order to cause an alarm). When the conditions of the trigger are met, the system records the date and time of the event. The measurement results of the event are recorded as well as the sound samples of that particular event. When a trigger is dispatched, an alarm or warning is automatically sent to a designated person either by SMS or email. This enables prompt investigation on the cause of the alarm and quick determination of the need for possible action. Triggers may be set individually for each measurement unit, and there may be an unlimited number of triggers per device.

The software provides elaborate statistical analysis, which gives a detailed view of the recent events in the soundscape as well as a long term time series of the development of the soundscape. The Aures reporting software provides custom made reports, including graphs and statistical analysis of the various parameters provided by the noise analysis tools. The reporting software may also be used to analyze short term noise occurrences. The web user interface (UI) is accessible to authorized users anywhere within the intranet via a web browser. (4)

The UI provides access to online graphs of all the active Aures units connected to the server. Graphs of wideband equivalent sound levels LAeq, LCeq and LZeq as well as one-third octave spectral data are available to the user. In addition to current sound levels, the UI may also be used to access a whole history of sound data stored on the server. While browsing the historical data, the user may also listen to sound samples, which provides for the reliable identification and analysis of noise events. For reporting, the user interface can be used to input the device number and requested time duration of the recording to be analyzed, resulting in the respective 1/3 octave band spectra generated by the system. The data can also be exported to standard spreadsheet format for further analysis. (5)

3. CASE WÄRTSILÄ

3.1 Background

One of Wärtsilä's large medium-speed diesel engine factories is located in the city center of Vaasa on the west coast of Finland. Whenever industrial operations are situated in urban areas, noise is a crucial part of the equation. Soundscapes in city centers tend to be complex affairs, and the job of estimating the contribution of the factory noise to the city's soundscape is not an easy task. For an urban industrial operation, constant on-site noise monitoring offers many advantages compared with sporadic measurements. The benefits range from improved relations with the neighboring community, improved communication with environmental authorities and even direct improvements to noise management designs implemented within engines.

3.2 Wärtsilä triggers

As basic function, the Aures system is able to provide live feed Leq level every second. By knowing the transfer function between the measurement location and the neighborhood area, it is possible to setup alarm triggers for the Leq value for notification of the event that the noise level is too high at the residential area.

Low frequency exhaust noise from medium speed diesel engines has been a particular challenge, as the low frequencies propagate over large distances and are easily distinguished from other environmental noise sources. Based on previous measurement experience, it was detected that engines exhaust noise is mainly dominating at low frequency range. To distinguish the exhaust noise from other noise events, a series of triggers have been set at low frequencies in one-third octave band. When the noise level at a certain frequency band has exceeded the preset criteria 10 minutes persistently, the trigger will be dispatched, see Table 1. From experience, the levels in the Table 1 are crucial to avoid neighborhood complaints about Wärtsilä exhaust noise disturbance. Especially at night-time, the exhaust noise can be extremely annoying once it is audible.

Table 1 Wärtsilä exhaust noise alarm trigger settings

1/3 octave band (P10)	Early warning	Action alarm
31,5 Hz	75 dB	83 dB
40 Hz	75 dB	83 dB
50 Hz	75 dB	83 dB
63 Hz	70 dB	78 dB
80 Hz	70 dB	78 dB
100 Hz	70 dB	78 dB

In Finland, the residential area noise limitation is 55 dBA in daytime and 50 dBA in night-time. To guarantee the factory neighborhood area's noise level stays below limitation, wide-band noise triggers are set for devices as shown in Table 2. The levels in Table 2 are obtained by previous measurements of noise transfer functions between Aures locations and closest neighborhoods. One has to keep in mind that even sometimes when the LAeq level is well below the limitation, noise complaints can still come because of low frequency annoyance. Therefore both exhaust noise triggers and LAeq triggers are essential.

Table 2 Wärtsilä LAeq alarm trigger settings

<table>
<tr><td>LAeq (P10)</td><td>A2</td><td>A3</td><td>A4</td><td>A5</td></tr>
<tr><td>Early warning (night)</td><td rowspan="2">65 dBA</td><td rowspan="2">65 dBA</td><td rowspan="2">65 dBA</td><td>65 dBA</td></tr>
<tr><td>Early warning (day)</td><td>70 dBA</td></tr>
<tr><td>Action alarm</td><td>70 dBA</td><td>70 dBA</td><td>70 dBA</td><td>75 dBA</td></tr>
</table>

When there is strong wind blowing to microphone, the noise spectra will increase at low frequencies. The wind trigger is setup at 16 Hz 1/3 octave band with level of 70 dB. Seagulls can also create high noise level to the system, for which case the trigger has been setup at 2500 Hz 1/3 octave band with level of 60 dB, Table 3. Both of these two triggers are setup to avoid redundant natural noise events influence, and improving the system's hit rate for the real factory noise. Figure 4 shows typical wind seagulls spectra.

Table 3 Wärtsilä wind and seagull noise trigger settings

(P1)	1/3 Octave Band	Level
Wind	16Hz	70 dB
Seagull	2.5kHz	60 dB

3.3 Monthly reporting

APL Systems provides monthly report for Wärtsilä regarding with the noise surveillance results during the month. One of the interesting information in the report is the statistical data of the number of warnings and alarms that have been received during the month on each unit. The triggers set for high exhaust noise level warning and alarm are in 1/3 octave band between 31,5Hz to 100Hz. The warning or alarm will be dispatched when whichever band exceeds the preset noise level. The preset alarm level is 8dB higher than the warning level for each band. It has also been well known that there are so many random noise events that are not related to factory noise may also trigger the system if the noise level is high instantly. Thus, in order to catch the real high noise events caused by the exhaust noise and have an improved hit ratio on the alarm system the warning and alarm is set in the way that only when the noise level is higher than preset level for 10 minutes persistently, a warning or alarm email will be sent out. It is also based on the fact that if there is a high exhaust noise level challenge it will last for long time. Figure 3 demonstrates an example of the statistical data of the number of exhaust noise warnings from the monthly report of May 2014.

Trigger	A2	A3	A4	A5
P1 1/3 oct	2579	2186	6486	7100
P3 1/3 oct	212	35	856	823
P10 1/3 oct	50	2	208	193

Figure 3 – Statistical data of the number of exhaust noise warnings from the monthly report of May 2014. P1: 1 minute persistently, P3: 3 minutes persistently, P10: 10 minutes persistently

Assuming that all the P1 warning events take place minute by minute continuously, the number of P1 warnings will be 3 times as many as P3 warnings, and the number of P3 warnings will be about 3 times as many as P10 warnings.

Taking A2 as an example, comparing the number of warnings of P1 and P3, one may notice that the number for P1 (2579) is about 10 times more than the number for P3 (212). This means that most of the P1 warning events happen sporadically, which implies stochastic events. Most of these random events have been filtered out by using the P3 trigger instead of P1 trigger. Similarly, comparing P3 and P10 for A2, the number for P3 (212) is about 4 times as many as the number of P10 (50), i.e. slightly more than 3 times. This means most of the P3 warning events on A2 are continuous events, and some are sporadic ones, which are filtered out by using P10 warning trigger.

Since the wind blowing onto the microphone will also generate noise with the level ramping up towards low frequency, to eliminate the wind events is also of importance. The trigger of strong wind event is set at a frequency band lower than the exhaust noise trigger bands. When the level is over the pre-set value for one minute, the wind trigger will be dispatched. Figure 4 shows the number of strong wind events from the monthly report of May 2014.

Trigger	A2	A3	A4	A5
Wind	121	375	57	278

Figure 4 – Statistical data of the number of strong wind events from the monthly report of May 2014.

It can be seen that the monitor unit of A3 has the most strong wind events, which is probably because of the location. This also explains why the number of exhaust noise warnings in Figure 3 for A3 has decreased significantly from P1 to P3 and from P3 to P10, which is simply because the wind has been disturbing. Similarly, the number of LAeq warnings from the monthly report of May 2014 is demonstrated in Figure 5. It can be seen that especially for A2 and A3 most of the high noise warning events are random for P3 trigger, and for A4 and A5, the noise events are more in a continuous pattern.

Trigger	A2	A3	A4	A5
P3 Leq(A)	**50**	**18**	**10**	**1041**
P10 Leq(A)	4	0	3	283

Figure 5 – Statistical data of the number of LAeq warnings from the monthly report of May 2014. P3: 3

minutes persistently, P10: 10 minutes persistently

It is believed that the P10 triggers are the proper triggers to be utilized for email deliver because it can effectively filter out the non-factory related random noise events. In Figure 6, the number of alarms from the monthly report of May 2014 is shown.

Trigger	A2	A3	A4	A5
P10 Leq(A)	0	0	0	0
P10 1/3 oct	0	0	28	14

Figure 6 – Statistical data of the number of alarms from the monthly report of May 2014

As can be seen, no LAeq alarm has been received throughout the month, which means according to transfer function between the measurement location and the residence area, the factory related noise level has always been staying below the limitation. For the exhaust noise, there have been 28 alarms received on A4 and 14 alarms on A5 during May 2014. This means in several occasions, the factory exhaust noise level has been high enough to cause discomfort to nearby neighbourhoods, even though the total level is still below the limitation. It also means there is high risk of receiving complaints from neighbourhood about the noise, especially if it continues to the night.

3.4 Equivalent wide-band noise (LAeq)

In Finland, the residential area noise limitation is 55 dBA in daytime and 50 dBA in night-time. One has to keep in mind that even sometimes when the LAeq level is well below the limitation, noise complaints can still come because of low frequency annoyance. Therefore both exhaust noise triggers and LAeq triggers are essential.

In the monthly report, the average LAeq levels for each day in the month are also presented in a plot comparing four devices. Figure 8 Left shows an example of the day time (07:00-18:00) LAeq results from April 2014.

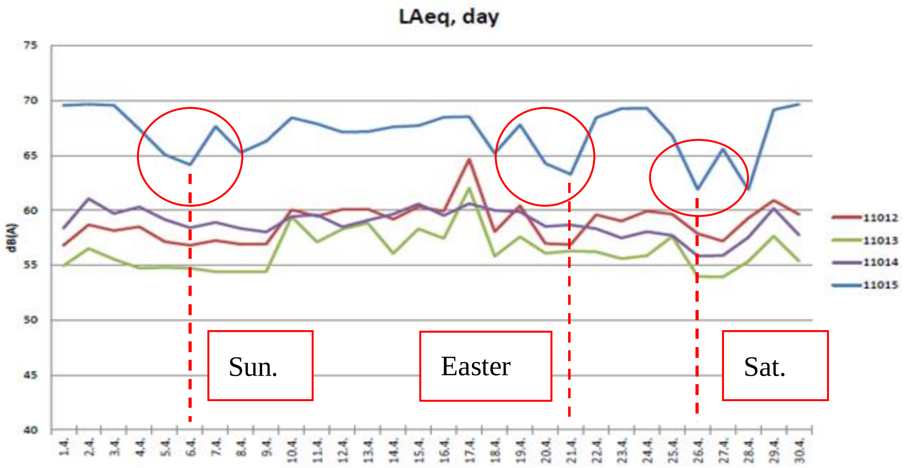

Figure 7 – LAeq daily noise level during April at different noise points

It can be seen that the device 11015 which is on the laboratory roof has generally higher levels than the ones at test runs. There are some days that the 11015 has low noise levels, which are marked in the figure with red oval. Those are the days of weekends and Easter holidays. That means something different between work days and holidays that has contributed to the high noise level at the location of laboratory. It is currently believed to be because of the nearby ventilation systems, and further investigation is needed.

Figure 8 shows typical noise spectra on A4 (Left, diesel test run) and A5 (Right, laboratory) during different time periods of a day, e.g. red curve means the average spectra from 07:00 till 18:00, and the green curve is the average spectra of the whole day of 24 hours.

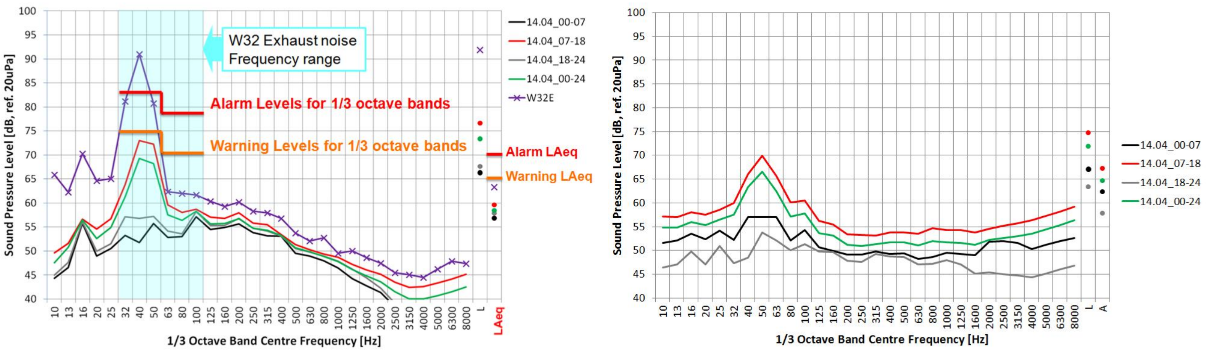

Figure 8 – Noise spectra during various time periods on 14th April 2014 recorded by A4 (Left, diesel test run) and A5 (Right, laboratory)

From Figure 8 Left, there is no big difference between the levels at different time periods of the day in the frequency range above 100Hz. The difference exists at low frequency ranges because of the exhaust noise. Normally when engines are running in test cells, the low frequency exhaust noise will increase about 15dB. Looking into the total level, the variation between the A-weighted value is much smaller than the variation between the linear value. That is why Wärtsilä has always been using the linear value for low frequency exhaust noise analysis because comparing to the LAeq, the LZeq is more sensitive to low frequency level change and is relatively more reliable for analyzing low frequency noise annoyance.

Moreover, the warning and alarm levels for frequency bands and total LAeq are also shown in Figure 8 Left. When the noise levels at any frequency band has exceeded the preset level, the warning or alarm will be sent via email the responsible persons. When a W32E (upgraded version of engine with higher output) was running in test run, the low frequency noise level will become much higher than normal value and exceed the pre-set alarm level. That is why test run silencers are being upgraded to be with better qualities. One should notice that even the W32E low frequency noise has exceeded the alarm level a lot, the total LAeq is still bellow the warning level, i.e. the factory noise from Wärtsilä is still well below the legal limitation while the neighborhood is being considerably disturbed by the factory exhaust noise.

From Figure 8 Right, the evening and night time noise level (6pm-7am) is about the same as A4. In the daytime the noise level at A5 is higher than night time in broadband frequency range, which has made the LAeq level in the daytime considerably higher as well.

4. LOW FREQUENCY LIMIT

As has discussed above, the noise limit on LAeq is obviously not enough to judge what the noise source is, and what kind of disturbance it might cause to people. Especially for low frequency range, most of the information is missing if only the LAeq is known. Thus to take the low frequency disturbance into account, based on the hearing threshold and legislations from other countries, the noise limit should be required at least in 1/3 octave band in a pattern shown in Figure 9.

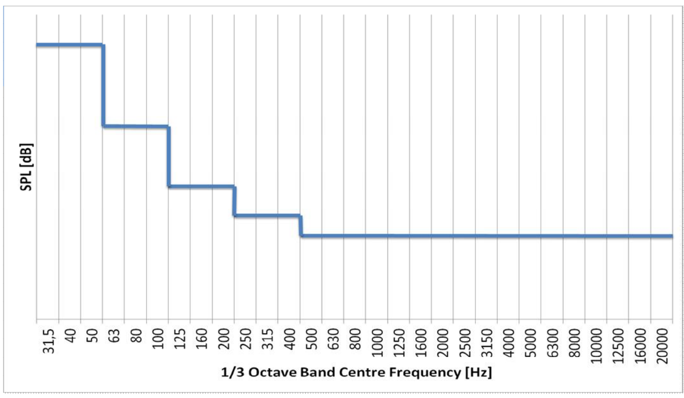

Figure 9 – Low frequency noise limit pattern proposal

It should be required as mandatory in the way that none of the 1/3 octave band noise level should exceed the limitation levels at the residential areas which are near industrial facilities. Only in this way could the environmental noise be really well concerned and the daily life of residence be really taken care of.

5. APL FUTURE - METATRIGGERS

One of the main advantages of Aures is its capacity to collect and store vast amounts of audio data from several locations at the same time. The current trigger system works on a local level sorting out relevant information from the data from individual measurement devices. In order to achieve more accurate results regarding the spreading of noise over large geographical areas a higher level of triggering is required. When triggers are combined from several measurement points and suitable algorithms are in place to deal with data coming from several measurement devices at different locations, real information regarding acoustical causal effects (or lack thereof) may be achieved. The added layer of triggers could be called metatriggers as they move one step beyond local triggers and integrate data from varied locations before reaching a conclusion.

For a simple example of a metatrigger in operation one may consider emergency steam releases that sometimes occur in process industry installations. The release of steam raises noise levels very sharply in one location. First level trigger will inform process control that there is a steam release going on. Once the preliminary trigger is activated the metatrigger level will start to scan the mesh of measurement devices located in the factory area or possibly in the neighboring residential area. If a correlation between the steam release and the residential area noise levels is found, a message will be dispatched to inform e.g. environmental management of the factory. This will enable the real time assessment and forecasting the likelihood of neighborhood complaints. At the same time the accumulated data will also give a very accurate picture of the real effects of the noise releases and their effect on the neighborhood which will be very helpful in dealing with various interest groups concerned about the noise caused by the installation.

The ability to gauge causal effects of noise events will no doubt be of great use to many industrial facilities operating near urban or residential areas. Wind farms are one obvious example that will benefit from continuous intelligent estimations of the effect their operation has on neighborhood noise levels.

6. SUMMARY

Wärtsilä Finland and APL Systems have developed the advanced noise monitor system (Aures) with the advantage of long-term recording and analyzing in frequency domain. By frequency analysis in 1/3 octave band, one can have a much better understanding of the detailed components of the noise, which is impossible if only a total LAeq value is given. It also makes it easier and quicker to find the cause of a certain high noise level and to solve the high noise problem. That is why this application is probably one of the best available environmental noise surveillance devices in the market.

This paper has clearly shown the fact that if only the total LAeq is given, huge amount of information will be lost. It has obviously become very old-fashion way of reporting the monitored environmental noise. With the new measurement instruments and advanced analyzing software, the situation can be improved by creating new noise guidelines. The 1/3 octave band values should definitely be utilized instead of only one figure as total level. Meanwhile, the low frequency (below 200Hz) noise components should also be seriously taken into account.

Aures has given Wärtsilä the means to catch, analyze and evaluate anomalies in the soundscape, providing a valuable tool for environmental awareness. The system will send noise alarms to designated email addresses if the factory environmental noise is riskily too high. The Aures system has been tested at the factory and is working well.

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