The Vented-box Effect on Thiele-small Parameter Loudspeaker

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Abstract Loudspeaker testing is usually using the Thiele-small parameter. To see the effect of the vented box on loudspeaker quality, Thiele-small parameters in vented box boxes are used. Research carried out by measuring the characteristics of loudspeaker response frequency, impedance, and Thiele small parameters in vented-boxes and panels. One factor affecting the acoustic parameters is the compressed air value generated by the loudspeaker or so-called air compliance. In vented-boxes, there is an effect of compressed air compliance in the box and the air coming from the hole which is causing the pure loudspeaker sound trigger. On the panel, there is no compressed air. From the measurement and results analysis, the ratio of compliance from the box is 8.29: 10.7. This value has impacted the losses of the vented-box. The losses of the vented-box are 0.63% and the losses that happened on the panel is 0.014%. The losses of the enclosure are caused by the shape of the enclosure design and the damping material in it.

1. Introduction
In this modern era, loudspeakers become one of the electronic components that often used. In many variations of loudspeakers in existing, most of them using box, closed-box system, or vented-box system. But often in its use, people don’t know the suitability loudspeaker type that will be installed with the box used. So many problems arise when the loudspeaker is turned on.

One of the loudspeakers producing and testing place is CV. SINAR BAJA ELECTRIC located in Surabaya. Before being marketed, the loudspeaker is tested first. In testing, one characteristic that used is the Thiele-small parameter. Loudspeaker test is using a vented-box and panel. Of course, both of vented-box and panel testing has its advantages and disadvantages with Thiele-small parameters.

The loudspeaker is an electroacoustic transducer that can convert electrical signals into analog sound signals [1]. In the process of change, the loudspeaker has various components that can be seen in Figure 1 below.
Figure 1. Loudspeaker Components [2]

Figure 1 describes the loudspeaker component consisting of three main systems i.e

1. Motor system, consisting of
   a. **Voice coil**
      Voice coil is a wire coil that produces a variable magnetic field and will vibrate because of a magnet in the middle
   b. **Magnet**
      Magnet serves to conduct a magnetic induction of the voice coil that will produce a magnetic field.

2. The suspension system, which functions in one unity attached to the basket and the periphery of the diaphragm (cone). This suspension system consists of
   a. **Spider**
      Spider is attached to the coil that is also attached to the edge of the middle diaphragm, serves to hold the voice coil to be stable, and remains in place when vibrating. Spider also serves to provide stiffness in the suspension, dampening the vibration of the diaphragm.
   b. **Surround**
      Serves to keep the loudspeaker protective leaf to be stable and fixed in position, so that the diaphragm will be flexible to vibrate back and forth. The material used is usually from a sponge.

3. Diaphragm system, that consists of the cone to continue vibration from voice coil then for vibrating air in front of it.[2]

The three systems work on their respective circuits. The electrical systems located on the motor system, the mechanical system located in the suspension system, and the acoustic system located on the diaphragm system. Figure 2 show how the sound can be generated by the loudspeaker.

Figure 2. Electric Circuits on Loudspeaker (A) Electrical Circuits (B) Mechanical Circuits (C) Acoustic Radiation (personal collection)
Based on figure 2, the electrical system plays is the magnet and the speaker coil. In this system, there are obstacles and in mathematical form is

\[ I = \frac{V}{R} \ldots \]  

(1)

Where V is the voltage (volt), I is the electric current (Ampere) and R is the resistance (ohm). Equation 1 above can be analogous as follows:

**Table 1. Analogy of the Mathematical Relation in the Loudspeaker Electrical Circuits**

| Mathematical Analogy in Electrical Circuits |
|--------------------------------------------|
| I = \frac{L}{B^2l^2} \cdot \frac{B^2l}{(R_e+R_g)} | e_g Bl |
| V = e_g Bl \cdot \frac{(R_e + R_g) + \gamma \omega l} {R_e + R_g} | Total Resistance in Circuits |

In table 1 above, we can see the mathematical relation that is analogous to the loudspeaker electrical circuit. In the mechanical system, spider and surround are playing the role. At the coil, the current will be converted to an induced magnetic field then cause a magnetic Lorentz force as follows:

\[ F = B \times I \times L \]  

(2)

With F being the Lorentz force (N), B is the magnetic field (Tesla), and L is the length (m).[3]. At the vented-box system, there are two holes called a bass-reflex. The first hole accommodates the driver, another hole called a vent or port that allows air to enter into and exit the enclosure in response to pressure variations in the enclosure. The vented-box system can be seen in Figure 3 below.

**Figure 3. Vented Box Loudspeaker System [4].**

Based on Figure 3, the characteristic of this loudspeaker vented-box system is lower sound distortion, the loudspeaker can handle more power in wide operating frequency area and lower cut-off point (cut-off frequency) than the closed-box system if using the same loudspeaker. In general, the vented-box system will be more efficient to produce a larger SPL. The electro-acoustic circuit of a vented-box system can be shown in figure 4 [3].

**Figure 4. Electroacoustic Circuit in Vented-Box Loudspeaker System (personal collection)**

Based on Figure 4 above, the resonance frequency can be formulated from vented-box i.e.
\[ \omega_0 = \frac{1}{\sqrt{C_{AB}M_{AT}}} \]  
(2)

With \( M_{AT} \) which is the total mass of the series of Figure 4 can be formulated as air mass in the box i.e.

\[ M_{AB} = \frac{B \rho_0}{\pi a} \]  
(3)

With B is the area of cone loudspeaker diameter attached, \( \rho_0 \) is the air density (1.18 kg/m³) and \( a \) is the radius in the port (m)

Air compliance generated by vented-box ie

\[ C_{AB} = \frac{V_B}{\gamma \rho_0} \]  
(4)

With \( V_B \) is the volume box (m³), \( \gamma \) is the air adiabatic pressure (1.4). So it can be calculated the cut-off frequency of the vented-box ie [6]

\[ f_c = \frac{R_{AB}}{2\pi M_{AB}} \]  
(5)

In the vented-box loudspeaker system, there are three types of losses: absorption losses, air leakage losses, and port losses. The magnification of each loss can be defined by Q from the box set at the resonance frequency box. On-air leakage losses can be formulated as follows:

\[ Q_L = \omega_B C_{AB} R_{AL} \]  
(6)

With \( \omega_B \) is the resonance frequency (Hz), \( C_{AB} \) is an acoustic compliance box (m³/N) and \( R_{AL} \) is a resistance of box losses (ohm). Often happens and give \( Q_L \) value between 5-20. While the absorption loss is formulated as follows

\[ Q_A = 1/\omega_B C_{AB} R_{AB} \cdots \]  
(7)

with \( \omega_B \) is the resonance frequency of box (Hz), \( C_{AB} \) is acoustic compliance of box (m³/N) and \( R_{AB} \) is resistance in the box (ohm). The absorption loss in the uncoated enclosure of the material is smaller and gives \( Q_A \) value of 100 or more. Some material that covers the wall of the enclosure can reduce \( Q_A \) to a value 30-80. So greater absorption losses occurred

\[ Q_P = 1/\omega_B C_{AB} R_{AP} \cdots \]  
(8)

The other part that supports a loss system box is the hole. The port losses that are not blocked by damping materials are usually in the range 50-100. If the port is hampered by damper material, it will produce a \( Q_P \) value below 20. So, the total Q of the vented-box system circuit at the resonance frequency box is

\[ \frac{1}{Q_B} = \frac{1}{Q_L} + \frac{1}{Q_A} + \frac{1}{Q_P} \cdots \]  
(9)

Following Thiele's statement, for \( Q_B = 5 \), the maximum response loss is formed at the enclosure frequency. Below the frequency of the enclosure, the absorption of losses has a great effect, and the least loss of influence in the response.

Constant efficiency is divided into two factors: \( k\eta(Q) \) in the form of driver losses, \( k\eta(G) \) in the form of response characteristics, and enclosure losses. Total constant efficiency is formulated as follows

\[ k\eta = k\eta(Q) \cdot k\eta(G) \cdots \]  
(10)

where

\[ k\eta(Q) = \frac{Q_T}{Q_{ES}} \cdots \]  
(11)

with \( Q_T \) is \( Q_{TS} \) from a driver
The $k \eta(Q)$ value for the vented-box system is between 0.8-0.95. Then the efficiency of the enclosure loss and the response characteristics can be shown by the equation

$$k \eta(G) = \frac{4 \pi^2}{c^3} \cdot \frac{V_{AS}}{V_B} \cdot \frac{f_s^3}{f_3^3} \cdot \frac{1}{Q_T} \cdots (12)$$

with $V_{AS}$ is the air volume that has been moved ($m^3$), $V_B$ is volume box ($m^3$), $f_3$ is cut-off frequency (Hz), $f_s$ is loudspeaker response frequency (Hz) and $Q_T$ is $Q_{TS}$ resulting value of the loudspeaker [6].

This paper discusses the study of vented-box characteristics to determine the effect of vented-boxes on loudspeaker parameter characteristics. Part I discusses the background and theoretical basis. Part II discusses the methodology. Part III discusses the results and analysis, while in part IV is the conclusion.

2. Methodology

The loudspeaker used in this research is PG-1254 subwoofer with specification: 12-inch diameter, maximum power 200 watts, $R_e 3.4 \Omega$, magnetic field 0.74 Tesla with magnetic weight 0.813 kg. The test was done at the CV. Sinar Baja Electric by using a Clio software.

The TS Parameter measurement with Clio software is taken by displaying the frequency response and impedance graphs that have been previously measured. Forms panel and vented-box can be seen in figure 5 below.

![Figure 5. position of loudspeaker for measurement (A) Vented box, (B) Panel](image)

3. Result and discussion

3.1 Data Analysis

In this study, the measurement was done with various data collection, such as a measurement difference of TS loudspeaker parameter using vented-box and panel and using loudspeaker variation. While the frequency response graph can be seen as a comparison of loudspeaker TS parameters in vented-box, port leakage loss, and air absorption loss that enter in the box.

3.2 Analysis of TS Loudspeaker Parameters with Variations of Vented-Box and Panel

In TS Parameter analysis, variations can be seen. There are changes in some parameters. Based on equation 4, the $C_{AB}$ magnitude is very influenced in the vented box. This value affects the impedance and frequency of the loudspeaker response. The following table 2 compares the TS parameter Loudspeaker to the vented-box and panel using 12 inch PG 1254-2.
| **Thiele Small Parameter** | **Subwoofer PG-1254 in Panel** | **Subwoofer PG-1254 in Vented-box** |
|---------------------------|---------------------------------|-----------------------------------|
| Fs                        | 28.43 Hz                        | 31.67 Hz                          |
| Vas                       | 149.52 L                        | 115.75 L                          |
| Qms                       | 3.48                            | 5.47                              |
| Qes                       | 1.08                            | 1.57                              |
| QtS                       | 0.82                            | 1.22                              |
| Bl                        | 6.71 T-m                        | 6.08 T-m                          |
| Cms                       | 0.37 mm/N                      | 0.29 mm/N                         |
| Cas                       | 10.7·10⁻⁷ m³/N                | 8.29·10⁻⁷ m³/N                    |
| CmΣS                      | 1789.53 μF                     | 2323.09 μF                        |
| Rat                       | 6306 ΩA                        | 4963 ΩA                           |
| Zmax                      | 14.31 Ω                        | 15.24 Ω                           |
| dB SPL                    | 87.02 dB                       | 85.71 dB                          |
| ηo                        | 0.22%                           | 0.30%                             |

Based on table 2 above, the value of Fs (frequency response) generated on the vented box and panel is different. In the vented-box, the value of Fs generated is 31.6760 Hz which is greater than the panel which value is 28.4367 Hz. This difference is caused by the air compliance in the box. This is demonstrated by the vented-box electric circuit that has been discussed in Figure 4 above. Based on the scheme, it appears that the vented-box has a parallel AC circuit system. So it makes Rat (total resistance) loudspeaker on vented-box lower than in panel.

Based on figure 4, seen, the electric current is defined as \( U_c \) which is physically in the box in the form of air velocity volume in a cone. The large electric current is the one which will cause the cone to move quickly and making the volume of air that moving around the cone becoming fewer. This is the evidence if the smaller \( V_A S \) result that is 115 L rather than the panel. So it also affects the pure frequency of the loudspeaker and produces a large Fs value. It can be shown by equation 2. The current on the larger vented-box makes the resulting movement cone (F) to be slower. Because on the loudspeaker diaphragm there is compressed air from the box, so the load is moving more and make the movement of the cone slower. It will make the resulting Vas value lower and the Bl value lower on the vented box to produce sound with good bass response. But instead, in the panel, the lower Fs value resulted from a low Qts value and a high Vas value. This is because of the smaller flows and there is no compressed air in the room. Making the air load on the cone lighter and the movement of the cone becomes faster so that it can move a lot of air volume so that the value of Vas produced is bigger than the vented-box.

High Qts indicates that the loudspeaker has a lower magnetic force Fs and Qts inversely proportional to the Vase. If Fs and Qts have a bigger value, then Vas is little. Vice versa. Qts values between 0.2 to 0.5 are commonly used in vented-box systems. And the Qts value above 0.5 is better if using closed-box. but if the Qts generated 0.8 loudspeakers can still use the vented-box system but in a box can only be used for one loudspeaker. With Qts results corresponding to those obtained from the measurements, the subwoofer loudspeaker fits into a vented-box loudspeaker system. Because of Qts result in panel 0.8

The \( Q_{MS} \) value generated on the vented-box is higher. It corresponds to equation 2.5 so that Qms is influenced by the value of Fs generated by the loudspeaker diaphragm. High Qms values show high impedance peaks that can produce louder sounds.
The result of $C_{AS}$ of loudspeaker PG-1254 in vented-box is higher 1.07.10-6 m3/N than $C_{AS}$ on panel 8.29.10-7 m3/N. $C_{AS}$ is an air acoustic compliance of the loudspeaker (surround and spider) suspension. $C_{AS}$ is affected by the volume box. before the loudspeaker is installed, there is compressed air inside the vented-box. So, when the loudspeaker is plugged in and powered by an electric current, the vibrating diaphragm moves the compressed air inside a box called $C_{AB}$. Large volume boxes will no be so influential for small diameter loudspeaker. Because the loudspeaker will only move a small volume of air from its small diameter. The SPL generated by PG-1254 loudspeaker on the vented-box is 87 dB higher than the 85.7 dB panel. Because by the principle of vented-box, there is incoming air pressure from the diaphragm movement that also drives the reference air pressure in the room. There is air coming out through the port as a result of the movement of the rear loudspeaker diaphragm. So there is a pressure difference that is $\Delta P = P - P_{ref}$. That's the SPL of the loudspeaker on the vented-box.

3.3 Analysis of Loudspeaker Impedance on Vented-box and Panel

Impedance is a bottleneck when the loudspeaker is working. In this condition, many factors influence the magnitude of the impedance. From voice coil wire, magnetic field, the suitability of suspension (spider and surround), and mass of the acoustic load. The maximum impedance peak is shown at the top of the line of the sinusoidal graph which also shows the $f_o$ of a loudspeaker. But the real impedance can be seen from when the line first declines from the peak of its impedance. While at the starting point impedance graph shows the value of $R_E$ inputted on the software according to loudspeaker type. On the graph the value of $R_E$ bigger than the value of $R_E$ that inputted. This is due to the inhibitory effect of the tinsel lead attached to the loudspeaker so that the value of $R_E$ becomes larger.

The measurements performed to give the impedance graph according to the TS parameter table above which can be seen in Figure 6 below. The red line indicates the PG-1254 loudspeaker before addition of clay mass on the panel is given and the green line shows after clay mass has been added. The yellow line represents the PG-1254 loudspeaker before the vented-box mass added and the orange line indicates after the addition of clay mass.

![Figure 6](image)

**Figure 6.** The Result of Measurement Impedance of PG-1254 Loudspeaker Using Vented-box and Panel

The green line produces a maximum impedance of 8.292 $\Omega$ at a frequency of 19.807 Hz. While the orange line produces a maximum impedance of 11.631 $\Omega$ at a frequency of 22.337 Hz. The measured impedance results in the vented-box shift 5 Hz lower than the panel. That's because, in the vented-box, the measured impedance is not only the pure impedance of the loudspeaker but rather the impedance of the loudspeaker and vented-box.
3.4 Analysis of Frequency Response with Loudspeaker Variations on Vented-box and Panel

Frequency response is the pure frequency of the loudspeaker characteristics. The red line indicates the frequency response on the panel and the blue line indicates the frequency response on the vented-box. The peak of the frequency response graph is the highest frequency point where the loudspeaker can produce the maximum SPL. If the loudspeaker frequency is above the peak, then the loudspeaker will produce distortion. SPL value is 90.96 dB for panel and 92.04 dB for vented-box. Based on the measurement results, the comparison of TS parameter values for vented-box and panel as in table 3.

Table 3. The Comparison Results TS Parameter Subwoofer PG-1254 on Vented-box and Panel

| TS Parameter | Subwoofer PG-1254 | Panel | Vented-box |
|--------------|-------------------|-------|------------|
| Fs           | 28.43 Hz          | 31.67 Hz  |            |
| Vas          | 149.52 L          | 115.75 L  |            |
| Qts          | 0.82              | 1.22   |            |
| Cas          | 10.7×10⁻⁷ m³/N    | 8.29×10⁻⁷ m³/N  | |
| Zmax         | 14.31 Ω           | 15.24 Ω  |            |
| dB SPL       | 82.71 dB          | 87.02 dB  |            |

Based on table 3, there is a change of SPL between the vented-box and panel. Cas value of the vented-box is larger than the panel. Because of the larger Cas of the vented box, making the impedance also becomes larger. That's what makes the loudspeaker resonance frequency on the vented-box also lower than the panel. The vented-box frequency is obtained from equation 2 and yields a value of 2.5. The cone diaphragm also removes less air volume (small Vas), causing an increase in the Fs value and loss of the resulting bass response.

In the vented-box, the result of a frequency response is the frequency response of the system from loudspeaker and vented-box. Many things affect the characterization of the loudspeaker in the vented-box. Among them are air compliance factor, vented-box response frequency, Qts loudspeaker, Qes loudspeaker, port resistance, air leak resistance, and box resistance. The ratio of compliance factor is 8.29:10.7 which means that with low compliance factor will cause bigger box loss. The greater the Qts and Qes loudspeaker values, the less the efficiency loss generated by the loudspeaker drivers. So the drivers used are still good and adequate. While the resistance on the port shows a loss on the port that is equal 0.0033 which means that port losses coated damper material has a very small effect on the enclosure.

For an air leak resistance produce air that is equal to 112.05 which means big air leakage losses occur in vented-box. Box resistance produces absorption loss on the damper material in it that is equal to 0.0089 indicating that the damper material more or less absorbs the sound produces. From port losses, leakage losses and absorption losses obtained vented-box system losses of 0.63%. Therefore, that vented-box experience a loss of 0.63% caused by the shape of the box design and damper materials used in the box. Whereas panel loss is 0.014%.

4. Conclusion

Based on data analysis, the conclusion is the effect of the vented-box on TS loudspeaker parameters lies in the acoustic compliance box of 8.29:10.7 with an air compliance ratio of 8.29:10.7 which makes greater vented-box response losses occur. The loss of the vented-box response reached 0.63% while the losses of the panel reached 0.014%. A big disadvantage occurs in the vented-box caused by the shape of the enclosure design and the damper material inside it. The vented-box produces a larger SPL of 5 dB than the panel because it requires more power.
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References
[1] Yolanda, 2015. Sejarah Loudspeaker. https://www.audioengine.co.id/sejarah-speaker/. Access on 10 September 2017 at 08.20 WIB
[2] http://santaidisiniyuk.blogspot.co.id/. Access on 20 September 2017 at 20.34 WIB
[3] Beranek. Leo L.1959, "Acoustics". New York: Acoustical Society of America through the America Institute of Physics Ballou Glen. 2009. Electroacoustic Devices: Microphones and Loudspeakers. Burlington: Elsevier
[4] http://maybelle.com.vn/mediacenter/media/images/426/news/ava/s1000_1000/115040image0-1497347093.jpg. Access at 08.55 WIB on 19 September 2017
[5] Short Elliot. George. 1988. The Aperiodically Damped Loudspeaker System. Virginia Polytechnic Institute and State University
[6] R.H. Small. 2006. Vented-box Loudspeaker System Part 1: Small Signal Analysis. The University of Sydney