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RELATION BETWEEN CLOSE CARVED SURFACE AND MEASURING POINTS OF SOUND POWER LEVELS FOR ELECTRIC CLEANERS USING SOUND INTENSITY METHOD

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ABSTRACT
The sound power level of home electric appliances based on sound intensity method contains the "finity error" caused by the limited number N of discrete microphone positions (measuring points N). In this report, three kinds of vacuum cleaners were selected. The relation between three kinds of close curved surfaces and the measuring points by the sound intensity method was discussed from the comparison of the results measured with the reverberation room method. As the results, it can be said as follows: (a) The number of dividing discrete points needs to measure about 24. (b) The power levels based on this measuring points can measure within the standard deviation 1.5dB, which satisfies the measuring accuracy of JIS and ISO, regardless of the properties of the noise source above, the sound fields and the shapes of close curved surface.

1 - INTRODUCTION

Generally speaking a vacuum cleaner is classified a "highly annoying" product. The noise labeling of the vacuum cleaner in Japan is the A-weighted sound pressure level by JIS C 9108. A microphone is set 1 meter from the side or the upper of vacuum cleaner to its position in an anechoic room. However, the value changes by the use environment and the measuring position.
On the other hand, the sound power level is adopted in Europe and America. There is a sound intensity method in one of the power level measurement methods [1]. The merit is not easily influenced by the stationary noise sources from the outside of a close curved surface of measurement. However, this measurement includes six kinds of errors [2]. One of them, the "finity error" influences by properties of the noise source. Especially, the discussion of a theoretical error of sound source like the vacuum cleaner is difficult.
First, we selected three kinds of typical vacuum cleaners made in Japan. Second, those sound power levels were measured with a reverberation room method. Third, the sound intensity method was used with the intensity probe microphone, the microphone traverse & controller and the frequency analyzer in an anechoic room. The shape of a close curved surface was a rectangular parallelepiped and the number of measuring points was 96. Finally, the sound intensity measurement in an ordinary room was adopted the shape of a hemisphere and a cylinder surfaces with a microphone stand made by us.

2 - SELECTION OF VACUUM CLEANERS

We selected typical three kinds (Type A: Business use, Type B: Simple broom type, and Type C: Home use (H: Highpower condition of operating, L: Lowpower condition of operating)) of vacuum cleaners. Table 1 shows the specification of the selected vacuum cleaners.

Type	Type A	Type B	Type C
Maker and form (in Japan)	National MC-G250	National MC-u30p	SANYO SC-9
Consumption electric power	1050W	430W	1k∼300W
Motor	AC commutator motor.	Single-phase series AC commutator motor	
Number of fans	6	6	8
r.p.m.	1910	3033	Highpower (H): 6407 Lowpower (L): 1213
Size:Width × Depth × Height	30×30×40 cm	30×28×60 cm	22×40×26 cm
Each nozzle and hose of three vacuum cleaners was removed.			

Table 1: Specification table of vacuum cleaners.

3 - MEASUREMENT OF SOUND POWER LEVEL

3.1 - Reverberation room method

Experiment: The reverberation room method is a measurement method corresponding to continuous measurement impossible by sound intensity method. Then, the measurement results at the power levels by the reverberation room method are based on the "finity error".

Measurement place	A reverberation room (68.7m^3) (Department of Electrical and Electronic Engineering, Shinshu University)
Measurement method	JIS Z 8734 [3]
Measuring points	16 [4] (Measurement frequency: 400Hz to 2kHz)
Results	No.2 of Table 4 (a) Type A, (b) Type B, (c) Type C (H) and (d) Type C (L) (1/3 octave band power level)
Standard deviation (Upper/Lower)	No.10 of Table 4 (No.11/No.12)

Table 2: Measurement conditions and results by reverberation room method.

Results: From Table 4 (a), (b), (c) and (d), it can be found that three kinds of vacuum cleaners have a different respectively peak level.
The measuring accuracy of the reverberation room method by JIS Z 8734 is prescribed for the standard deviation of measuring value is within 1.5dB. From No.10 of Table 4, the maximum standard deviation is 1.49dB. Therefore, it can be said that it is satisfied this measuring accuracy.

3.2 - Sound intensity method

Experiment in an anechoic room: The sound power by the intensity method is based on Gauss's theorem. It is given by the next equation,

$$W = \sum I_{ni} \Delta S_i \tag{1}$$

where I_{ni} is the sound intensity component of perpendicular direction on the surface. Fig. 1 shows block diagram of the intensity method. The intensity probe microphone (B&K 3545, the gap: 12mm, the bias error: 0.2dB from 200Hz to 5kHz [5]) is 1/2inch. It was set in the microphone traverse. The controller can arbitrarily set the movement interval. The microphone outputs were connected with the input terminals of a real-time analyzer. The operation of sound intensity is a direct integration method. The power levels are calculated from ΔS_i shown in Table 3 and the equation (1).

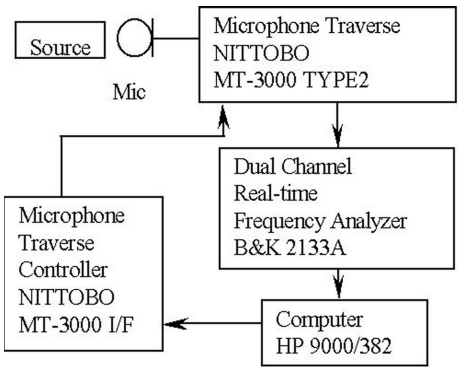

Figure 1: Block diagram of the intensity method.

Measurement place	An anechoic room (215.6m^3) (Research Institute of Nagano Pref.)		
Close curved surface	Rectangular parallelepiped		
Type Total surface area Square per one point	Type A 1.7m^2 ΔS_i [cm]	Type B 1.996m^2 ΔS_i [cm]	Type C 1.442m^2 ΔS_i [cm]
Measuring points 96	W=12.5, D=12.5, H=15	W=12.5, D=11.5, H=20	W=11.5, D=15, H=10.5
Measuring points 48	W=12.5, D=12.5, H=30	W=12.5, D=11.5, H=40	W=11.5, D=15, H=21
Measuring points 24	W=25, D=25, H=30	W=25, D=23, H=40	W=23, D=30, H=21
Measuring points 12	W=25, D=25, H=60	W=25, D=23, H=80	W=23, D=30, H=42
Results (96, 48, 24, 12)	Table 4 (No.3, No.4, No.5, No.6) (1/3 octave band power level)		
95% confidence interval (48, 24, 12)		Table 4 (No.7, No.8, No.9)	
Standard deviation (24) (Upper/Lower)		Table 4 No.13 (No.14/No.15)	

Table 3: Measurement conditions and results in an anechoic room.

Results: From No.3 and No.6 of Table 4, it can be found that there is the level difference of about 3dB.

1	400	500	630	800	1000	1250	1600	2000	400	500	630	800	1000	1250	1600	2000
2	58.1	59.0	63.5	64.6	61.3	57.5	59.7	62.5	60.3	63.2	62.3	63.6	66.9	70.0	70.2	68.7
3	57.2	58.1	63.2	64.7	61.9	58.1	59.4	61.2	59.6	62.8	61.4	63.3	67.4	70.1	69.3	68.0
4	57.2	58.2	63.4	64.8	62.0	58.3	59.5	61.9	59.4	62.8	61.1	63.1	67.3	70.0	69.1	67.9
5	56.9	58.2	63.0	64.7	61.6	58.2	59.4	60.8	60.2	63.4	61.9	63.9	68.2	70.9	70.6	68.7
6	54.9	56.0	60.6	62.5	59.5	56.2	57.9	58.4	58.6	62.0	60.2	62.2	66.2	68.8	69.5	69.4
7	0.32	0.16	0.37	0.21	0.20	0.39	0.33	1.08	0.02	0.03	0.01	0.05	0.13	0.10	0.16	0.22
8	0.87	0.22	1.06	1.13	1.04	1.10	0.76	0.53	1.10	0.99	1.23	1.46	1.47	1.70	1.45	0.07
9	2.43	2.55	2.68	*2.69	*2.74	*2.65	1.92	*3.14	2.12	2.11	2.43	*2.69	*3.04	*3.49	*2.80	0.47
10	1.37	1.31	1.24	1.44	1.24	1.01	1.47	1.35	1.34	0.95	1.39	1.19	1.15	0.87	1.49	0.98
11	59.4	60.3	64.7	66.0	62.5	58.5	61.2	63.9	61.6	64.1	63.7	64.8	68.0	70.9	71.7	69.7
12	56.7	57.7	62.3	63.2	60.0	56.4	58.3	61.1	59.0	62.3	60.9	62.4	65.7	69.1	68.7	67.7
13	0.77	0.19	0.94	1.00	0.92	0.97	0.67	0.47	0.97	0.88	1.09	1.29	1.30	1.50	1.28	0.06
14	57.4	58.4	63.6	65.2	62.3	58.9	59.9	61.4	60.6	63.8	62.3	64.4	68.7	71.4	71.1	68.7
15	55.9	58.1	61.7	63.2	60.5	57.0	58.6	60.5	58.6	62.0	60.2	61.8	66.1	68.4	68.5	68.6
16	59.0	58.8	64.3	64.6	61.8	58.4	58.9	63.7	60.6	62.9	61.7	64.5	67.8	70.6	70.8	69.6
17	57.6	58.6	63.1	64.0	61.2	57.1	58.4	61.2	60.5	63.6	63.2	64.2	67.8	70.1	70.9	68.0
18	59.3	59.9	64.5	64.9	62.2	57.2	59.5	62.1	61.6	64.1	62.7	64.2	65.8	69.1	69.0	68.0
	(a) Type A								*(b) Type B*							
1	400	500	630	800	1000	1250	1600	2000	400	500	630	800	1000	1250	1600	2000
2	65.0	68.9	68.0	66.6	68.4	70.1	66.1	66.1	52.7	54.0	55.0	52.3	55.1	56.5	54.6	55.9
3	65.6	69.1	68.5	66.7	68.8	70.4	66.5	66.6	53.4	54.6	55.8	52.8	55.6	56.9	55.1	56.3
4	66.1	70.2	68.9	66.6	69.1	70.8	67.0	67.0	53.8	54.4	55.5	52.6	56.1	57.6	55.6	56.1
5	65.9	70.0	68.9	66.8	69.1	70.8	67.1	67.1	54.0	54.7	56.4	52.1	57.0	58.7	55.8	56.6
6	66.4	70.7	69.4	67.5	69.3	71.1	66.9	67.3	54.1	55.4	57.7	54.3	58.1	59.9	56.9	57.1
7	0.93	0.74	0.78	0.04	0.88	0.98	0.88	0.91	0.20	0.29	0.49	0.29	0.23	0.08	0.08	0.43
8	0.64	0.58	0.69	0.63	0.60	0.65	0.67	0.72	0.44	0.24	0.75	0.91	1.12	1.26	1.29	1.27
9	2.24	0.03	2.84	0.80	0.29	0.29	0.37	0.36	0.72	0.10	0.49	0.78	1.61	2.35	1.09	1.16
10	0.76	1.15	0.85	0.95	0.85	1.00	0.54	0.65	0.99	0.97	1.40	0.94	1.06	1.07	1.18	1.45
11	65.8	70.1	68.9	67.5	69.3	71.1	66.6	66.7	53.7	55.0	56.4	53.2	56.2	57.6	55.8	57.3
12	64.3	67.7	67.1	65.7	67.5	69.1	65.6	65.5	51.7	53.0	53.6	51.4	54.0	55.4	53.4	54.5
13	0.57	0.51	0.61	0.55	0.53	0.57	0.59	0.64	0.39	0.21	0.67	0.81	0.99	1.11	1.14	1.12
14	65.8	70.0	68.8	67.0	69.0	70.8	67.0	67.0	54.1	55.1	56.7	53.4	57.4	59.1	56.3	57.2
15	64.7	69.0	67.6	65.9	68.0	69.6	65.8	65.8	53.4	54.7	55.4	51.8	55.5	56.9	54.0	55.0
16	64.5	67.7	67.4	66.2	67.6	69.9	65.6	65.5	52.5	54.7	53.8	51.6	54.2	55.7	53.7	56.7
17	64.4	67.9	67.3	65.7	67.8	69.2	65.7	65.7	52.4	53.2	53.7	51.4	54.3	56.0	53.8	55.9
18	65.5	67.7	68.9	66.3	67.8	69.2	66.2	65.6	53.2	54.2	56.4	53.3	56.0	56.9	55.6	56.4
	(c) Type C (H)								*(d) Type C (L)*							

Table 4: Results.

Numbers of the extreme left column are as follows:

- **No.1**: Frequency [Hz],
- **No.2, No.3, No.4, No.5** and **No.6**: PWL [dB] (Reverberation room method, Intensity method measuring points 96, 48, 24 and 12),
- **No.7, No.8** and **No.9**: 95% confidence interval (measuring points 48, 24 and 12),
- **No.10 (No.11/No.12)** and **No.13 (No.14/No.15)**: Standard deviation (Reverberation room method (Upper/Lower) and intensity method measuring points 24 (Upper/Lower)),
- **No.16, No.17** and **No.18**: Experiment in each ordinary room (Rectangular parallelepiped, hemisphere and cylinder).

1/3 octave band center frequency [Hz]	95% confidence limit [dB] (Engineering)
200 to 630	3.5
800 to 5000	2.5

Table 5: Measuring accuracy of the sound intensity method.

Table 5 shows the measuring accuracy of the sound intensity method [6]. From Table 5 and Table 4, it can be found that the measuring points 24 are necessary for all vacuum cleaners.
Next, the "finity error" between the reverberation room method and the sound intensity method was discussed. From Table 4, it can be found that the measurement results from the measuring points 96 to 24 of the intensity method is included within the range of a standard deviation of the reverberation room method. Therefore, it can be said that the results between the measuring points 24 and the reverberation room method correspond within 1.5dB.
Experiment in ordinary rooms by various close curved surfaces: From an engineering point of view, the sound intensity measurement in each ordinary room was adopted the shape of a rectangular parallelepiped and a hemisphere and a cylinder surfaces with a microphone stand made by us. The microphone stand was made to become a cylinder of 1 meter in height and 1 meter in radius. The microphone probe always turns in the perpendicular direction on the surface, and rotating by installing the caster in the stand can move the measuring points.

Closed carved surface: Rectangular parallelepiped, Measuring points 20 (measuring points 4 per one surface)	Square per one point is the same as the experiment of measuring points 24 in an anechoic room.	Results No.16 of Table 4
Measurement place	Laboratory (151.2m^3) (Research Institute of Nagano Pref.)	
Closed carved surface: hemisphere Measuring points 12 (radius 1m)	Division of side: 3, Division of vertical: 12 (Top: 1 + Center: 5 + Under: 6)	Results No.17 of Table 4
Measurement place	Laboratory (151.2m^3) (Research Institute of Nagano Pref.)	
Closed carved surface: cylinder Measuring points 22	Division of the upper surface: 4, Division of side surface: 18 (Side: 3 × Vertical: 6)	Results No.18 of Table 4
Measurement place	Lecture room (400m^3) (Shinshu University)	

Table 6: Measurement conditions and results in two ordinary rooms.

Results: From Table 4, it can be found that the results of the measurement in the ordinary rooms by various close curved surface are included within the range of a standard deviation of the reverberation room method in any vacuum cleaners. Therefore, it can be said that the number of N=24 of measuring points satisfies the measuring accuracy of JIS and ISO for each close curved surface.

4 - CONCLUSIONS

In this report, about three vacuum cleaners selected, the "finity error" of the sound power level by the intensity method was discussed from the comparison of the results measured with the reverberation room method. As the results, it can be said as follows: (a) The number of dividing discrete positions needs to measure about 24. (b) The sound power levels based on the measuring points 24 can measure within the standard deviation 1.5dB, which satisfies the measuring accuracy of JIS and ISO, regardless of the properties of the noise source above, the sound fields and the shapes of close curved surface. (c) The manual type stands of the microphone probe position fixation of cylinder surfaces made by us are effective to the measurement in an ordinary room.

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