Acoustics'08 Paris
June 29-July 4, 2008
www.acoustics08-paris.org

A study on the adaptive design of loudspeaker driver parameters for a given enclosure

Seokjin Lee, Junguk Noh and Koeng-Mo Sung

Applied Acoustics Lab., INMC, 132-302, Seoul National University, San 56-1, Sillim-dong, Kwanak-gu, 151-742 Seoul, Republic of Korea
sjlee@acoustics.snu.ac.kr

The effective frequency range of a loudspeaker driver is basically determined by mechanical properties of loudspeaker driver's vibration. Lower frequency limit is firstly related to the driver's resonance frequency. Also, targeted maximum sound pressure level is an important matter of designing a loudspeaker. The maximum SPL is determined by frequency, effective surface area and peak linear displacement of driver diaphragm, which are physical limits of a loudspeaker driver. We investigated and classified the specification database of loudspeaker driver unit into size order, and we suggest guideline to choose the driver unit size. Finally, we propose the optimization method with given enclosure and driver.

1 Introduction

The demands to achieve full expansion of reproducible low frequency range for smaller loudspeaker driver units are longstanding problem. These demands become particularly important today in case of planning digital TVs, mini home theater systems, mini components, or PC speakers. However, most of the solutions to expand low frequency range are merely equalizations on frequency domain which compensate the frequency responses of loudspeakers with target frequency responses. These equalizations are sometimes forced without sufficient understanding about acoustic or mechanical limitations of the drivers. For example, a mid-range driver, which is suitable to play more than 500 Hz, is used to play nearby 100 Hz with forced equalization on low frequency ranges. This forced equalization would cause much more distortion over wider frequency range and lower the maximum output sound level seriously, far from obtaining fully expanded reproducible low frequency ranges to the target frequency. These mistakes happen mainly due to lack of expert engineer in such a consumer electronics manufacturer. Even if there are skilled engineers, because the market, whose main subjects are general consumers, is not the same as that of hi-fi audio, the product is focused on its design, rather than sound quality.

Moreover, the design is often determined only to meet the product plan without any considerations on acoustics of driver or enclosure then the driver unit is chosen to suit the already designed enclosure size and tuned by force to target sound quality. Therefore, possible sound quality, or frequency range, is usually restricted by already determined design. To achieve good sound quality with these conditions, engineers must have design process which can make good loudspeaker with given enclosure design.

In this paper, a basic estimation of a driver's reproducible frequency range will be presented first. Then, peak volume displacement will be discussed which is closely related to the lower frequency limit at targeted maximum sound pressure level. And statistical analysis on practical peak volume displacements derived from specification data of actual drivers will be followed. And, a guide to estimate and determine the frequency range of a small driver from its size will be presented which would be useful to consider at a design stage. Finally, optimization method with given enclosure and driver is proposed.

2 Determine the driver size with peak volume displacement

2.1 Effective frequency range of a loudspeaker driver

The effective frequency range of a loudspeaker unit is basically determined by mechanical properties of loudspeaker unit's vibration. Lower frequency limit is firstly related to the unit's resonance frequency, and determined by enclosure geometry, which are enclosure volume and enclosure type-opened, closed, or vented and so on. Upper frequency limit is determined by the relationship between unit size and wavelength.

Assuming the unit diaphragm behaves as a rigid circular piston and is mass controlled, the power response is shown in Fig. 1 where f0 is the system fundamental resonance frequency [1].

Above this the system is mass controlled and provides a level response up to f1; this corresponds to $ka = 2$ where k is the wave number and a is an effective diaphragm size.

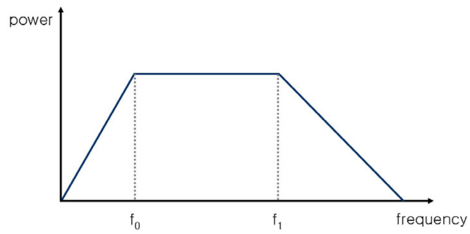

Figure 1. frequency response of rigid piston

The relationship between f_1 and effective diaphragm size a is

$$ka = \frac{2\pi}{\lambda} a = \frac{2\pi f_1}{c} a = 2 \tag{1}$$

Therefore, f_1 can be obtained as

$$f_1 = \frac{c}{\pi a} \tag{2}$$

Where *c* is the sound speed, which is about 340 m/s in the air at a room temperature.

This frequency can be roughly thought as upper frequency limit of a loudspeaker unit.

2.2 Peak volume displacement of a loudspeaker unit

Targeted maximum sound pressure level is also an important matter of designing loudspeaker. A loudspeaker unit has to be capable of displacing a sufficient volume of air without generating excessive distortion. The peak volume displacement is a product of effective surface area and peak linear displacement of driver diaphragm given by

$$V_D = S_d \cdot x_{\max} \quad \text{(Eq. 3)}$$

where,

$$S_d = \pi a^2 \quad \text{(Eq. 4)}$$

When a loudspeaker unit vibrates as peak linear displacement at a specific frequency, the product of that frequency and peak volume displacement is the peak volume velocity given by

$$\hat{Q} = \omega \cdot S_d \cdot x_{\max} = \omega \cdot V_D \quad \text{(Eq. 5)}$$

Assuming the unit diaphragm behaves as a rigid circular piston mounted in infinite baffle, the peak volume velocity determines peak sound pressure as a function of peak volume displacement and frequency[2].

$$\hat{p} \approx \frac{\omega \rho_0 \hat{Q}}{2\pi r} = \frac{2\pi \rho_0 f^2 V_D}{r} \qquad \text{(Eq. 6)}$$

Where ρ_0 is the density of the air which is about 1.21 kg/m^3. Because the volume velocity is proportional to the frequency, the peak volume displacement of a loudspeaker unit is closely related to the lower frequency limit at targeted maximum sound pressure level.

2.3 Peak volume displacements of actual loudspeaker driver units

To find the relation between the system fundamental resonance frequency – f0, and the lowest frequency of peak volume displacement to satisfy the targeted maximum sound pressure level, we investigated and classified the specification database of loudspeaker unit into size order; 51 units of 18 inch class, 230 units of 15 inch class, 255 units of 12 inch class, 216 units of 10 inch class, 105 units of 8 inch class, 164 units of 6.5 inch class, 78 units of 5 inch class, and 69 units of 4 inch class. The database is selected in LEAP EnclosureShop software library. The result is viewed in Figure 2 to Figure 5.

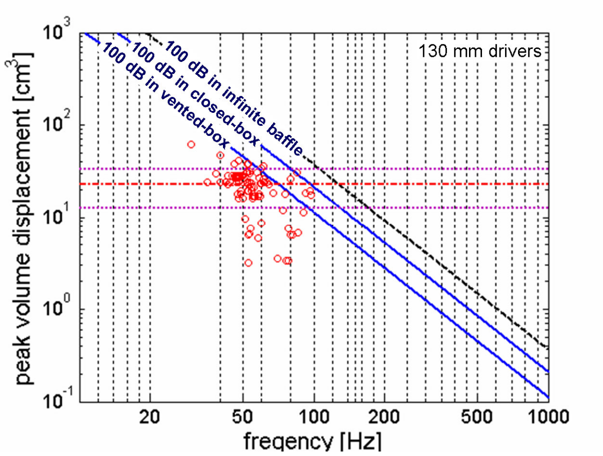

FIG. 2 Distribution of peak volume displacements of 130 mm drivers plotted by f0.

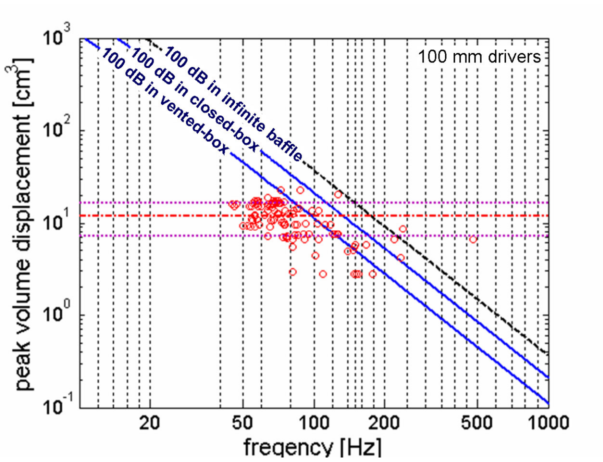

FIG.3 Distribution of peak volume displacements of 100 mm drivers plotted by f_0.

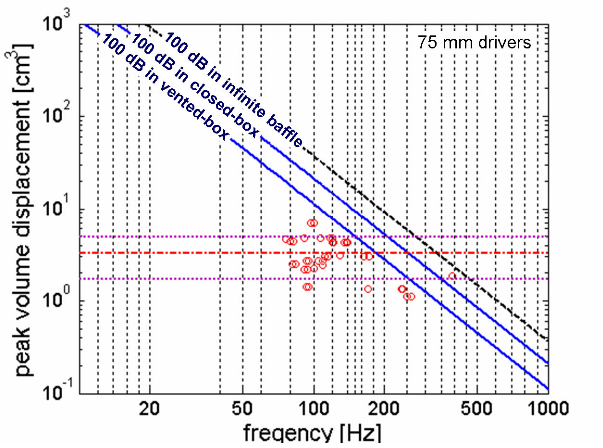

FIG.4 Distribution of peak volume displacements of 75 mm drivers plotted by f_0.

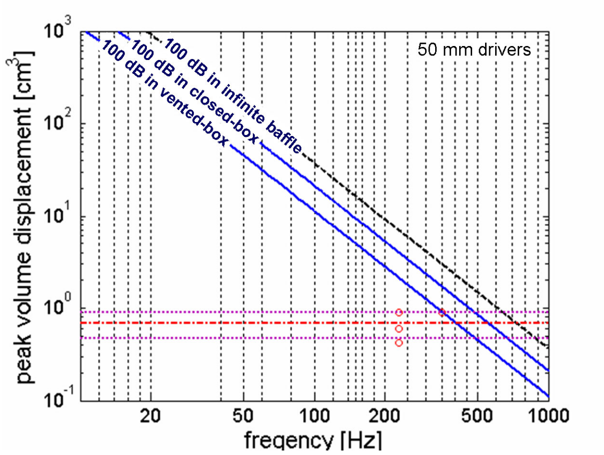

FIG. 5 Distribution of peak volume displacements of 50 mm drivers plotted by f_0.

The f0s and PVD(pick volume displacement) are presented with Figure 2. The horizontal dash-dot lines are the mean of the PVDs, and the two horizontal dotted lines are the standard deviation of the PVDs in each class. Three diagonal lines show required PVD to produce 100 dB SPL in three mounting conditions discussed above, that are infinite baffle(dashed line), closed-box, and vented-box conditions.

In the small-signal condition, the frequency response curve must be flat from f0. But in the large-signal condition, the lower frequency limit will be the frequency that the multiplication of the frequency and PVD reaches the targeted maximum sound pressure level. In the case of 15 inch loudspeakers, for example, the f0 is 35 $\pm$10 Hz, and if the targeted maximum sound pressure level in the low frequency range is 100 dB, the possible lower frequency limit is about 30~60Hz from the PVD. In the case of 5 inch loudspeakers, on the other side, the f0 is about 53 $\pm$13 Hz, but the possible lower frequency limit is up to 145~230 Hz when the targeted maximum sound pressure level is 100 dB. The only way for generating the low frequency sound with the relatively small units is increasing the Xmax. But, this method is not good because of unbalance of magnetic flux density, nonlinear oscillation, etc.

3 Adaptive design with chosen driver units

3.1 Closed-Box loudspeaker system

In the closed-box system, frequency response of given system is,

$$G(s) = \frac{s^2 T_c^2}{s^2 T_c^2 + sT_c / Q_{TC} + 1} \quad (7)$$

Therefore, T_c and Q_{TC} are adjusted for adjustment of frequency response.

$$T_C = \frac{1}{2\pi f_C} = \sqrt{C_{AT} M_{AC}} \quad (8)$$

$$Q_{TC} = \frac{1}{\omega_C C_{AT} R_{ATC}} \quad (9)$$

Where,

$$C_{AT} = (C_{AB}^{-1} + C_{AS}^{-1})^{-1} \quad (10)$$

$$M_{AC} = (C_{AS} \omega_S^2)^{-1} \quad (11)$$

$$R_{ATC} = R_{AB} + R_{AS} + \frac{(Bl)^2}{(R_g + R_E) S_D^2} \quad (12)$$

1) Adjustment of V_B

If V_B is modified, $C_{AB} = \frac{V_{AB}}{\rho_0 c^2}$ is also modified. If there are no absorption materials, $V_{AB} = V_B$, so C_{AB} is proportional to V_B . According to Eq. (10), we can determine C_{AT} with the C_{AB}, and then, we can compute T_c and Q_{TC} . Finally, we can calculate the frequency response with T_c and Q_{TC}.

2) Adjustment of V_{AS}

If compliance of unit $\left(C_{AS} = \frac{V_{AS}}{\rho_0 c^2} \right)$ is controlled, C_{AT} is determined from Eq. (10). If the compliance could be controlled with no change of mass, resonance frequency of unit is,

$$f_S = \frac{1}{2\pi \sqrt{C_{AS} M_{AS}}} \quad (13)$$

In Eq. (13), M_{AS} is treated as constant, so f_S is proportion to $1/\sqrt{C_{AS}}$. And we can calculate T_c and Q_{TC} , the frequency response could be determined with them.

3.2 Vented-Box loudspeaker system

1) Adjustment of V_B

Resonance frequency of vented box f_B is given by,

$$f_B = \frac{c}{2\pi} \sqrt{\frac{S_V}{L_{VE} V_B}} \quad (14)$$

L_{VE} is effective vent length (end correction is considered), S_V is area of vent, and V_B is volume of enclosure box.

2) Adjustment of V_{AS}

Equal to closed-box case, resonance frequency of unit f_S is given by Eq. (13). So, f_S is reciprocal proportion to $\sqrt{C_{AS}}$, and C_{AS} is proportion to V_{AS} .

3) Adjustment of L_V , S_V

According to Eq. (14), resonance frequency of vented-box can be determined by L_V and S_V . So, low frequency response can be controlled by length and area of vent.

4 Adaptive design method

As we can see at the above, there are some factors that can affect to low frequency response. So, designed loudspeaker can be optimize with regulation of these factors. We made this optimization software with MATLAB. Fig. 6 shows the capture of the software. These tools can help saving time during design process.

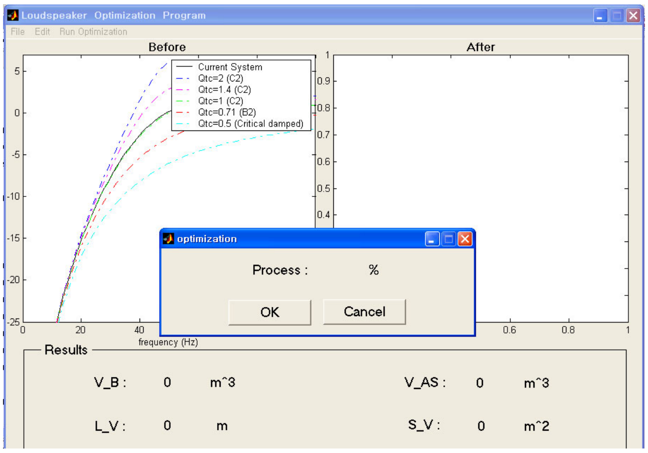

Fig 6. loudspeaker optimization tool using MATLAB

This tool consists of three steps. First, determine the enclosure type, which is closed-box type or vented-box type. Next, set the loudspeaker parameters. And finally, run optimization. After the optimization process, the result are presented.

5 Conclusion

In this paper, we discuss about electro-mechanical parameters of loudspeakers and effective frequency range of loudspeaker. And then, for guarantee the target maximum SPL, possible lower limit of frequency is discussed with peak volume displacement. With investigation about peak volume displacement of actual loudspeaker driver units, we propose guideline to choose the size of drive unit. Finally, we propose the adaptive design method with given enclosure and driver.

These methods and guideline can be useful tools in the poor design condition which the external look is prior to sound quality. Especially, these tools can be useful in the case of that good low frequency response is required to engineers with extremely limited enclosure size, or in the case of that sufficient SPL is required in the low frequency range.

Reference

[1] Ian R. Sinclair, "Audio and Hi-Fi Handbook," 2nd edition, Butterworth-Heinemann, 555-556 (1993)

[2] Heinrich Kuttruff, "Acoustics: An introduction," Taylor & Francis, 87-89 (2007)