

# The study on the woofer speaker characteristics due to design parameters

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#### ABSTRACT

In the vehicle speaker, because the sound characteristics are changed by the space of vehicle which mount the speaker, the speaker elements should be determined according to sound field. In this study, the nonlinear characteristics, the frequency response and the sound pressure for the same size speakers which is adapted to domestic vehicle model are investigated. The vehicle model is classified to semi-midsize, midsized, full size vehicle in order to change the vehicle space. As a result, we can investigate the differences of the force factor and the stiffness of suspension system for speaker. According to the change of the speaker characteristics, the sound pressure is changed, also. In the future, these data will be used to investigate the correlation between the sound quality and measurement data.

Keywords: Woofer speaker, Force factor, Stiffness of suspension system, Mechanical mass of moving system, Resonant frequency I-INCE Classification of Subjects Number(s): 76.9

## 1. INTRODUCTION

The speaker is conversion device from electrical energy to acoustical energy like a sound. The speaker sound level is appear differently depending on strength of electric current and signal frequency, loudness is determined to depend on displacement of diaphragm inside the speaker.

Speaker can be classified as a Cone type, Dome type, Flat type, Ribbon type, Horn type, Micro speaker and etc.. according to differences in the structure and shapes of speaker. And can be categorized due to differences in the frequency band. 'Woofer' can be reproduce below 3kHz, 'Middle-range' can be reproduce between 1kHz to 10kHz, 'Tweeter' can be reproduce above 4kHz, 'Full-range' can be reproduce in audio frequency band and 'Subwoofer' can be reproduce under the 200Hz and 'Super-tweeter' can be reproduce up to 20kHz frequency band. In addition, the speakers can be classified according to the type and structure of the unit. Depending on use there are many type of speakers such as automotive, home, display, micro acoustic transducer, multimedia and etc..

Automotive speakers are separated by a Tweeter, Woofer, Sub-woofer generally. In this study, woofer is target what a reproduce low and middle frequency band and applied to a lot of a car generally.

The diaphragm is a one of the important part in the speaker, and sounds are generated by vibration of diaphragm. Generally called it 'Cone paper' and it generate sound wave through variation of compressed air receiving by vibration from voice coil. Diaphragm is determining most of the sound quality of the speaker, and also frequency characteristics like a sound quality are change depending on

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the material, thickness, shape, and many research results of these were published.<sup>(1,2,4)</sup>

Usually, use the 'Thiele-small' parameter in order to display the characteristics of the speaker. This parameter was defined by Neville Thiele and Richard Small, These factors can make used speaker to usage and purpose properly. Indicates large amount of distortion generated by speaker inherent non-linearity in a large amplitude area can move diaphragm of speaker.

In this study, these non-linearity characteristics calculate through experimentation, and investigated the change of the linear and non-linear characteristics, the sound pressure characteristics, according to change design parameters of the speaker.

# 2. EXPERIMENTAL METHODS AND SPEAKER CHARACTERISTIC VARIABLES

#### 2.1 Linear Characteristics<sup>(3)</sup>

Speaker can be analyzed into an electric circuit, and resistance and inductance in the electrical circuit can be referred by resistance and mass of air in the speaker.

Characteristic variables of the speaker are separated by impedance, air mass of the speaker, the effective mass of the diaphragm, compliance of the speakers, force factor, inductance and mass of the voice coil, resistance, speaker polarity, acceleration of the diaphragm and 'thiele-small' parameter. In this study, using the KLIPPEL system of Figure 1, and figured out the speaker characteristic variables.

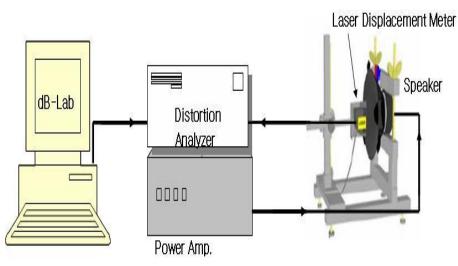


Figure 1 – Schematic diagram of measuring system for the speaker parameters(KLIPPEL System)

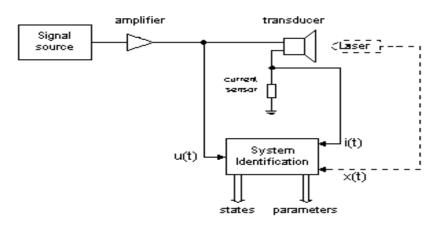


Figure 2 – Block circuit of linear parameter measurement

The Sine wave of 20~20kHz is generated from the distortion analyzer, after being amplified through the power monitor, and this signal is input to the speaker. By analyzing the current signal and a vibration signal generated from the speaker, it is possible to constitute the equivalent electric

circuit and speaker characteristics. Figure 2 is a diagram for measuring the electrical / mechanical parameters of the speakers that are used in KLIPPEL system. Measuring, Voltage u(t) and Current i(t) of the speaker terminal, and impedance can be calculated using Equation (1).

$$Z(f) = \frac{U(f)}{I(f)} \tag{1}$$

Mechanical parameters can be defined by using laser displacement sensor and measuring the transfer function from these.

$$\mathcal{H}_X(f) = \frac{X(f)}{U(f)} \tag{2}$$

In Equation (2), X(f) is the displacement of the voice coil, and U(f) is voltage at the speaker terminals. The Table 1 refers to the definition of the electrical / mechanical parameters of the model and the linear speaker model can be constructed using the values obtained from each experiment.

	Electrical Parameters	Mechanical Parameters		
Symbol	Parameters	Symbol Parameters		
R <sub>e</sub>	Electrical voice coil resistance	B1	Force factor	
Le	Voice coil inductance at low frequencies	C <sub>ms</sub>	Mechanical compliance of driver suspension	
L <sub>2</sub>	Para-inductance at high frequencies	$M_{ m ms}$	Mechanical mass of driver diaphragm assembly including air load and voice coil	
$\mathbf{R}_2$	Resistance due to eddy currents	<b>R</b> <sub>ms</sub>	Mechanical resistance of total-driver	

#### Table 1 – The components of linear speaker model

#### 2.2 Non-linear Characteristics<sup>(3)</sup>

When a large force is applied to the diaphragm, the non-linear characteristic of support and vibration systems of the speaker were displayed, can establish a non-linear model of the speaker. For measuring the elements of the equivalent circuit/electrical circuit and the non-linear curve shape by Force factor (Bl-product), measure Force factor / Compliance / Stiffness / Inductance / Electrical Capacitance / Resistance / Resonance frequency / Loss factor, etc.. using Speaker Terminal current and voltage information. Table2 shows the mechanical parameters of the model and speaker model can be constructed using the values obtained from each experiment.

Table 2 – The mechanical component of nonlinear speaker model

Symbol	Prameters	
M <sub>ms</sub>	mechanical mass of driver diaphragm assembly including voice-coil and air load	
R <sub>ms</sub>	mechanical resistance of driver suspension losses	
<i>BI</i> ( <i>x</i> )	instantaneous electro dynamic coupling factor (force factor of the motor) defined by the integral of the permanent magnetic flux density B over voice coil length l	
$C_{ms}(x,t)$	mechanical compliance of driver suspension (the inverse of stiffness)	

#### 2.3 Sound Pressure Characteristics

Identify for the characteristics of the sound pressure, using an experimental device such as a Figure-3. The speaker attached to in front of baffle surface located in anechoic chamber, and 1 kHz sine wave and white noise from the signal generator, connect to be transferred to the speaker. The signal inputted from a microphone, and analyzed using a frequency analyzer (FFT analyzer).

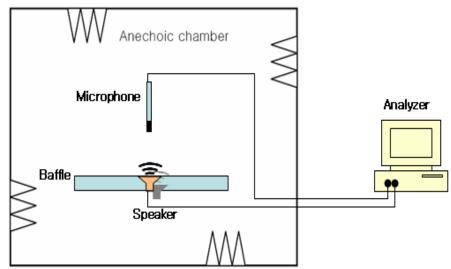


Figure 3 – Schematic diagram of measuring system for sound pressure level

# 3. RESULTS AND DISCUSSIONS

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Speaker of the car that was used in this study is a 165mm diameter, nominal impedance is  $4\Omega$ . Alter the characteristics of the damper and the cone paper most important sound reproduction of the speaker, and figured out the characteristics of the mechanical parameters of the speaker as shown in Table 3.

c 1.

Design parameter	Sample 1	Sample 2	Sample 3	Sample 4
Cone paper	2.0 g	2.5 g	2.0 g	2.5 g
Damper	0.6 g	0.6 g	0.9 g	0.9 g

## 3.1 Linear Characteristics

Figure 4 shows the variation of force factor due to the mass change of the cone paper. Force factor is proportional to the length of the voice coil and the magnetic field when the current is constant, it can be seen that it is changed in accordance with a characteristic change of the damper and the cone paper.

Figure-5 shows the Q parameter value. This is an amount that can be attenuated vibration of the speaker through electrical/mechanical methods, and it means can be control used as a quantity of the amplitude of the speaker diaphragm at the resonant frequency. If the value of the damper is large, the mass of the cone paper increases, it can be seen that the Q parameter value increases.

In other words, make it smaller the control ability to amplitude of the vibration of the speaker at the resonant frequency, and the sound pressure becomes higher, and the control ability is reduced.

In Figure 6, shows the characteristics associated with the mechanical parameters of the speaker. Compliance indicating the rigidity of the elements to support the drive unit of the speakers was reduced by the mass increase of the cone paper. In addition, the mass of the drive unit is increasing, can be seen that the mechanical resistance decreases.

It is figure out caused by the increase in mass of the cone paper, and induce changes in the resonant frequency caused by the mass and stiffness.

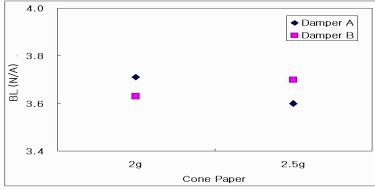


Figure 4 – Force factor for the cone paper and damper

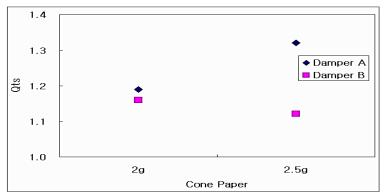


Figure 5 - Q factor(loss factor) for the cone paper

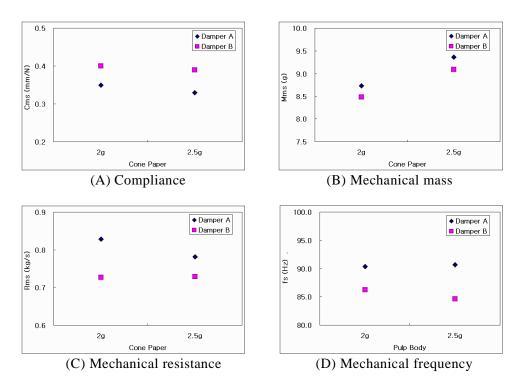


Figure 6 – Mechanical parameters for the cone paper

## 3.2 Non-linear Characteristics

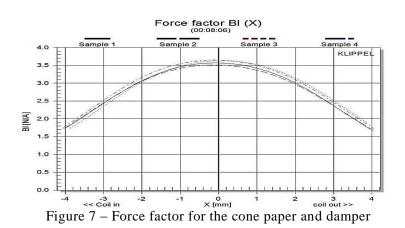
The Figure 7, shows the changes in the force factor by the mass change of the cone paper. Force factor is proportional to the length of the voice coil and the magnetic field when the current is constant, if damper and the mass of the cone paper increases, it can be seen that the force factor

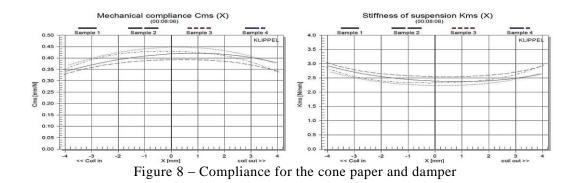
increases too. In addition, the damper is increased, according to the change of the cone paper, force factor has changed significantly.

Figure 8 shows the attributes that are associated with the rigidity of the speaker. The compliance is meaning the mechanical flexibility of the support systems, and if the value is flat the displacement width show larger. In stop position, i.e can be flexible in case of x = 0, and can be small the occurrence of displacement in case of Coil-in/out. That the stiffness will increased in case of Coil-in/out. It can be seen that the stiffness of the support system is increased when mass of the cone paper is increased, and the stiffness decreased when the damper is increased.

The Figure 9, it is shown the resonant frequency of the speaker, is obtained by Equation (3).

$$f_{S}(x) = \frac{1}{\sqrt[2]{M_{ms} \cdot C_{ms}}(x)}$$
(3)







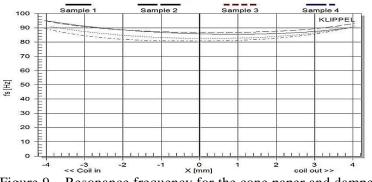
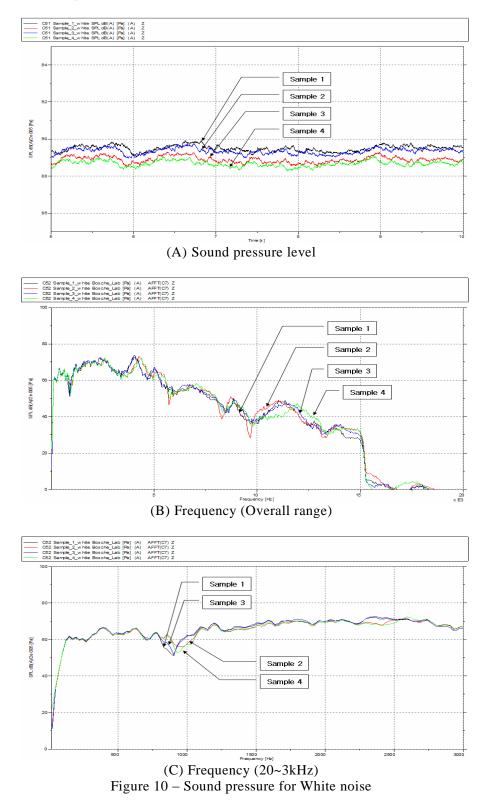


Figure 9 - Resonance frequency for the cone paper and damper

#### 3.3 Sound Pressure Characteristics

Figure 10 is shown about the characteristics of a sound pressure of the white noise. The sound pressure appeared in the Sample 1 is the highest, and in Sample 4 is the lowest. This is thought to occur due to differences in support systems stiffness and force factor of the speaker. Reproduced area of woofer speaker used in this study generally in the 3 kHz frequency bands.

It seems that the frequency response characteristics of Sample 2, Sample 4 is being played almost flat in the interest frequency band. In other words, it can be seen that as the rigidity increases, the speaker shows a flat frequency characteristics.



# 4. CONCLUSION

In this study, we investigated experimentally the characteristic parameters of the speaker according to changes in the design parameters of the woofer speaker for automobiles, and it was determined the following conclusion.

## 4.1 Linear Characteristics

- 1. Compliance indicating the rigidity of the elements to support the drive unit of the speakers was reduced by the mass increase of the cone paper. In addition, the mass of the drive unit is increasing, can be seen that the mechanical resistance decreases. It is figure out caused by the increase in mass of the cone paper, and induce changes in the resonant frequency caused by the mass and stiffness.
- 2. If the value of the damper is large, the mass of the cone paper increases, it can be seen that the Q parameter value increases. In other words, make it smaller the control ability to amplitude of the vibration of the speaker at the resonant frequency, and the sound pressure becomes higher, and the control ability is reduced. Therefore, must be considered Q parameter value according to speakers usage.

## 4.2 Non-linear Characteristics

- 1. The difference in the resonance frequency is generated by the difference of mass and stiffness, and the speakers are used in this study, it seems the increase of the damper is greatly affects the resonant frequency than the mass of the cone paper.
- 2. The mass of the cone paper increases, it can be seen that the Q parameter value increases, and the value of the damper increases, it can be seen that the Q parameter value decreases. It is required that in order to improve the ability to control the amplitude of the vibration of the speaker at the resonant frequency, the increase in the value of the damper and the decrease mass of the cone paper.

#### 4.3 Sound Pressure Characteristics

- 1. It can be seen that the stiffness of the support system is increased when mass of the cone paper is increased, and the stiffness decreased when the damper is increased. Also, if the mass of the damper and cone paper are small, the sound pressure is generated largely, and as stiffness of the support system is increased, the flatness of the reproduced frequency band was excellent.
- 2. If the rigidity of the diaphragm is large, the sound pressure of speakers of the 1kHz sine wave increased, and it can be seen that the sound pressure is smaller as the damper is larger.

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