Research Article
Volume S1, 2021
DOI: 10.37421/bset.2021.S1.007

Journal of Biomedical Systems & Emerging Technologies

ISSN: 2090-5092 Open Access

Acoustic Noise of IH Cooker Caused by the Power Supply Noise

Hironobu Yonemori*, Natsumi Tsuguta

Department of Mechanical & Electronic Engineering, Salesian Polytechnic, 4-6-8, Oyamagaoka, Machida, Tokyo, 194-0215, Japan

Abstract

In this paper, we discuss the acoustic noise generated while driving an IH cooker with a power supply that includes high-frequency noise. This is because the acoustic noise generated from the IH cooker is of the order of kHz, which causes health issues amongst the users, e.g., headache, nausea, dizziness, and discomfort. In this study, we clarify the data that contribute to the formulation of the guidelines on acoustic noise specifically in IH cookers. We conducted an acoustic noise measurement focusing on the amplitude and frequency components of the noise contained in the power supply. The measurement results were compared with the environmental standards announced by the Ministry of the Environment, Japan. As a result, we clarified the conditions for generating acoustic noise that exceeds environmental standards.

Keywords: IH cooker • Power supply noise • Pan vibration • Acoustic noise

Introduction

In recent years, environmental problems such as global warming have become more urgent which has called for the reduction in carbon dioxide emissions and efficient use of electricity. As a result, all-electric homes that do not use gas have become widespread in Japan [1]. The increase in the demand for IH cookers is an example of this trend. The merit of the IH cooker lies in the fact that it does not use a direct fire; hence, there is no risk of fire if in case one forgets to turn it off, which makes it is highly safe to use. In addition, the top plate on which the pan is placed has the advantage of being easy to clean because of its flat shape. According to the "2014 National Survey of Consumption" announced by the Ministry of Internal Affairs and Communications of Japan, the penetration rate of IH cookers in 2009 was 18.2%, which increased in 2014 to 23.9% [2]. However, there are reports that the noise generated from the IH cookers causes discomfort and health issues such as headache, dizziness, and nausea among users [3,4]. In our previous study, we investigated the mechanism of noise generated by induction heating in induction cookers, high frequency noise above 20 kHz, and audible noise. As a noise mechanism, unnecessary noise generated from inverter equipment in the home, such as refrigerators and fluorescent lamps, IH cooker drive frequency (20 kHz), and commercial power frequency (50 Hz / 60 Hz) are superimposed on the power supply. It has been clarified that the pan vibrates by doing so, and the vibration becomes the noise [5]. In addition, it has been clarified that the noise level changes depending on the size of the pan used while cooking in an IH cooker, and that the larger the diameter of the bottom of the pan, the louder the noise [6]. High-frequency noise is usually outside the audible range (20 kHz or higher) and cannot be recognized as a sound. However, it has been reported that humans perceive high-frequency noise of 90 dB or more, which is known to cause discomfort [7]. On the other hand, it has been reported that noise in the frequency band lower than the drive frequency of the IH cooker is generated [5]. Previous studies have suggested that the noise level changes depending on the noise component superimposed on the power supply, but the cause has not yet been clarified. In a previous report, it was clarified that when noise of approximately 0.05% to 0.7% was superimposed on 100 V of the commercial power supply, it exceeded the environmental standard set by the Ministry of the Environment [5]. Japan's Ministry of the Environment's noise-related environmental standards for "areas exclusively used for housing" and "areas mainly used for housing" have a standard value of 55 dB or less during the day and 45 dB or less at night [8]. On the other hand, although there are regulations regarding the frequency component of noise superimposed on the power supply, according to the CISPR standard 14-1, 9 kHz or less is not subject to regulation. Therefore, it is necessary to formulate new guidelines to prevent noise from the IH cookers. The purpose of this study is to reduce the noise in the human audible range emitted from the IH cooker and to clarify the data that contribute to the formulation of the guidelines on the noise for the IH cooker. A large number of experiments must be repeated to achieve the research objectives.

In this study, in order to contribute to the formulation of guidelines for noise dedicated to IH cookers, the amplitude values of the superimposed noise were set to 720 mVrms, 500 mVrms, 300 mVrms, and 100 mVrms, and the frequency of the superimposed noise was set from [5]. We will clarify the frequency characteristics of audible noise generated when the frequency is changed from 1 kHz to 9 kHz outside the CISPR standard 14-1 and the measurement results of the OA (over-all) value. We will then compare it with environmental standards and noise standards in daily life, and report on the noise problem generated by IH cookers.

Acoustic noise problems and standard values in Japan

Noise is one of the "typical seven pollutants". The definition of pollutants announced by the Ministry of Internal Affairs and Communications of Japan includes agents due to which a "damage to human health or living environment occurs". In addition, noise is generally regarded as "unpleasant sound, unpleasant sound" [9]. There are four types of noise: combustion noise, fluid noise, mechanical noise, and electromagnetic noise [10]. The noise generated from an IH cooker is an electromagnetic noise, which is similar to the noise generated as "beats" caused by the electromagnetic force of transformers and AC motors. This electromagnetic noise is what people hear near transformers and AC motors. In Japan, the objective is to regulate environmental noise based on the "Basic Environment Law", and noise emissions are regulated accordingly.

Table 1 lists the environmental quality standards [8] for noise announced by the Ministry of the Environment of Japan. “A” and “B” are environmental standards for noise in residential areas. Therefore, for comparison with the sound pressure level (SPL) measured in this study, the evaluation indexes of A and B are 55 dB or less during the day and 45 dB or less at night.

Table 2 lists the guidelines for noise in daily life [11]. From previous research,

***Address for Correspondence:** Hironobu Yonemori, Department of Mechanical & Electronic Engineering, Salesian Polytechnic, 4-6-8, Oyamagaoka, Machida, Tokyo, 194-0215, Japan, Email: yonemori@salesio-sp.ac.jp*

Received 15 September 2021; **Accepted** 30 September 2021; **Published** 07 October 2021

the high-frequency noise over 90 dB [7] generated by the drive frequency of the IH cooker has a sound pressure level comparable to that of the subway when compared in the audible range. Therefore, the authors pointed out the problem that familiar household IH cookers are a major source of noise.

Noise generation

Figure 1 shows the noise propagation route [12]. From Figure 1, the noise generated from the inverter is roughly classified into three types: (1) conduction noise, (2) induction noise, and (3) radiation noise. In this study, (1) the conduction noise was considered. Conduction noise is propagated to the power supply side and motor side through conductors, such as circuit wiring, and affects the peripheral equipment. In this way, the inverter device causes the noise to flow back to the power supply line.

Figure 2 shows an example of the harmonic current generated on the commercial power supply side when the IH cooker is operated. The effective value of the harmonic current after the second harmonic is presented. The effective value of the current of 17.57 Arms is measured at 60 Hz, which is the power supply frequency. From Figure 2, it is evident that the effective value of the harmonic current decreases as the order increases.

Figure 3 shows the distortion factor after the second harmonic. Here, the current at 60 Hz, which is the power supply frequency, was set to 100%, and the distortion factor after the second harmonic was calculated. From Figure 3, the distortion factors are particularly large: 3rd harmonic, 180 Hz; 5th harmonic, 300 Hz; 7th harmonic, 420 Hz; 11th harmonic, 660 Hz; 19th harmonic, 1140 Hz; 25th harmonic, 1500 Hz. In addition, as with the effective value of the harmonic current, the distortion factor decreases as the order increases.

Figure 4 shows an example of the configuration of a voltage-resonance-type inverter for the IH cookers. From Figure 4 it can be seen that there is an LC filter consisting of L1 and C1 on the input side of the IH cooker. The LC filter suppresses the noise generated in the IH cooker from flowing out to the power supply line within the standard value, further contributing to the improvement in the power factor. However, as shown in Figure 1, the inverter equipment has the problem of causing a small amount of switching noise to flow back into the power supply line. When multiple inverter devices are present in the same power supply line, the noise may increase depending on the conditions.

Figure 5 shows the noise generated by the IH cooker. Here, the leakage magnetic flux and the noise generated by the pan vibration are treated as noise problems. Noise generated from IH cookers can be roughly divided into the following three types:

1. Leakage magnetic flux during electromagnetic induction heating.
2. High-frequency noise generated by the inverter in the IH cooker.
3. Audible area noise generated by noise superimposed on the commercial power supply.

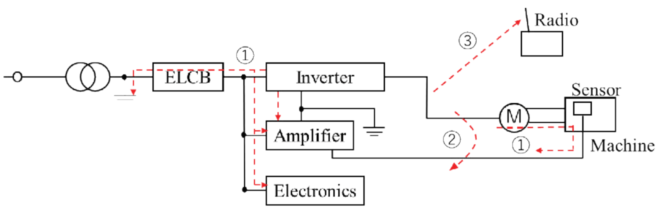

Figure 1. Noise propagation route [1].

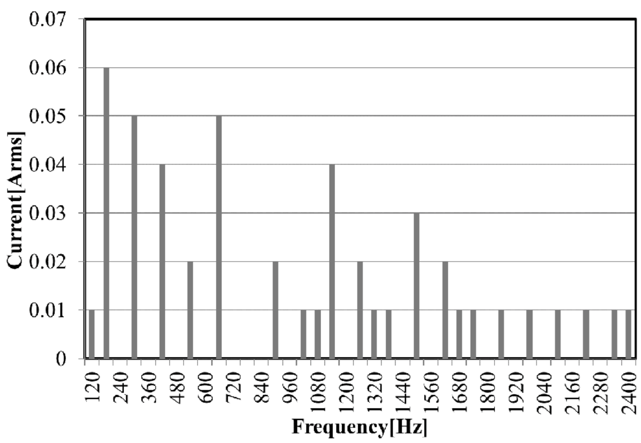

Figure 2. Effective value of harmonic current.

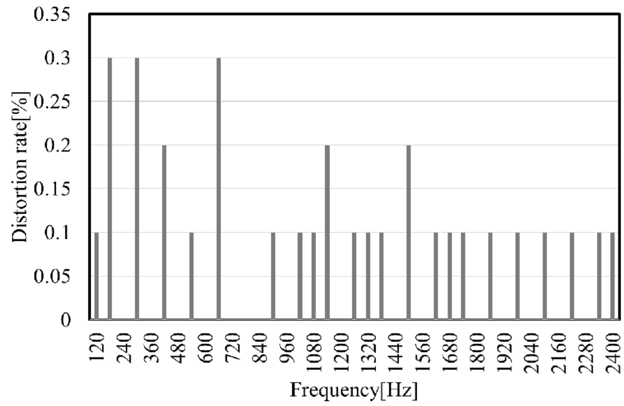

Figure 3. Distortion rate.

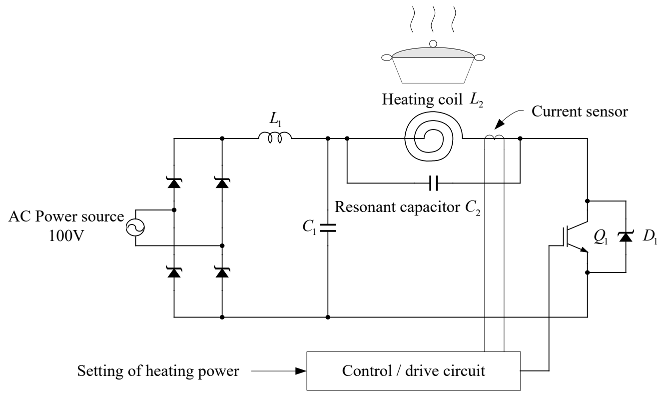

Figure 4. Configuration of voltage resonance type inverter for IH cooker.

Table 1. Environmental standards for acoustic noise [8].

Regional type	Standard value	
	Daytime	Night
AA	50 dB or less	40 dB or less
A and B	55 dB or less	45 dB or less
C	60 dB or less	50 dB or less

Table 2. Estimated acoustic noise level in daily life [11].

Sound pressure level [dB]	Estimated noise
120	Jet engine
110	Helicopter
90	Inside the subway (Ginza line)
85	Phone bell
70	Normal conversation
65	Noisy street
55	Small voice conversation
35	Quiet residential area
30	Secret story

Although the frequency bands of (2) and (3) are different, noise is generated by the vibration of the pan caused by electromagnetic induction.

Experimental method

Table 3 shows the equipment used and Figure 6 shows the configuration of the measurement environment. This experiment was conducted in an anechoic room conforming to ISO-3745 at the Salesian Polytechnic College because ambient sounds may affect the experimental results. Table 4 lists the background noise of the anechoic chamber. Only the equipment necessary for the noise measurement was installed in the anechoic chamber, and equipment such as the power supply was installed outside the anechoic chamber. The IH cooker used in the experiment was a commercially available desktop 100 V type (output 1.4 kW). In this experiment, a three-layer SUS pan with a pan bottom diameter of 20 cm was used as the heating target. In addition, during the experiment, the pan was heated without a lid.

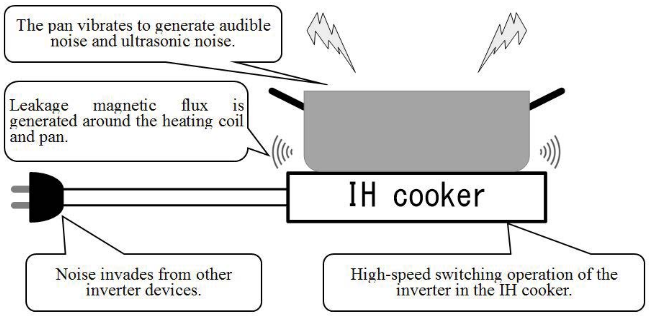

Figure 5. Noise generated from the IH cooker.

Table 3. List of equipment.

Equipment	Manufacturer name	Model number
Digital oscilloscope	Tektronix	TDS5034B
FFT analyzer	RION	SA-78
Condenser microphone	RION	UC-59
Stabilized power supply	NF	DP015S
Arbitrary function generator	HP	33120A
IH cooker	Desktop type (100 V, 1.4 kW)	

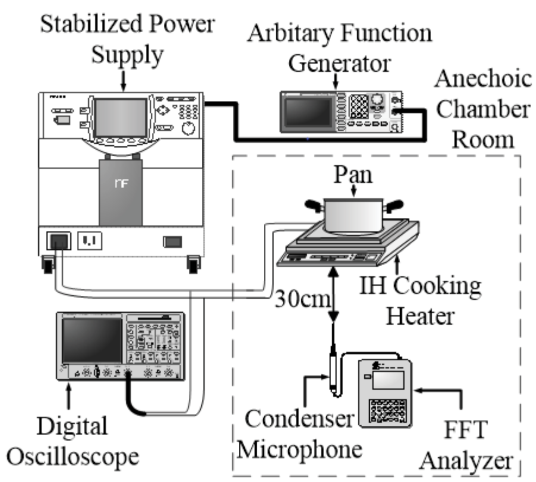

Figure 6. Experimental configurations.

Table 4. Background noise level.

Air conditioning	Sound pressure level[dB]
With air conditioner	20
Without air conditioner	18

Figure 7 shows the arrangement of the pan and the microphone placed on the IH cooker. The measurement frequency range of the condenser microphone used was 10–20 kHz. This microphone was connected to an FFT analyzer for the frequency analysis. The experimental method for measuring audible noise is detailed as follows in (1) to (11).

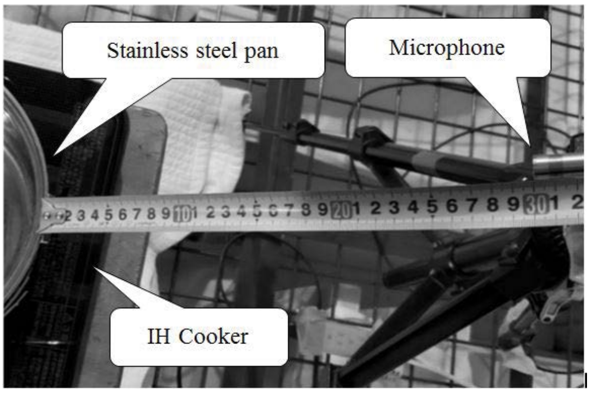

Figure 7. Distance between pan and microphone.

1. Each device was prepared as shown in Figure 6. At this time, in order to simulate the situation where a person is cooking using a pan, the distance between the pan and the condenser microphone was set to 30 cm as shown in Figure 6.
2. One liter of tap water was poured into the pan. At this time, the water depth was approximately 3.3 cm and the pan bottom diameter was 20 cm; thus, tap water of approximately 1037 cm^3 was used.
3. The programmable AC regulated the power supply to rated 100 V, 60 Hz, 1.4 kW, sine wave output, and output.
4. The function generator was used to set the power supply noise amplitude value to 720 mVrms and change the power supply noise frequency to 1 kHz, 2 kHz, 4 kHz, 7 kHz, and 9 kHz.
5. The pan was heated using an IH cooker.
6. Using an oscilloscope, the power supply noise amplitude value was set.
7. The FFT analyzer was used to measure the noise level (SPL) at the power supply noise frequency and the combined power (Over All: OA value) of the entire frequency band. OA value is total value of all frequencies (0.1 - 20 kHz) within the measurement range.
8. The water was changed, and steps (4) to (7) were performed five times for each power supply noise frequency.
9. Experiments (4) to (8) were carried out by changing the power supply noise amplitude values to 500 mVrms, 300 mVrms, and 100 mVrms.
10. An average for each result was taken.
11. Each of the SPL and OA values were compared with Japanese environmental standards.

As a precaution during the experiment, because the IH cooker performs frequency sweeps to automatically detect the resonance point immediately after the start of heating, it is necessary to measure the noise after the frequency becomes constant. In addition, while changing the water in the pan, even a slight shift in the position of the pan will change the experimental results, so the water should be replaced without moving the pan.

Experimental results

Frequency characteristics of the acoustic noise

Figure 8 shows the measurement results when the power supply noise changes. In each graph, the vertical axis is the SPL [dB], and the horizontal axis is the noise frequency [kHz]. Figure 8(a) shows the measurement result when the power supply noise amplitude value is 720 mVrms superimposed, (b) shows the measurement result when the power supply noise amplitude value is 500 mVrms superimposed, (c) shows the measurement result when the power supply noise amplitude value is 300 mVrms superimposed, and (d) shows the measurement results when the power supply noise amplitude value is superimposed at 100 mVrms. From Figure 8 (a), SPL of 1 kHz: 39.8 dB, 2 kHz: 45.2 dB, 4 kHz: 48.8 dB, 7 kHz: 46.5 dB, 9 kHz: 53.9 dB could be confirmed. From Figure 8 (b), SPL of 1 kHz: 39.7 dB, 2 kHz: 40.4 dB, 4 kHz: 43.8 dB, 7 kHz: 44.3 dB, 9 kHz: 48.3 dB could be confirmed. The SPL peak was confirmed at the same frequency as the superimposed power supply noise frequency, as shown in Figure 8(a). Comparing Figure 8(a), and 8(b), it can be confirmed that the SPL is lower in (b). From Figure 8(c), the SPL of 1 kHz: 40.7 dB, 2 kHz: 41.1 dB, 4 kHz: 38.1 dB, 7 kHz: 37.1 dB, and 9 kHz: 46.2 dB could be confirmed. The SPL peak was confirmed at the same frequency as the superimposed power supply noise frequency, as shown in Figure 8 (a) and Figure 8 (b). Comparing Figure 8(b) and 8(c), Figure 8 (c) shows a decrease in the SPL. From Figure 8(d), the SPL of 1 kHz: 39.2 dB, 2 kHz: 30.8 dB, 4 kHz: 31.7 dB, 7 kHz: 29.8 dB, and 9 kHz: 34.3 dB could be confirmed. The peak of the SPL was confirmed at the same frequency as the superimposed power supply noise frequency as in Figure 8(a-c). Comparing Figure 8(c) and 8(d), Figure 8 (d) showed a decrease in SPL. Therefore, it was clarified that the power supply noise amplitude value and SPL have a proportional relationship. It was also confirmed that the noise component superimposed on the power supply as power supply noise is radiated as the noise as it is.

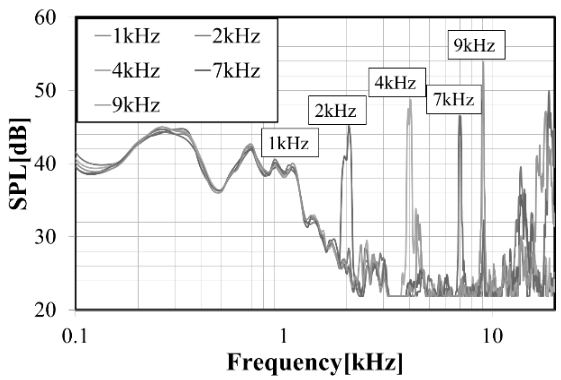

Figure 8(a). Power supply noise amplitude: 720 mVrms.

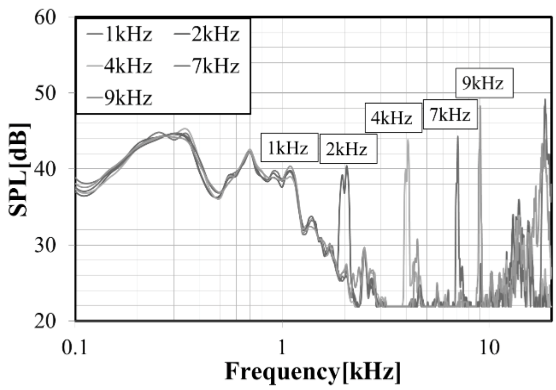

Figure 8(b). Power supply noise amplitude: 500 mVrms.

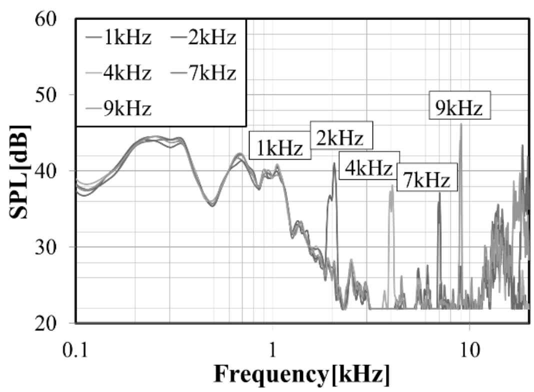

Figure 8(c). Power supply noise amplitude: 300 mVrms.

Here, for reference, we will compare the experimental results with the noise environmental quality standards [9] announced by the Ministry of the Environment and summarized in Table 1. Table 5 shows the SPL when the power-supply noise is superimposed. The colored values in the table exceed the environmental standard values in Japan. From Table 5, at 720 mVrms, the 2 kHz, 4 kHz, 7 kHz, and 9 kHz values exceeded the standard value. At 500 mVrms and 300 mVrms, only the 9 kHz value exceeded the standard value. At 100 mVrms, no value exceeded the standard value.

From the above, it was found that the SPL generated from the IH cooker is reduced by reducing the superimposed power supply noise amplitude value and power supply noise frequency. The drive frequency when heating the three-layer SUS pan targeted for heating in this experiment was approximately 20 kHz to 23 kHz. Therefore, the spectrum above 10 kHz in Figure 8 is a distortion component near the drive frequency that occurs when the pan vibrates.

OA value of acoustic noise

From the results in the previous section, it was clarified that when the IH cooker is operated with a power supply to which noise is added, the superimposed noise component becomes the noise. However, Figure 8 shows that there is a spectrum of components other than the noise components intentionally superimposed in the experiment. This is the harmonic component due to the waveform distortion of the voltage-resonance-type inverter present inside the IH cooker, the noise of the circuit cooling fan, and the noise due to the main frequency of the inverter. In the previous section, the SPL of the noise component intentionally added was evaluated, but because the above-mentioned noise exists, this section clarifies the OA value (total value of all frequencies within the measurement range) that quantifies all the noise.

Figure 9 shows the OA values of the noise. The vertical axis shows the OA value (dB), and the horizontal axis shows the superimposed frequency (kHz). As with SPL, the OA value was plotted with the average value of the results of

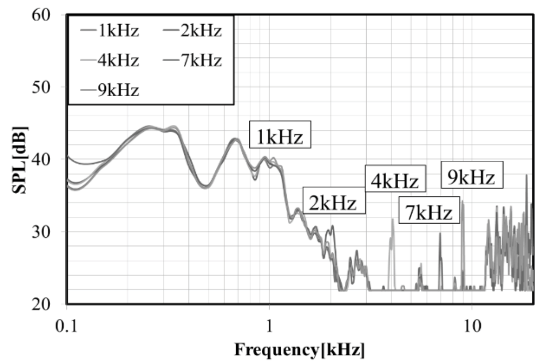

Figure 8(d). Power supply noise amplitude: 100 mVrms.

Table 5. SPL [dB] at each power supply noise frequency.

Power supply noise Frequency [kHz]	Power supply noise amplitude value [mVrms]			
	720	500	300	100
1	39.8	39.7	40.7	39.2
2	45.2	40.4	41.1	30.8
4	48.8	43.8	38.1	31.7
7	46.5	44.3	37.1	29.8
9	53.9	48.3	46.2	34.3

※The standard value is 45 dB at night.

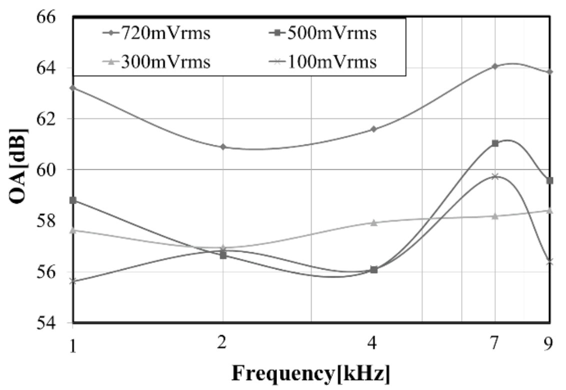

Figure 9. OA value of acoustic noise.

five measurements. From Figure 9, the OA values of 1 kHz: 63.2 dB, 2 kHz: 60.9 dB, 4 kHz: 61.6 dB, 7 kHz: 64.0 dB, and 9 kHz: 63.8 dB were confirmed when the power supply noise amplitude value was superimposed at 720 mVrms. When the power supply noise amplitude value was superimposed at 500 mVrms, the OA values of 1 kHz: 58.8 dB, 2 kHz: 56.6 dB, 4 kHz: 56.1 dB, 7 kHz: 61.0 dB, and 9 kHz: 59.6 dB could be confirmed. When the power supply noise amplitude value was superimposed at 300 mVrms, the OA values of 1 kHz: 57.6 dB, 2 kHz: 56.9 dB, 4 kHz: 57.9 dB, 7 kHz: 58.2 dB, and 9 kHz: 58.4 dB could be confirmed. When the power supply noise amplitude value was superimposed at 100 mVrms, the OA values of 1 kHz: 55.6 dB, 2 kHz: 56.8 dB, 4 kHz: 56.1 dB, 7 kHz: 59.7 dB, and 9 kHz: 56.4 dB could be confirmed. 720 mVrms and 500 mVrms showed almost the same tendency, but 300 mVrms and 100 mVrms showed different tendencies. The cause is under investigation, but the current inference is that when the noise amplitude is small, the influence of the cooling fan, etc., is greater than the superimposed noise.

Here, for reference, it is compared with the standard noise in daily life. Comparing the results of Table 2 and Figure 9, it can be said that the OA value is concentrated between 55 dB and 65 dB, so it can be said that noise equivalent to that of a quiet conversation or a noisy street is generated.

Conclusion

In this study, in order to contribute to the formulation of guidelines for noise dedicated to IH cookers, the amplitude values of the superimposed noise were set to 720 mVrms, 500 mVrms, 300 mVrms, and 100 mVrms following ref. [5], and the frequency of the superimposed noise was set. We clarified the frequency characteristics and OA value measurement results of the audible noise generated when the frequency was changed from 1 kHz to 9 kHz outside the CISPR standard 14-1.

We then compared the results with the environmental standards in Japan and noise standards in daily life. The facts clarified in this study are as follows:

1. The SPL of the frequency characteristic generated from the IH cooker when the pan was induced and heated by the IH cooker was measured and compared with the environmental standard announced by the Ministry of the Environment of Japan. As a result, the reference value at night was exceeded for frequencies of 2 kHz, 4 kHz, 7 kHz, and 9 kHz at a power supply noise amplitude value of 720 mVrms. At 500 mVrms and 300 mVrms, only the 9 kHz frequency exceeded the Japanese environmental standard. It was confirmed that at 100 mVrms the Japanese environmental standard was not exceeded for any frequency. From this, it was found that the SPL of the frequency characteristic also decreased as the power supply noise amplitude value and power supply noise frequency decreased. From the above, it can be stated that if a noise filter can be inserted into the power supply and the noise amplitude value mixed in the power supply line can be reduced to 100 mVrms or less, the reference value will not be exceeded.
2. The OA values measured at the same time as the frequency characteristics were compared with the noise standard in daily life for each power supply noise amplitude value. As a result, it was found that the OA value was concentrated between 55 and 65 dB, so that noise equivalent to that of a quiet conversation or a noisy street was generated. In addition, when comparing each power supply noise amplitude value with the OA value superimposed, the result was different from the frequency characteristics described above. The results of 500 mVrms, 300 mVrms, and 100 mVrms were mixed, and the OA value did not decrease as the power supply noise amplitude value decreased, unlike the frequency characteristics.

In addition, the 100V type IH cooker used in this study is a standard model on the market in Japan. Therefore, although there are some differences depending on the manufacturer and model, the results of this study are basically standard values.

In future, we would like to increase the number of experiments and improve the certainty of the data in order to contribute to the formulation of guidelines dedicated to IH cookers. In addition, because pans used at home are not limited to three-layer SUS pans with a pan bottom diameter of 20 cm, we would like to measure audible noise with pans of other sizes and materials. When formulating the noise guideline, which is the final goal of this research, we plan to express it with the A characteristic, which is close to the way the human ear hears.

References

1. http://www.tepco.co.jp/ir/tool/jigyou/pdf/200612
2. https://www.stat.go.jp/data/zensho/2014/pdf/gaiyo
3. Hironobu, Yonemori, and Ryo Maruyama "Study on the High Frequency Acoustic Noise and Vibration of a Pan Generated by an IH Cooking Heater". Proceedings of the 25th Electromagnetic Force Related Dynamics Symposium (2013): 80–81.
4. Koich Nakamura, Hideki Mori, and Kazuo Iizuka. "Acoustic Noise Interference on Induction Cooking Heater Due to High Harmonic Power Frequency". *J IEIE Jpn 34* (2014): 500–507.
5. Masayoshi, Nakagawa, and Hironobu Yonemori. "A Study on the Audible Frequency Area Noise Emanating from a Pan When the IH Cooker Is Fed by the Power Source Including Harmonics", The 18th International Symposium on Applied Electromagnetics and Mechanics (ISEM 2017), P-SOC-3:5, SP-245 (2017).
6. Eito, Moriyama and Hironobu Yonemori. "A Study on the Audible Range Noise Emitted from Each Pans Heated by IH Cooking Heater". Proceedings of the 10th university consortium Hachioji student presentation (2018): 94–95.
7. Hironobu, Yonemori, Akihiro Fujiwara, Ryo Maruyama, and Miki Kobayashi. "Study on the High Frequency Acoustic Noise and Vibration of a Pan Generated by an IH Cooker". *Int J Appl Electromagn* 45 (2014): 449-456.
8. https://www.env.go.jp/kijun/oto1-1.html
9. https://www.soumu.go.jp/kouchoi/knowledge/how/e-dispute.html
10. Shizuo, Nishiyama, Kazuo Ikegaya, Zenji Yamaguchi and Motoyoshi Okujima. "Acoustic and Vibration Engineering" Corona publishing Co. Ltd (2002): 180–182.
11. Hisao, Sakai, and Takeshi Nakayama. "Hearing and acoustic psychology, Edition of the Acoustical Society of Japan, Acoustic engineering course 6, Corona publishing Co. Ltd (1999): 68.
12. https://www.jema-net.or.jp/jema/data/08-031-in.pdf
13. Natsumi, Tsuguta and Hironobu Yonemori. "Relationship between

Power Noise Amplitude Value Superimposed on IH Cooking Heater and Noise". Proceedings of the 11th University Consortium Hachioji student presentation CD-ROM (2019).

14. Eiichi, Ohno, and Sakae Yamamura. "Introduction to power electronics" Ohmsha, Ltd (1991): 243–247.
15. Koji Imai. "Power Electronics Handbook" R&D planning (2002): 941.
16. Natsumi, Tsuguta, and Hironobu Yonemori. "An Acoustic Noise Generated by Noise Mixed in the Power Line of IH Cooking Heater" Proceedings, 2019 (1st) Electrical Equipment Society Student Presentation Program (2019): 48-49.
17. Hironobu Yonemori, and Akihiro Fujiwara. "Study on the Emission of High Frequency Acoustic Noise from the IH Cooking Heater". *J IEIE Jpn* 31 (2011): 56-57.
18. Hironobu, Yonemori. "Noise generated from IH cooker." *JSAEM* 28 (2020): 3-8.

How to cite this article: Hironobu Yonemori, Natsumi Tsuguta. "Acoustic Noise of IH Cooker Caused by the Power Supply Noise." *J Biomed Syst Emerg Technol* S1 (2021): 007.