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A STUDY ON TIMBRE AND SOUND QUALITY OF AN ELECTRIC GUITAR BY SELECTCTION OF MATERIAL AROUND PICKUP

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An electric guitar is a popular instrument, but there are many kinds of guitars both popular or cheap and high-grade ones and their grades are ranked by not only the quality of used material for body but that of used electric parts. Mechanism to pick-up sound signal is similar to a LP record player of stereophonic equipment. So, their timbre or sound quality seem to have great influence of its compositions like as body, neck, pickup, electric devices *etc*. under induced vibration by excited strings. Especially, the cheap one seems inferior in sound quality like sustain, clear sound, smoothness, *etc*. On the other hand, an effector can add effects of distortion, reverb, etc., but original timbre of the guitar could not be changed. So artists change their guitars to adjust the timbre to music impression on the stage. When the artists can change the timbre or sound quality without changing the guitar but changing just only the pick-guard in short time, it seems very useful to express the nuance of music. In the previous study, we had found out the tendency of timbre related to the characteristics of materials for the pick-guard which supports pick-up coils like as hardness, density and internal damping. The employed materials were wood (MDF, agathis, oak), nonferrous metals (copper, brass), ferrous metals (FC, SK5, SS) selected under consideration of the above characteristics. Especially, the internal damping was effective to the timbre of clear sound. In this study, by increasing the kinds of materials including polymeric materials, we propose a map of timbre or sound quality to illustrate the tendency of the sound related with the characteristics of pick-guard's material. Furthermore, we proposed noise reduction method with use of polymeric solution.

1. Introduction

An electric guitar is a popular instrument, but there are many kinds of guitars both popular or cheap and high-grade ones and their grades are ranked by not only the quality of material for body but that of electric parts. Mechanism to pick-up sound signal is similar to a LP record player of stereophonic equipment. So, their timbre or sound quality seem to have great influence of its compositions like as body, neck, pickup, electric devices *etc*. under induced vibration by excited strings. Especially, the cheap one seems inferior in sound quality like sustain, clear sound, smoothness, *etc*. This distinguished sound quality is difficult to change its fundamental timbre into more clear, bright or another one. Though, there are various methods to change the timbre, artists mainly use an effector on the stage. The effector can add effects of distortion, reverb *etc*., but original timbre of the guitar could not be changed. So artists change their guitars to adjust the timbre to music impression on the stage. When the artists can change the timbre or sound quality without changing the guitar but changing just only changing the pick-guard in short time, it seems very useful to express the nuance of music. In this study, we tried to change the timbre of electric guitar using just one guitar.

In the previous study [1], we proposed a method to change pick-guard and found out the tendency of timbre related with the property like as hardness, density and internal damping for several materials. Wood (MDF, agathis, oak), nonferrous metals (copper, brass) and ferrous metals (FC, SK5, SS) were employed for pick-guard by considering their properties. Especially, we could find out that the internal damping is effective to the timbre of clear sound.

In this study, to draw a timbre or sound quality map illustrating the tendency of sound related with property of pick-guard's material, we added other materials for pick-guard including two kinds of nonferrous metals and polymeric materials. First, we measured the power spectrum of output signal for each material of pick-guard to evaluate the difference in spectral envelope. Next, we carried out listening test to associate the difference in spectrum envelope with that in perception of timbre. After that, we drew maps illustrating the relation between a property of material and corresponding timbre. Next, we employed polyethylene glycol solution attached under electromagnetic pickup to reduce broad band noise of output signal.

2. Controlling method of timbre based on structure of electric guitar

As an electric guitar consist of various components like as body, neck, nut, bridge, electromagnetic pickup, pick-guard, strings and *etc*., it is known that the timbre of it is influenced by these components. The vibration on the strings excites these components including electromagnetic pickup, and it becomes complex vibration due to the feedback mechanism [2].

2.1 Structure of electric guitar

Figure 1 shows an electric guitar employed in this study, (a) original and (b) modified ones. This electric guitar has a solid body and is called as a stratcaster type. Characteristically, there are 3 lines of electromagnetic pickups to pick-up various modes of vibration of the strings at different places and transform into electric signal. They are attached to a pick-guard made of resin as shown in Fig.1 (a). So, as the electromagnetic pickups vibrate under the influence of vibration on the pick-guard, its electric signal output should be influenced by colouring effect of material caused by the vibration. That is, when one characterises the material of pick-guard, one could change the timbre of the electric guitar by replacing the pick-guard.

Table 1: Properties of materials used for pick-guard.

material	mass m[g]	Young's modulus E[GPa]	internal damping $Q^{-1}\times 10^{-3}$
MDF	65	25.0	15.9
agathis	31	8.7	10.9
oak	57	13.3	30.5
copper	251	117.0	1.9
brass	235	110.0	2.1
lead	321	16.1	28.5
aluminum	79	72.0	2.0
FC	198	100.0	7.0
SK5	222	206.0	6.2
SS	217	206.0	2.2
nylon	34	1.8	85.5
PET	36	2.5	10.2
acrylic resin	34	3.1	68.2
normal	51	4.1	43.0

2.2 Timbre control by changing pick-guard

In this study, as shown in Fig.1 (b), the pick-guard around electromagnetic pickup is partly cut and replaced by other materials. Considering the typical mechanical properties of material, we employed 13 kinds of material including newly chosen 5 kinds of materials to make pick-guard. They are classified in wood (MDF, agathis, oak), nonferrous metals (copper, brass, aluminium, lead), ferrous metals (FC, SK5, SS) and polymeric materials (Nylon, Acrylic acid resin, PET). As typical mechanical properties of materials, we treated mass, hardness and internal damping. Table 1 shows mechanical properties, hardness and internal damping of employed materials. Here, the internal damping was measured from response of damped oscillation under impulse excitation and adjuster passing through a band-pass-filter which extract most significant frequency component of impulse response.

(a) original one (b) modified one

Figure 1: Electric guitar used in experiment.

2.3 Noise reduction with use of polymeric solution

Based on the previous study [3], some kinds of polymeric solution possess property of vibration abruption because of molecule structure especially polyethylene glycol (abbr., PEG). In this study, we employed PEG which has a *n*-th single strand binding polymer of $C_2H_{15}O$ having OH^- and H^+ at both ends and represented by $H(C_2H_{15}O)_nOH$ as water solution mixed with two kinds of molecular weight 2 million and 500 thousand. As this solution is designed to absorb mechanical vibration and electromagnetic noise in audio frequency [3], we expected to reduce wide-band vibration caused on the electromagnetic pickups and electric noise on the output signal. Particularly, PEG solution is more effective in a strong magnetic field. As shown in Fig.2, packed PEG solution in a polyethylene bags are installed to the back space between pickup and body.

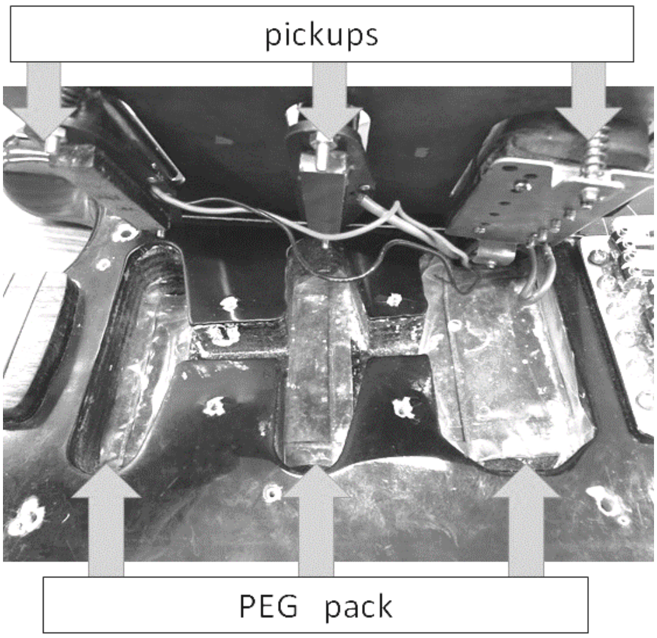

Figure 2: Installation of PEG package under electromagnetic pickup.

3. Measuring method

Timbre of an instrument should be evaluated both physically and perceptual attribute. In the physical scaling to evaluate the difference in timbre, the spectral composition of the sound is fundamental. So, first we measured the power spectrum of output signal for each material as the most important factor in the perception of timbre. Next, we carried out listening test to evaluate the difference in timbre in relation to property of material.

3.1 Measurement of spectral envelope

The timbre may be considered the subjective counterpart of the spectral composition of tone. Then, the physical correlates on timbre of an instrument are given by "relative amplitude of the various harmonics" [4]. For musical tones, timbre depends upon spectrum. Musical tones are thought on comprising three sections: "attack", "steady state" and "decay". More precisely, spectral envelope can divide "attack time", "decay time", "sustain time", and "release time". On the other hand, bullet stringed instrument such as the guitar doesn't have the sustain time and it is regarded decay time and release time as one condition. In this study, to consider the tempered characteristic, we regarded that the vibration of strings has "attack part" and "sustain part". The differences of timbre owing to the materials of pick-guard are measured as the characteristic of spectral envelope in "attack part" and "sustain part".

The frequency characteristic of output signal from electric guitar was analysed by FFT analyser [DS2000, ONO SOKKI] with anti-aliasing filter and Hanning window just after picking 5th string (110 Hz) with use of a guitar pick. Only the central electromagnetic pickup within 3 pickups was used. The volume and tone controls were set maximum. Spectral envelopes are extracted from the observed power spectrum by picking up the harmonics of 110 Hz at every 1 second up to 3 seconds. Kalman filter was used to reduce the background noise because of faint level of signal in higher frequency.

3.2 Listening test

In this test, we carried out following questionnaires to understand the experience in music or sound of subject:

(1) Do you listen to music every day?
(2) Are you particular about setting of equalizer function in audio equipment?
(3) Can you play a guitar?
(4) Have you used the provided evaluation word shown in Table 2?

Table 2: Five pairs of evaluation words for timbre of guitar sound used in questionnaire of listening test.

1	2	3	4	5
strong <=> weak	clear <=> muffle	hard <=> mild	bright <=> dark	harsh <=> pure

The evaluation words on sound of electric guitar used in listening test are shown in Table 2. Each evaluation words were chosen from among the words that guitarists use to impress the sensation of timbre of guitar. In this listening test the paired comparison method was employed and the tone of "original" provided the standard of evaluation. After presenting the standard tone, the objective tone produced with use of objective pick-guard was presented. Tones for the test were chord played as stoke and arpeggio. The test tones were previously recorded and provided to subject by replaying with precise stereophonic equipment. The subject answered the points from 1 up to 5 for 5 paired words. We assigned point 5 to the word on the left and point 1 to the right of each pair of words in Table 2. When the subject perceived the test tone has same timbre as "original", he should give point 3.

4. Experimental results for pick-guard

In this section, as the change in timbre related with property of material employed for pick-guard can be evaluated by spectral envelope in physical mean and by listening test in perceptual mean, first, we estimated the spectral envelope to detect the change in physical factors related to property of material. Next, we carried out listening test to connect the changes in material and in timbre.

4.1 Difference in spectral envelope related with pick-guard material

To evaluate the difference of timbre in physical scaling, we extracted spectral envelope from power spectrum observed for each pick-guard material. As the timbre is influenced by temporal changes, we extracted spectral envelope at “attack part” and at 3 second after the attack as typical one of “sustain part”.

4.1.1 Comparison of spectral envelope at “attack part”

Figure 3 shows the estimated results of relative spectral envelopes against power spectrum of fundamental frequency 110 Hz for pick-guard material of “oak” and “brass” in “attack part”. In this figure, “oak” keeps about 5dB higher level than that of “normal” in higher frequency range. And there are some significant peaks at 7.2, 7.7 and 8.5 kHz. For “brass”, spectral envelope is decrease about 10 or 20 dB comparing with “normal” in lower frequency range from 1 kHz up to 4 kHz. On the other hand, it keeps about 5dB higher level in higher frequency range from 6 kHz to 9 kHz.

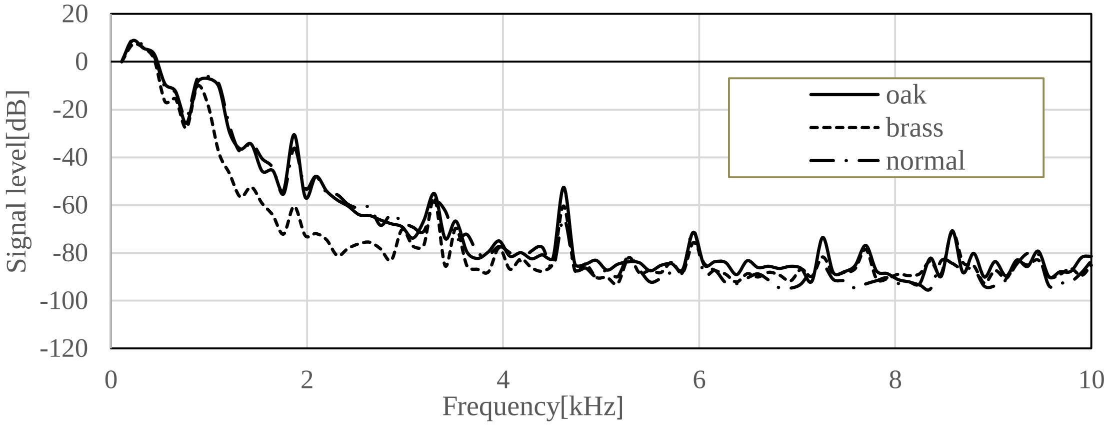

Figure 3: Comparison of spectral envelope for “oak” and “brass” versus “normal” in “attack part”.

4.1.2 Comparison of spectral envelope in “sustain part”

Figure 4 shows spectral envelope at 3 second later from attack as “sustain part” for “oak” and “brass”. From this figure, it is shown that the spectral envelope decreases about 5dB for “oak” and 10dB for “brass” comparing with “normal” in lower frequency range (under 4 kHz). But for “brass”, the spectral envelope keeps more than 5 dB higher levels same as “attack part” in higher frequency range (over 3k Hz).

From these figures, the peaks of spectral envelopes appear fixed positions because of influence by vibration modes of strings. Changes in properties of materials appear in relative amount of spectral envelope and cause significant peaks of spectral envelope. Especially in “sustain part”, the spectral envelope is kept higher level than that of “normal” in higher frequency range over 3 kHz.

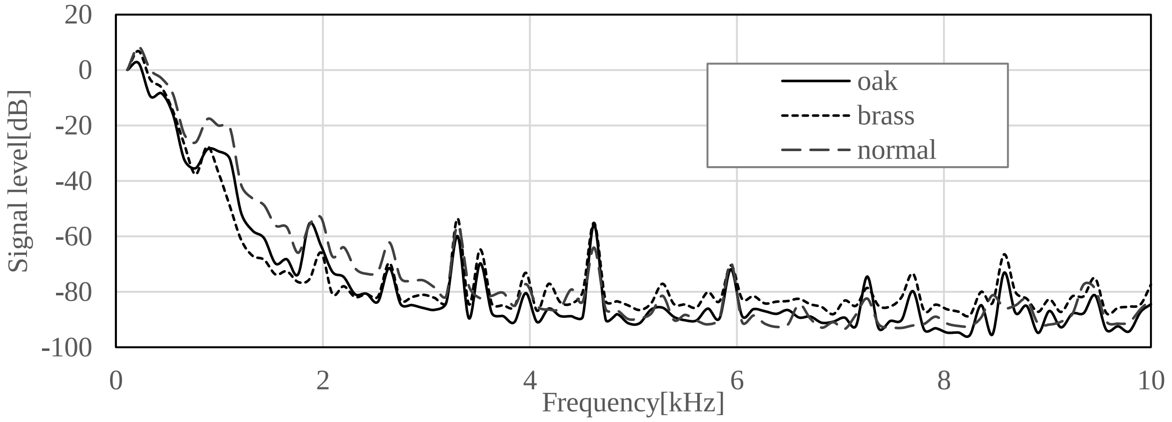

Figure 4: Comparison of spectral envelope for “oak” and “brass” vs. “normal” in “sustain part”.

4.2 Results of listening test

In Fig.5, the results of listening test are shown by comparing the material “oak” and “brass”. Here, score for “normal” is set to “3”. In this figure, “oak” got high score in evaluation word of “bright” because of enough energy in spectral envelope over 5 kHz with many remarkable peaks. But it shows also “weak” because of low level in the frequency range under 4kHz in “sustain part” as shown in Fig. 4. On the other hand, “brass” marked high score on “harsh” and “strong” because of high energy in higher frequency range over 5 kHz. Furthermore, because of low level in spectral envelope in lower frequency range under 4 kHz as shown in Figs. 3 and 4, the high frequency sound seems to be emphasized.

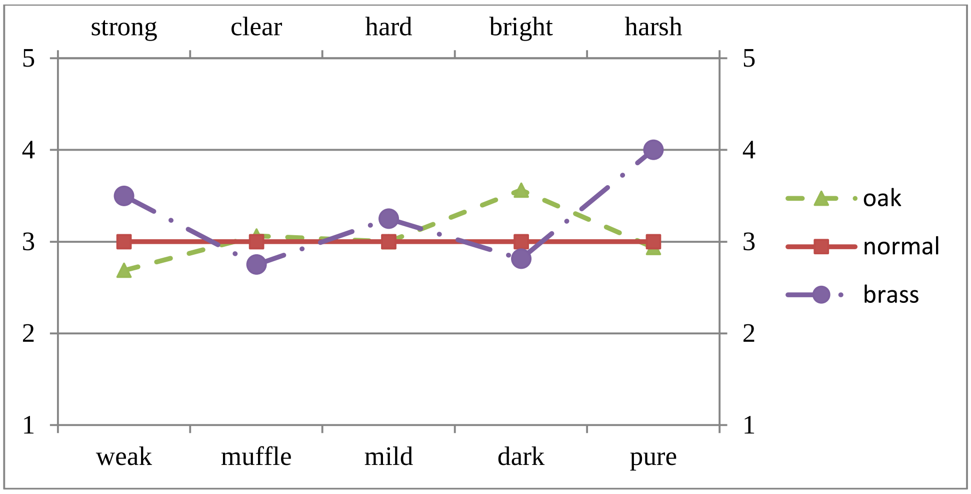

Figure 5: Result of sound quality test for oak and brass comparing with normal one.

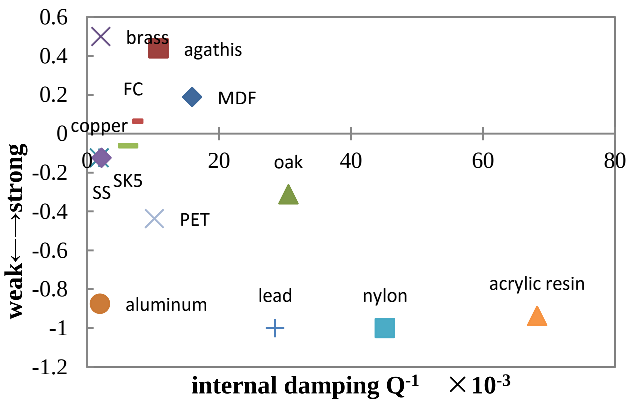

Figure 6: Relationship between internal damping and the word “strong”.

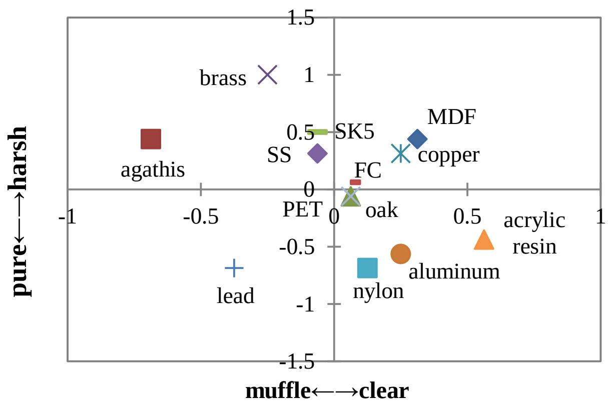

Figure 7: Timber map on materials related with evaluation words “clear” and “harsh”.

4.3 Map of timbre related with property of material

In Fig.6, a map (scatter diagram) illustrating relationship between “internal damping” and evaluation word “strong” and opposite “weak” is drawn for each material. In this figure, as the tendency between character of “strong” and property of material “internal damping”, the sound character “strong” is in inverse proportion to “internal damping” except “aluminium”. This tendency seems to be related to internal decay of vibration. That is the early decay makes the vibration energy decrease and weak sound.

Next we draw a timbre map (scatter diagram) for selection of material to adapt the desired tone. Figure 7 shows the scatter diagram of materials related with evaluation words of “harsh” and “clear”. From this figure, when one likes “clear” and “pure” sound, “acrylic resin”, “aluminium” and “nylon” are recommended. For “harsh” and “clear” sound, “MDF” or “copper” is recommended.

5. Experimental results for noise reduction method by PEG

5.1 Result on broad-band noise reduction

Effect of PEG packs to reduce broad band noise is evaluated by subtracting power spectrum with use of PEG packs under electromagnetic pickup from that without PEG packs. A typical example for SK5 pick-guard is shown in Fig. 8. In this figure, positive value means effective for reduction of broad band noise by PEG pack. From this figure, it seems that the PEG pack is useful for lower frequency region. Noise reduction level by PEG solution was 19.0dB in overall.

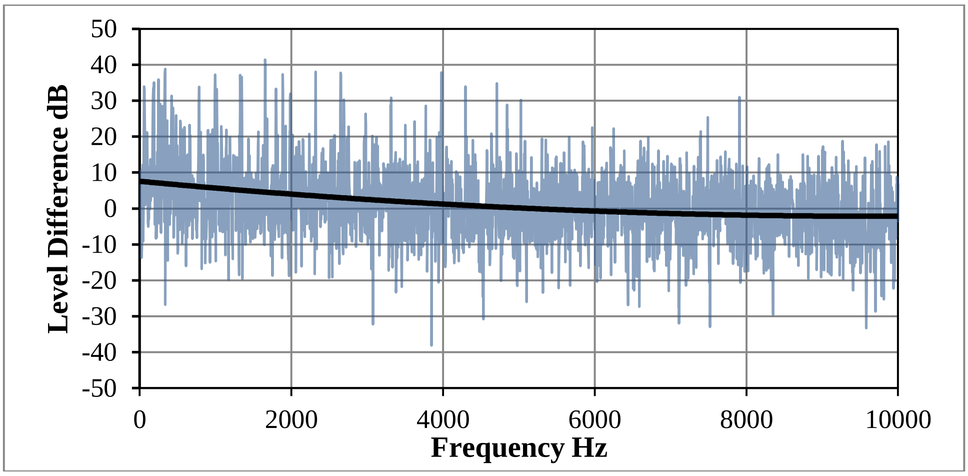

Figure 8: Difference in background noise evaluated by subtracting the power spectrum with use of PEG packs from that without PEG packs for pick-guard by SK5.

5.2 Difference in spectral envelope related with use of PEG solution

Comparisons of spectral envelope in “attack part” and “sustain part” are shown in Figs.9 and 10. In Fig. 9, spectral envelope is decrease in lower frequency range from 800Hz up to 3000Hz. On the other hand, in Fig. 10, the spectral envelope is kept high as same as in “attack part” in higher frequency range. From these figures, it is obvious that the PEG shows a tendency to keep the signal level constant.

6. Conclusions

In this study, by considering that the electromagnetic pickup is influenced by vibration through surrounding material, we proposed adjusting method for timbre of electric guitar by replacing pick-guard and noise reduction method by PEG solution. Then we could have following conclusions.

1. The effect of material appears in the signal level in lower frequency and peaks in higher frequency of spectral envelope.
2. Evaluation word "strong" is inverse proportional to "internal damping".
3. Vibration control by PEG solution decreases in signal level in lower frequency range but keeps high signal level in higher frequency range without changing the outline of spectral envelope.
4. By using PEG pack, the timbre changes into "quiet sound" because of decrease in broad band noise in lower frequency range.

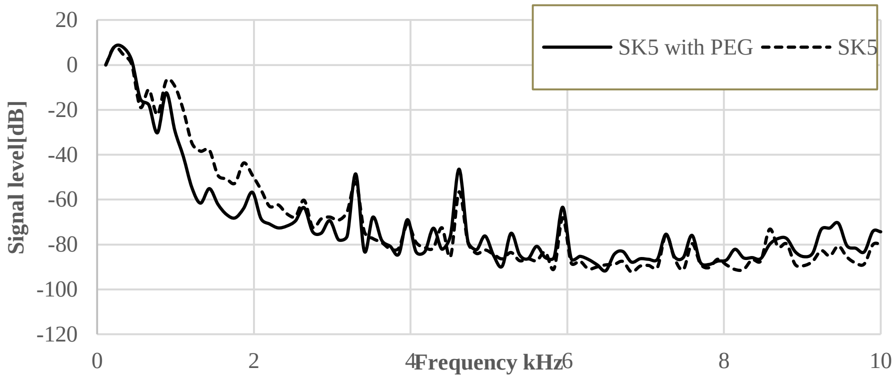

Figure 9: Comparison of spectral envelope between with and without PEG in "attack part" for SK5.

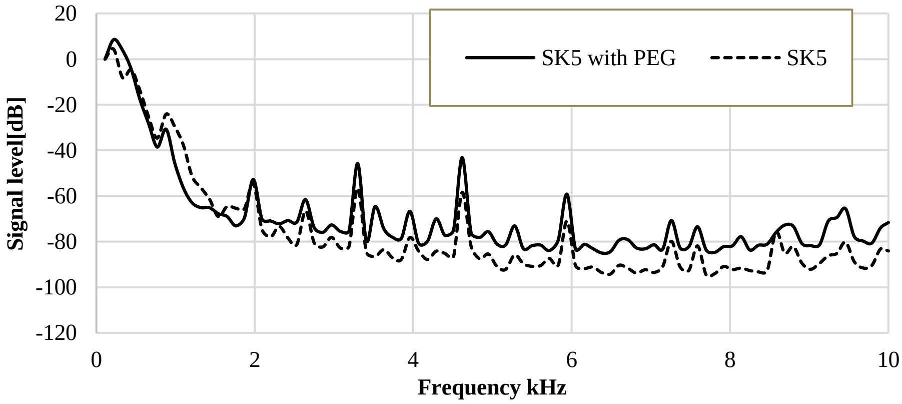

Figure 10: Comparison of spectral envelope between with and without PEG in "sustain part" for SK5.

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