inter•noise 2009
innovations in practical noise control
2009 August 23-26
Ottawa, Canada

Subjective impression of copy machine noises: an improvement of their sound quality based on physical metrics

Osamu Takehira [a]
Ricoh Co. Ltd., JAPAN

Sonoko Kuwano [b]
Seiichiro Namba [c]
Osaka University,JAPAN

Hugo Fastld [d]
Technische Universitaet Muenchen, GERMANY

ABSTRACT

Sounds of copy machines are required to be more comfortable and not to disturb the people working in offices, where the machines come to be placed close to the people in the office. In the process of developing such a product, some of significant things are how to decide an appropriate specification of sound quality and how to realize such specification. However, this is not easy since the sound of copy machine consists of several sound sources and is time varying during operation. A trial to improve the sound quality of two products, whose impression were worse than other samples, was conducted based on the physical metrics, which were found to be effective in our former studies examining subjective impression of various copy machines. After identifying some components relating to the impression, they were modified. An experiment was conducted in Japan and Germany to verify the effect of the improvement on subjective impression. The result suggested that reduction of L_{Aeq} and sharpness by the modification improved sound quality. The metrics are exceedingly useful for developing a copy machine of good sound quality effectively and economically.

1. INTRODUCTION

Copy machine nowadays is called Multifunction Peripheral (MFP), which has the capability not only copying but also printing out, sending facsimile, scanning and saving an electric file to the

[a] Email address: osamu.takehira@nts.ricoh.co.jp
[b] Email address: kuwano@see.eng.osaka-u.ac.jp
[c] Email address: namba.seiichiro@nifty.com
[d] Email address: fas@mmk.e-technik.tu-muenchen.de

storage device in it. In order to meet the needs of frequent use, copy machines come to be placed in offices where people are working. In this situation, their sounds are desired to be more comfortable and not to disturb the people. For the development of such a product, it is exceedingly important to examine how to evaluate the sound quality. In the former study[1-3], CI (comfort index) that consists of L_{Aeq} and sharpness, as the following equation

$$CI = 1/10\ L_{Aeq} + \text{sharpness},$$

was proposed and found to be useful for evaluating the sound quality of copy machine as the first approximation. Moreover, it was suggested that there was a little systematic difference in the subjective impression among in Japan and Germany[3].

In reference to the results of our former studies of the sound quality[3,4], New products of copy machines have been developed. Figure 1 shows examples of predicted scale values of the pleasantness impression using CI of several copy machines. The line in Figure 1 shows the relation between CI and the values observed in the experiments in our former study[4]. Machine A and machine B indicated the bad impression among them. The sound level pattern of machine B is shown in Figure 2, which indicates that this sound includes a lot of impulsive noise. The feature was supposed to be the cause of the bad impression. After searching for the noise source, it was found that the noise occurred at the timing that the sheet path selector collided with other part in its operation. In order to reduce the noise, some countermeasures, e.g. to select a kind of material and thickness of shock absorber sheet or to adjust spring force to operate the selection, were tested in relation to subjective impression. A modified machine B was built with a countermeasure selected in consideration of both the effect and cost. The sound quality of machine B is supposed to be improved because CI and the predicted scale values of the modified machine B became 7.4 and 3.8 respectively as shown in Figure 1. The same process of modification was applied to the machine A.

In this study, an experiment was conducted in order to verify the effect of the improvement of the sound quality using semantic differential in Japan and in Germany.

2. EXPERIMENT

A. Stimulus

The sounds from various copy machines were recorded in a semi-anechoic chamber according to the procedure described in ISO7779 at the bystander's position. The duration of recorded sounds were edited to be 6 second, in which at least one cycle of copy operation was included. Sixteen kinds of sound were used in the experiment as shown in Table 1. Stimuli Nos. 1-10 and Nos. 13-14 are original sounds. Among them, stimuli No.10 and No.14 are from the prototypes of modified machine A (stimulus No.1) and modified machine B (No.9), respectively. Four sounds, stimuli Nos. 11, 12, 15 and 16, are with simulated active noise reduction (ANR) technology which may be applied to copy machines in the near future since it comes to be more available recently. They were recorded through the headphone with a function of noise cancelling as shown in Figure 3.

B. Procedure

Sixteen kinds of sound were presented to the participants in random order. The participants were requested to judge the impression of each sound using semantic differential. Seventeen kinds of seven-point adjective scales were used as shown in Figure 4 on the basis of the former studies[5]. The adjective scales were indicated in Japanese in the experiment in Japan and in English in

Germany. After training with two sounds, the participants repeated the experiment with different order of stimulus presentation. Three kinds of orders of adjective scales were prepared and each participant used one of them. The experiment was conducted in Osaka University in Japan and Technische Universitaet Muenchen in Germany.

C. Equipment

The sounds were reproduced with a DAT recorder and presented to both ears of the participants through an amplifier, a free-field equalizer[6] and headphones (Beyer DT48) in a sound proof room. Similar equipment was used in the experiments in the two places.

D. Participants

Eight Japanese females and twelve Japanese males aged between 21 and 48 (average age 26.8 years old) participated in the experiment in Japan. Twenty German males aged between 22 and 34 (average age 26.3 years old) participated the experiment in Germany. All had normal hearing ability.

3. RESULTS AND DISCUSSION

The scale values of all participants were averaged for each trial of the experiment in each place. Coefficients of correlation between the first and the second trials were 0.938 in Japan and 0.922 in Germany. These coefficients are significant and the judgments of the two places can be regarded as reliable. Therefore, the following analyses were conducted using 40 judgments in Japan and Germany.

A. Semantic Profiles

Six samples of a semantic profile relating to machine B are shown in Figure 4, the left-hand side figures show the results in Germany and the right was in Japan. Two results are shown together in each sample in order to show the effect of the modification and the ANR: the legend G9 indicates the data of stimulus No.9 in Germany. Stimulus No.10, i.e. the modified A (No.9) was judged as being soft, beautiful, soft, pleasant, quiet, smooth etc. in both places. Therefore, it is confirmed that the modification was effective to improve the sound quality.

On the other hand, the profiles of stimuli with ANR suggest that ANR used in this experiment is not or is less effective in improving the sound quality. The profile of stimulus No.11 is quite similar to that of its original sound (stimulus No.9). Stimulus No. 12 compared with its original sound (stimulus No.10) was judged slightly as more gentle, fresh, quiet and not attentive. Accordingly, there is a possibility that ANR has a small effect on improving sound quality. These results suggest that an effect of ANR on the sound quality depends on its original sound. The same characteristics was found in the profiles of stimuli relating to machine A.

B. Improvement of sound quality of copy machine based on CI

The relation between predicted values using CI and observed scale values of "pleasing-unpleasing" are shown in Figure 5 with the data in our former study[3] using original sounds of copy machines. The left-hand side was the results in Germany and the right was in Japan. Fairly high correlation can be seen between them.

Figure 6 shows the improvement of sound quality in the adjective scale "pleasing-unpleasing" for "modified B", "ANR1", "ANR2", "modified A", "ANR3" and "ANR4" that indicate subtracting the values of stimuli Nos. 10, 11, 12, 14, 15 and 16 from those of stimuli

Nos. 9, 9,10,1,1 and 14, respectively, including predicted and observed scale values both in Germany and in Japan. It is suggested from Figure 6 that CI is capable of evaluating the improvement of copy machine's sound quality. In the case of "ANR", all the subtractions of predicted scale values were about -0.2, while the observed ones varied from minus score to plus one. However, the absolute values are small.

In order to examine in detail, the amounts of difference in L_{Aeq} and sharpness for Figure 6 are listed in Table 2. It is found in "ANR" that sharpness increased while sharpness decreased in the case of "modified" sounds and the reduction of L_{Aeq} was less in "ANR" than in "modified" sounds. These features were related to their power spectra of the sounds as shown in Figure 7. The profile of stimulus No.1 ("machine A") had the highest peak at 900Hz and the higher components in the frequency range from 300Hz to 900Hz. The reductions at the highest peak and in the frequency components higher than 2 kHz in stimulus No. 14 were related to sufficient reduction of both L_{Aeq} and sharpness to improve the sound quality. Although the ANR used in this study was capable of reducing in the range from 100 Hz to 600 Hz, the highest peak remained as the same. This change of the spectrum resulted in the increasing sharpness and slight reduction of L_{Aeq} in "ANR". According to the equation of CI definition[1] it is found that CI mostly depends on sharpness in the case of "ANR".

In viewing on the experimental results of "ANR" in more detail, it is noticed that all experiments for "ANR" had the same tendencies that the impressions in Germany were worsened while improved in Japan in the case of "ANR1" and "ANR3", and the impressions in "ANR2" and "ANR4" were improved more than in "ANR1" and "ANR3". The former tendency was due to increasing sharpness since the values of L_{Aeq} showed little change. This supports the cultural difference in the subjective impression that German tends to prefer the sounds with less sharpness as reported in our former studies[3,4]. If the latter tendency depended on slight reduction of L_{Aeq}, the effect can not be clarified by the equation of CI. This suggests that it is necessary to investigate a new index capable of evaluating more accurately the sound quality improvement under the condition of slightly varying L_{Aeq}.

4. FINAL REMARKS

Practical use of CI to improve the sound quality of copy machine was examined. The sound quality from two actually modified machines was improved on CI evaluation. An experiment to verify the achievement was conducted using these four sounds before and after modification, eight sounds from other copy machines and four sounds with simulated active noise reduction in Japan and Germany. The following results were found.

(1) It was verified that CI was useful for predicting the improvement of the sound quality of copy machine in the development process as the first approximation.
(2) The experimental results "ANR" suggested that there was the systematic difference in the subjective impression of high frequent component of sounds between in Japan and in Germany, which was consistent with our former study.

Further investigation on varieties of sound and the possible cultural difference would clarify new universal physical metrics to evaluate and predict the sound quality more accurately.

REFERENCES

[1] S. Kuwano, S. Namba and T. Hatoh, "Sound quality of traffic noise transmitted into buildings", *Seminar on The Sound Quality Study and it's Application to Traffic Noise,* (2003)

[2] T. Yamada, S. Ebisu and S. Kuwano, "Relationship between subjective impression and physical properties of the sound of dental air turbine", *Proceedings of Inter-noise 2007* (2007).
[3] S. Kuwano, S. Namba, O. Takehira, M. Nagamiya and H. Fastl, "Cross-cultural Comparison of Subjective Impression of Copy Machine Noises using Original and Modified Sounds", *Proceedings of Inter-noise 2008,* (2008).
[4] S. Kuwano, S. Namba, O. Takehira, and H. Fastl, "Subjective impression of copy machine noises: an examination of physical metrics for the evaluation of sound quality", *Proceedings of Inter-noise 2009,* (2009), in press.
[5] S. Namba and S. Kuwano, *Method of Psychological Measurement for Hearing Research,* (Coronasha, 1998).
[6] H. Fastl and E. Zwicker, *Psychoacoustics – Facts and Models,* Springer (2007).

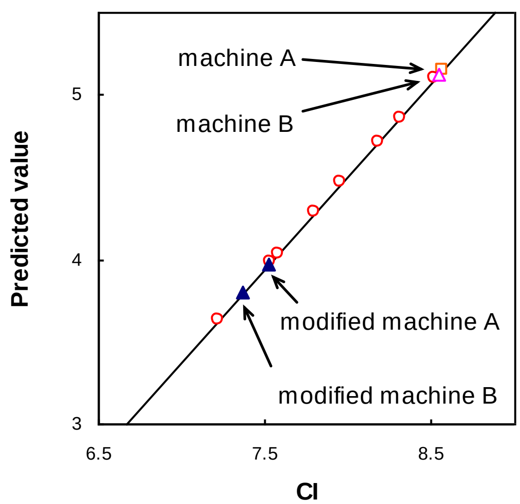

Figure 1: Predicted scale values of "pleasing – unpleasing" (vertical line) using CI (horizontal line) of several copy machines. The line is the relation between CI and observed values of the experiments in our former study[4].

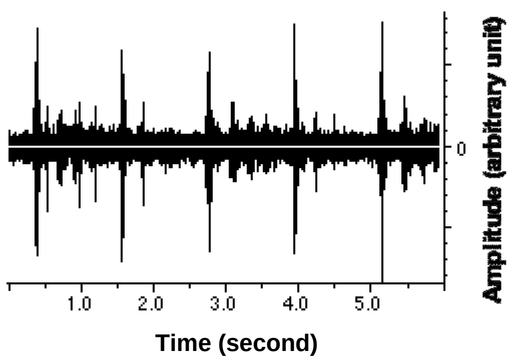

Figure 2: Sound level pattern of machine B

Table 1: Stimuli list used in the experiment

No.	Stimuli
1	original sound of machine A
2	original sound
3	original sound
4	original sound
5	original sound
6	original sound
7	original sound
8	original sound
9	original sound of machine B
10	original sound of modified machine B
11	simulated ANR of No.9
12	simulated ANR of No.10
13	original sound
14	original sound of modified machine A
15	simulated ANR of No.1
16	simulated ANR of No.14

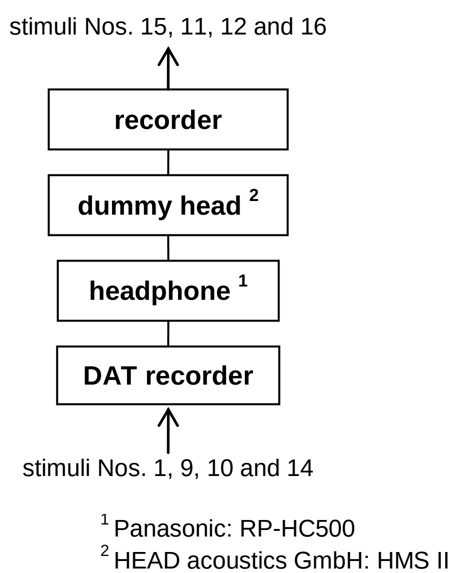

Figure 3: Flow chart to record ANR sound.

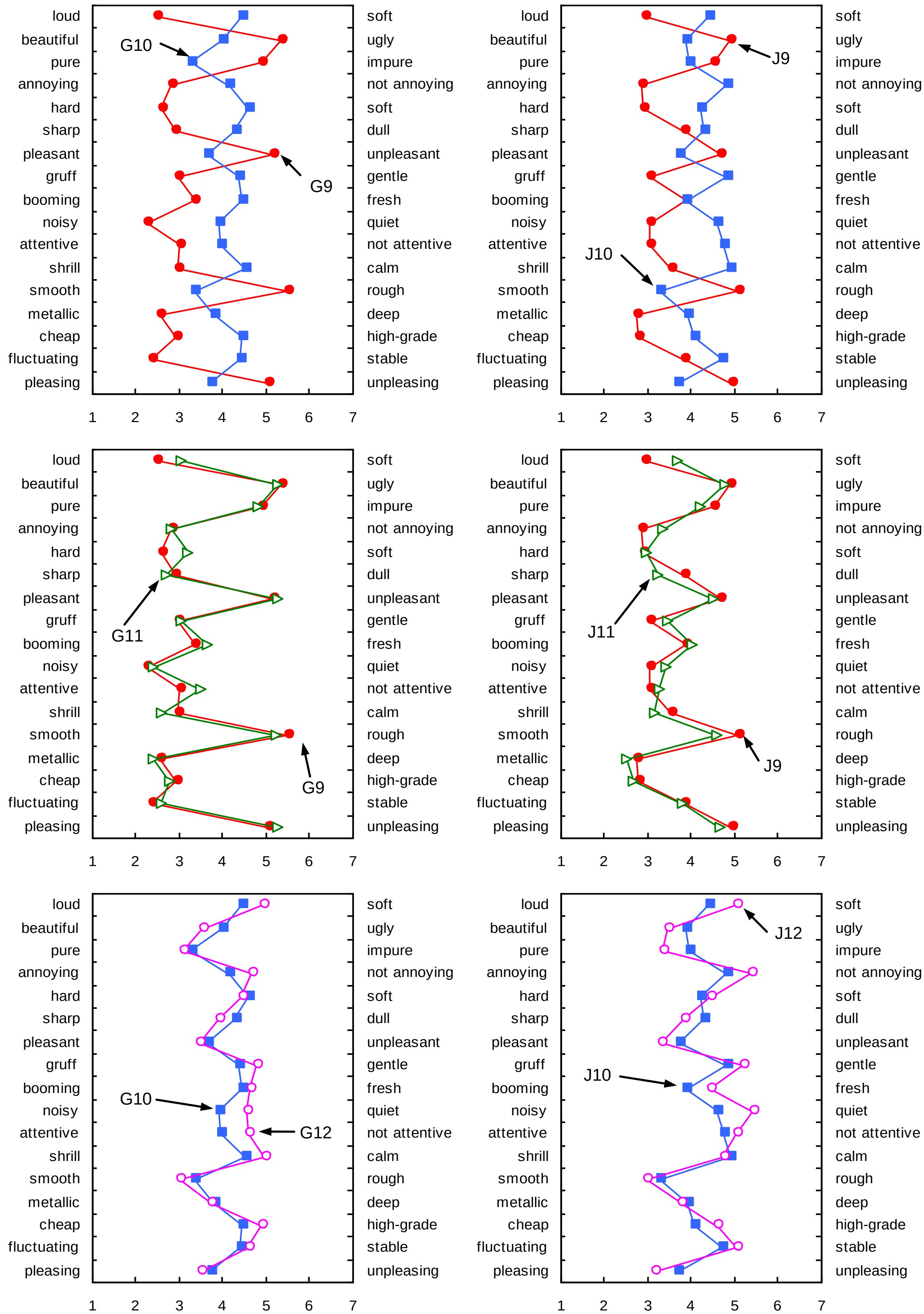

Figure 4: Six samples of semantic profile relating to machine B
(the left-hand side is the results in Germany and the right is in Japan)

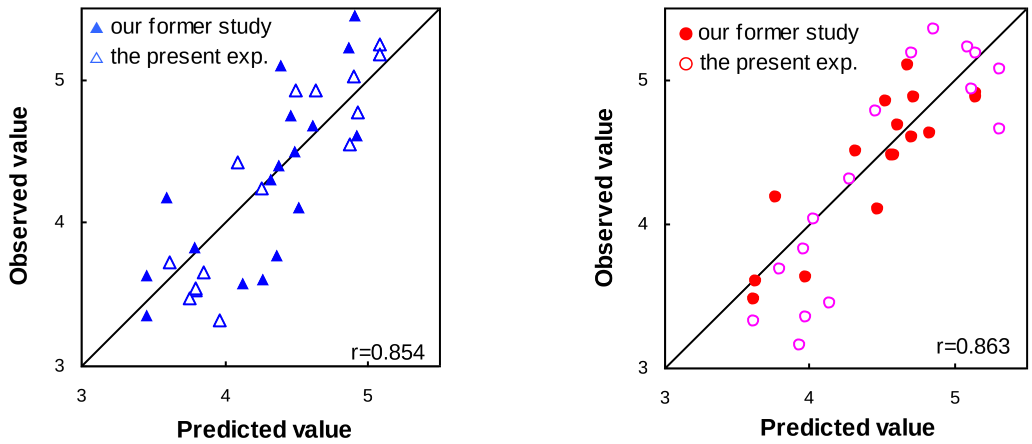

Figure 5: Relationship between predicted values of “pleasing – unpleasing” using CI (horizontal line) and observed values (vertical line) from the experiments. The left hand figure shows the results in Germany and the right in Japan. Filled symbols indicate the results in our former study and open symbols those of the present experiment.

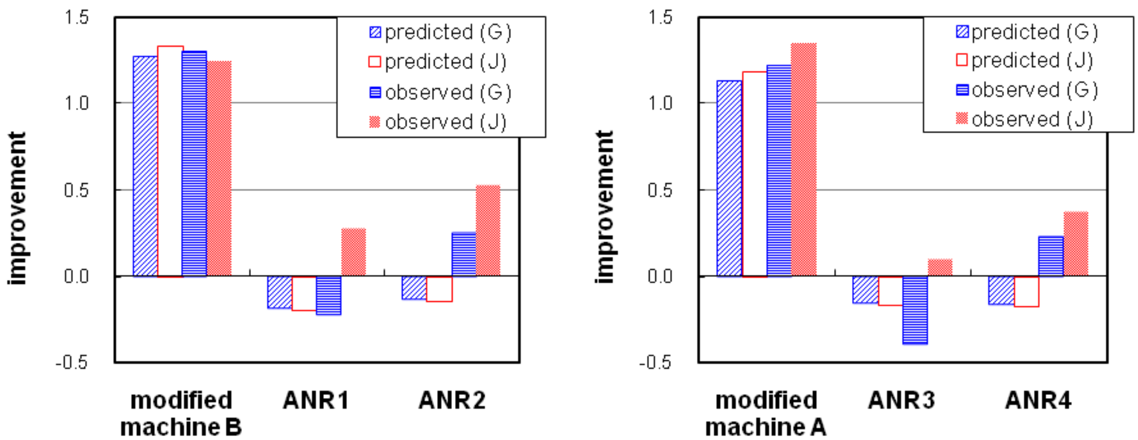

Figure 6: Improvement of the impression of pleasantness
(the left-hand side is the results relating machine B and the right is relating machine A)

Table 2: Amount of reduction in L_{Aeq} and sharpness

	modified B	ANR1	ANR2	modified A	ANR3	ANR4
L_{Aeq}	7.45	0.50	1.45	6.50	0.55	1.00
sharpness	0.43	-0.23	-0.27	0.40	-0.21	-0.26

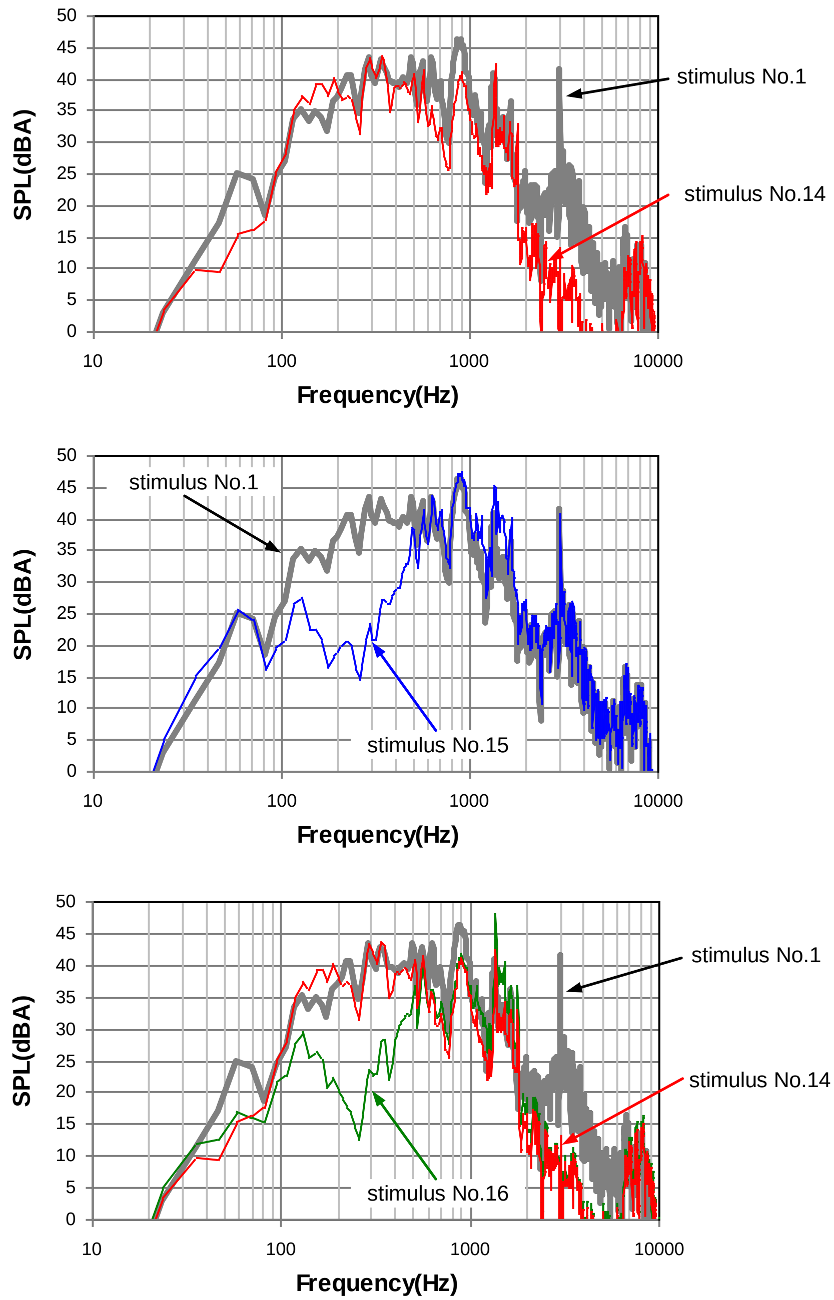

Figure 7: Power spectra of stimuli Nos.1, 13, 15 and 16 relating to machine A