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ACOUSTIC PATTERN OF THE LITTLE TOOL-MACHINES SUPER-FAMILY

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Abstract

The acoustic pattern of a family of machines is the result of the average behaviour of the set of machines belonging to it. Once the existence of acoustic patterns of several families of tool-machines, such as drills, grinders and jigsaws has been tested, one can try to find the acoustic pattern of the complete super-family of little tool-machines. So, the evaluation of the acoustic and psychoacoustic effects of any such machine in the workers could be done immediately in the practice. It also should permit the design of a desired and non-dangerous pattern, which the new designed machines should fit.

INTRODUCTION

The acoustic characterization of a machine is achieved from the knowing of its sound power, together with the required paremeters used for it, and the sound exposure of the worker; as well as the determination of the sound quality in its two parts, the objective and the subjective ones. With all these data we can produce a report, that will be the acoustic characterization.

Once the machines are characterized, cross-studies can be done between the acoustic and psychoacoustic parameters to derive possible relations; but in spite of that, the most interesting point is the determination of the acoustic patterns of families of machines, where indexes and relations are established for all the studied machines.

Those studies can be extended to obtain common results from those for several similar families of machines, getting superfamilies patterns then. As an example, this paper will state the one obtained for the superfamily of drills and grinders.

Required Measurements

The first measurement taken is the sound power, following for that the procedures given in the norms ISO 9614-2 [2] and ISO 3744[3], of sound power measurement from intensity scanning and sound pressure in free-field, respectively. If IS0 3744 is used inside some room, the reverberation time has also to be obtained, according to the norm ISO 3382 [4], as this is compulsory to know the parameter K_2 for room correction.

The next step is to determine the most important objective psychoacoustic parameters. Those are Loudness, Roughness, Sharpness and Fluctuation Strength, all of them defined by Zwicker [9], apart from SIL (Speech Interference Level) [1].

Subjective Evaluation

Surveys have been used for the subjective evaluation of sound quality. Those are done from two tests of differential semantics taken by a minimum of 16 listeners properly qualified for each evaluated machine [7] under optimum conditions for that [8]. In the first test, the adequacy of the listeners is verified through the answers to certain calibrated sound stimuli [5]. Furthermore, this test acomplishes with a training function, as it is done from the evaluation of 4 characteristics of 6 sound samples. Once passed this initial test, the subjective evaluation of the machines follows. The listenes must choose the type and number of machines to evaluate.

The survey is self-passed at random, as each listener can answer on his/her own to the samples chosen at random from all the stored in a data base. Table 1 shows the questions made.

SOUND PATTERN OF A MACHINE

”Family of machines” or ”type of machines” means those machines with something in common, generally because they have the same function. Then, it seems logical to think that if they do the same, they should share the same working philosophy, and therefore, a sound emission, at least, similar.

This reasoning can be checked by comparing different factors among the machine characterizations, as sound power, objective sound quality and subjective sound quality, for a number of machines high enough to give coherence to the analysis to probe if there is any trend in the behaviour of the machines.

Then, a sound pattern of a family can be defined as the combination of all these acoustical data, what would give a complete information about the sound emission typical for that family.

Table 1: Items for the psychoacoustic survey and their relations with the objective and subjective psychoacoustic parameters.

N	QUESTION	RELATED TO...
1	Strong / Weak	Average sound level, L_{pA}, Loudness
2	Constant / Variable	Sound variation with time, Roughness and Fluctuation Strength
3	Cyclical / Non cyclical	Sound repetition pattern, Roughness and Fluctuation Strength
4	Enveloping / Detailed	Existence of very present peaks and Sharpness
5	Dry / Reverberant	Sound extinction, reverberation, liveness, Loudness, Roughness and Fluctuation Strength
6	Presence of treble / Absence of treble	Content at high frequency and Sharpness
7	Presence of bass / Absence of bass	Content at low frequency, Roughness and Fluctuation Strength
8	Compatible with normal speech / Incompatible with normal speech	Interference with simultaneous conversations ans perceived SIL
9	Pleasant / Unpleasant	Pleasantness and Psychoacoustic annoyance
10	How many continuous hours, from a working day of 8 hours, would you be able to use the machine that makes the noise you are hearing?	Maximum sound exposure time, Pleasantness and Psychoacoustic annoyance

Commonly, data of 10 or more machines are required to derive a pattern with the minimum accuracy. Undoubtedly, the higher number of machines involved, the more accurate the pattern will be.

Utility of a Sound Pattern

The utilities that a sound pattern of a type of machines offer are uncountable. Some can be remarked, but, as in all the fields of research that are new-born, multiple possibilities that must be proved are opened.

The first use for a pattern could be the adequacy of its sound depending on the possible buyers or users of that product [6]. If the population, to whom the machine is intended for, is taken into account when the surveys are done, the degree of acceptance of that machine should be achieved for that population. If the result is negative, that problem should be solved in the development department of the manufacturers until those machines give a sound adequate for their characteristics. This should be done through a precise analysis taking into account all the factors involved, from the surveys to the design of the machine, its engine, transmission relation, possible vibrations, etc. When a positive result is achieved, intended as the adequacy of the sound emitted, a comparison can be made between the characteristics of the machine with the pattern it should fit. Then, the machine design can be modified to accomplish with the pattern [6].

There can be also known if a type of machine produces certain particular effects over workers, or if they need personal hearing protectors for that specific type of machine.

It is convenient to remark that this is a dynamic process that changes continuously, given that the subjective evaluation made to the users through surveys, that is maybe the most important factor, depends on the actual trend, so an adequate sound nowadays may not be so adequate in a few years.

Another possibility of use of the sound patterns is to find out possible relations among the patterns of different families of machines with the aim of grouping the machines in big sets, making a classification depending on the sound emission, and not only on the task for what they were designed. This use opens a new range of possibilities, like the definition of a labeling code that includes more information apart from the sound power in dBA, which is not enough to characterize a machine.

RESULTS FOR THE SUPERFAMILY OF DRILLS AND GRINDERS

The working principle of this family of little tool-machines is always the same: the engines, both of the drills and the grinders, give a spin in some tool of these, either a bit or a disk.

The ovelapping of the spectrum for all the measured machines points to a clear frequency trend made of little emission at low frequency that increases continuously.

To find out a prediction equation for this spectrum, an inverse regression analysis has been made with an adjustment factor of $R^2 = 0.936$, or through a S-curve that has a better factor $R^2 = 0.946$. Those equations are 1 and 2, displayed in Fig. 1(a).

$$L_W = 84.2527 - \frac{5903.5}{f} \tag{1}$$

$$L_W = e^{\;4.4226 - \frac{85.951}{f}} \tag{2}$$

Table 2 reflects the values for all the objective parameters for drills and grinders. The average values obtained are similar to those for the single families, except for a little increase in the standard deviation, given that now the number of machines is quite high and so the variability. It has to be stressed the little difference between the linear power level and the A-power level, and the little deviation for the subjective parameters, except for loudness. Regarding sound exposure, almost all the machines allow practically the whole working day, but using hearing personal devices.

The next step is to find out relations among the objective psychoacoustic parameters. The most relevant are those relating the A-weighed sound power level and the loudness, with

Table 2: Values for the objective values of the superfamily. Lw, sound power level in dB; LwA, A-weighed sound power level in dBA; L, loudness in son; S, sharpness in acum; R, roughness in asper; FS, fluctuation strength in vacil; Texp, sound exposure time in hours; Prot, personal protection required.

Model	Lw	LwA	L	S	R	FS	Texp	Prot?
B&D KD162	86.9	87	79.9	2.61	0.47	0.96	8	No
Casals VT622	95.1	95.6	111.3	2.73	0.47	0.98	8	Yes
Skil 1750	94.9	85	85.1	2.33	0.47	0.97	8	Yes
Skil 6365	92.9	93.2	66.1	2.77	0.51	1	8	Yes
LG D913A	91	91.2	92.85	3.3	0.48	1.05	8	Yes
AEG PN4000E	90.8	91.2	87.6	2.67	0.48	1.35	8	Yes
AEG PN3500X	99.7	100.2	122.5	2.89	0.63	0.93	5.9	Yes
Bosch GBH3-28FE	97.7	98.4	128.2	2.91	0.49	0.98	7.57	Yes
Mannesman BM5000	85	85.2	49.4	2.62	0.43	0.93	8	No
AEG SBE550R	86.1	87.1	79.91	2.61	0.47	0.96	8	Yes
Casals AG21	100.4	100.8	226	3.14	0.51	1	3.73	Yes
Casals AG6-115	95.4	95.4	75.1	3.09	0.62	1.19	8	Yes
Bosch PWS600	99.7	99.7	94.3	3.53	0.54	0.98	6.23	Yes
Metabo W7-115	93.1	93.5	89.25	2.9	0.48	1.04	8	Yes
AEG WS7-115M	93.4	93.7	82.2	2.91	0.46	0.98	8	Yes
LG G705	95.3	95.5	80.2	2.96	0.51	1.08	8	Yes
Casals DL178	100.1	100.3	115	2.8	0.52	1	5.82	Yes
Bosch GWS7-115	95.7	96.2	86.4	2.87	0.45	0.85	5.58	Yes
Bosch GWS6-115	93.6	94	91.85	2.94	0.51	0.95	8	Yes
Milwakee AG8-115Q	97.8	97.9	109.15	3.07	0.47	0.89	4.47	Yes
MEAN	94.23	94.56	97.12	2.88	0.50	1.00	7.17	
STD DEV	4.44	4.41	34.92	0.26	0.05	0.11	1.32	

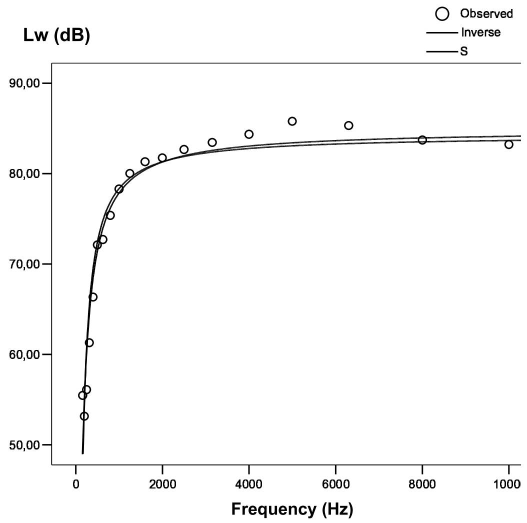
an adjustment factor of 0.588, giving the equation 3 as the model, that is shown in Fig. 1(b).

$$L_{W_A} = 72.2344 + 0.3273S - 9 \cdot 10^{-4} S^2 \tag{3}$$

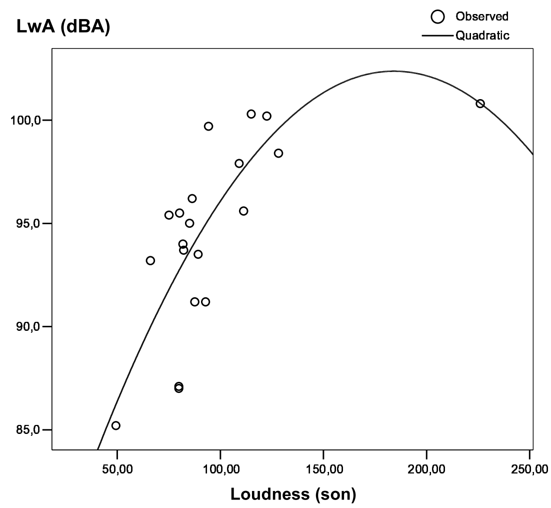
The table 3 keeps all the average answers given for each one of the questions of the psychoacoustic survey. The evaluation of the global sound quality through the question number 9 gives a qualification of a quite annoying quality.

Complexity increases considerably when the objective is to find out correlations for the psychoacoustic tests of different families of machines, taking into account that this process is already difficult for only one family alone. Despite that, two representative relations have been deduced. The first relates question 1 with sharpness, due to the important presence of high frequencies for both types of machines. The adjustment factor achieved for this relation is 0.485, that is shown in Fig. 2(a) with a prediction equation modeled by Eq. 4.

$$Q_1 = 0.5195 - 0.13S + 0.2063S^2 \tag{4}$$



(a)

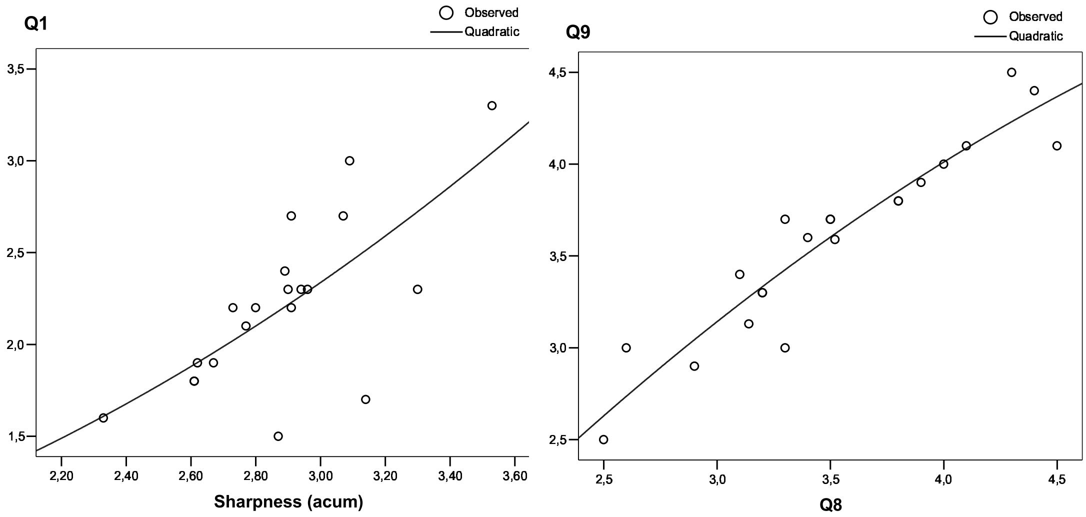


(b)

Figure 1: (a): Mean spectrum and prediction curves from the regression analysis. (b): Relation between the A-weighed sound power level and loudness.

Table 3: Answers to the psychoacoustic survey for the superfamily of drills and grinders.

Model	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
B&D KD162	1.8	1.8	2.9	2.2	2.8	2.7	2.5	3.2	3.3	2.5
Casals VT622	2.2	2.0	3.2	2.8	3.1	2.4	3.4	3.8	3.8	2.6
Skil 1750	1.6	2.0	3.8	2.6	2.8	3.0	2.6	4.3	4.5	1.6
Skil 6365	2.1	1.7	3.0	2.3	2.8	1.7	3.5	3.9	3.9	1.6
LG D913A	2.3	1.5	2.4	2.1	2.1	1.6	4.1	4.4	4.4	2.2
AEG PN4000E	1.9	1.6	2.7	2.4	3.0	3.0	2.4	3.5	3.7	3.7
AEG PN3500X	2.4	1.7	2.7	2.3	2.3	2.8	2.3	3.1	3.4	2.8
Bosch GBH3-28FE	2.7	1.7	3.3	2.7	3.0	3.0	3.1	3.3	3.7	3.1
Mannesman BM5000	1.9	1.6	2.9	2.1	2.8	2.4	3.1	4.1	4.1	1.9
AEG SBE550R	1.8	1.8	2.9	2.2	2.8	2.1	2.5	3.1	3.1	2.7
Casals AG21	1.7	1.9	3.6	2.6	2.6	2.3	3.0	4.0	4.0	3.1
Casals AG6-115	3	2.6	2.5	2.8	2.9	2.6	3.0	2.5	2.5	4.1
Bosch PWS600	3.3	3.0	2.5	2.9	3.3	2.2	3.6	2.6	3.0	3.1
Metabo W7-115	2.	2.0	3.8	2.1	3.0	2.4	3.2	3.4	3.6	3.1
AEG WS7-115M	2.2	1.2	4.3	2.0	2.6	2.4	3.8	3.2	3.3	3.7
LG G705	2.3	2.4	3.4	3.0	3.2	2.9	3.0	3.8	3.8	3.4
Casals DL178	2.2	2.4	2.8	2.6	2.8	2.3	2.6	3.3	3.0	2.9
Bosch GWS7-115	1.5	1.2	3.8	2.0	3.0	2.1	2.7	4.5	4.1	3.5
Bosch GWS6-115	2.3	1.3	4.0	2.0	3.0	2.5	3.1	3.5	3.7	4.0
Milwakee AG8-115Q	2.7	1.6	3.4	2.3	2.7	2.2	3.1	2.9	2.9	3.5
MEAN	2.21	1.85	3.25	2.40	2.83	2.43	3.03	3.52	3.59	2.96
STD DEV	0.45	0.45	0.51	0.32	0.28	0.39	0.47	0.55	0.51	0.71



(a) (b)

Figure 2: (a): Relation between question 1 and sharpness. (b): Relation between pleasantness and compatibilty with normal speech.

The second relation seems logical, as it is accomplished for both families on their own. It relates question 8 and 9, that is, the pleasantness versus the compatibility with the speech at normal voice. The correlation factor, 0.884, is very high. The prediction is made through Eq. 5, which illustrated in Fig. 2(b).

$$Q_9 = -0.7169 + 1.5993Q_8 - 0.1043Q_8^2 \tag{5}$$

SUMMARY

To characterize a machine acoustically implies the joint of objective and normally measure-able (acoustic power, sound exposure time, etc.) information, with information of sound quality of the machine, that includes both, psychoacoustic parameters and the results of subjective surveys answered by the users. All this information, organized and correlated, produces the acoustic report, that is, its acoustic characterization.

If several acoustic characterizations of machines of the same family are available, patterns can be derived from the correlation of the data of all the machines. Then, the pattern will be the element that should describe the typical emission of a family of machines. And from different patterns, superfamilies patterns can be derived.

Through the patterns, machine design can be adjusted to a pleasant and accepted pattern, mean predictions of noise emitted by those machines can be made, the risk for workers to noise exposure can be evaluated in advance, etc. Undoubtedly, the benefits that the knowledge of the patterns can report are enormous, but maybe the highest one would be the possibility of correcting, at the design stage, the problems that the noise emitted by the machines can cause afterwards.

It has been probed, from the existence of the patterns for drills and grinders, that there also exists the pattern of the superfamily composed of both types of machines. This new super-pattern shows a mean sound power level of 94.23 dB (94.56 dBA), what reveals the important presence of the high frequencies in their sound emissions. These high levels made, almost compulsory in all the cases, the use of personal hearing devices to avoid hearing damages. As a whole, the noise made for these machines is annoying for the users, who are only willing of using them for just three hours in an 8 hours working day.

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