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Low-frequency response test device of electret condenser microphone

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ABSTRACT

Arterial pulse measurement using electret condenser microphone requires the standard to validate the value of the measurement. This standard requires the test device to reproducing the mechanical vibration to emulate the arterial pulse vibration. The main objective of this paper is to discuss the test device of electret condenser microphone using class A amplifiers and low-frequency loudspeaker. To validate this pulse measurement, this class A amplifier is examined under an experimental setup. The experiments showed that the device can be used as an alternative solution to generate the mechanical signal source to simulate the human arterial pulse.

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1. INTRODUCTION

An electret condenser microphone (ECM) is a microphone designed in the audio frequency range about 20 Hz-20 kHz [1, 2]. ECM is utilized to accurately measure the arterial pulse in the low-frequency i.e, 1 Hz [2, 3]. The arterial pulse frequency is around 1.5-2.1 Hz at the normal condition of human [4-8]. The ECM works to detect the arterial pulse and is operated by taking a mechanical signal from the arterial pulse [3]. This ECM is used to measure arterial pulses frequently [9-13]. The arterial pulse measurement is based on the Traditional Chinese Medicine method [14-16]. Even though ECM has been conducted by many kinds of literature, the research on ECM is still relevant today. In [3], the arterial pulse recording device has been designed from ECM using a mechanical filter and electronic filter [17]. In practical applications, this ECM requires a tool to determine the response of electrical and mechanical responses such that it can be known whether this ECM is stationery at the frequency of 0.5-10 Hz. By considering this problem, the test device is required to examine and obtain the frequency response of ECM or even can be used as a human pulse emulator.

Since the pulse frequency is typically low frequency, between 0.5-2 Hz, special treatment is implemented to satisfy these frequency ranges. The previous works related to ECM for the application of low-frequency device has not yet been conducted. The test device based ECM to obtain the frequency response is constructed in this paper. The test device generates the mechanical signal coming from the loudspeaker. In this paper, the type of loudspeakers used is an oval woofer type from the TV [18].

The loudspeaker is then operated in the frequency range 0,5-10 Hz for mechanical vibration such that it can be used as a pulse emulator. The additional device that is able to drive the loudspeaker is often called a signal amplifier or an amplifier.

The class A amplifier is selected to eliminate the distortion of the signal. Class A amplifier has continuous current flows without any distortion because the transistor is operated continuously [19]. This type of amplifier is a kind of amplifier exhibiting low efficiency as the current flowing in the transistor is continuous. This study discusses the displacement response on a test device when given a low-frequency signal from a signal generator amplified by the class A amplifier. Displacement amplifier used as a mechanical signal source is also utilized as a pulse emulator and mechanical signal generator. Figure 1 shows the configuration of the low-frequency response test the device of ECM using a low-frequency amplifier and loudspeaker. In front of the loudspeaker, soft silicon rubber is installed and responsible to increase mechanical coupling between the loudspeaker and ECM. The detail description of the mechanical coupling has been discussed in [3].

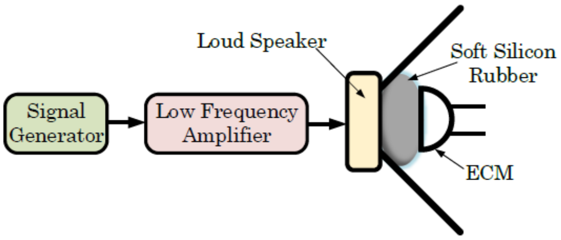

Figure 1. The configuration of the low-frequency response test device of ECM based low-frequency loudspeaker [3]

To observe the speaker impedance, the impedance test is required to measure the speaker impedance in the range frequency of 0,5-10 Hz. In this study, the impedance of the speaker is tested using a vector network analyzer (VNA) [20, 21] type Bode-100. In addition, the low-frequency amplifier is analyzed to observe the impedance of the amplifier. This paper discusses test devices using low-frequency amplifiers and low-frequency loudspeakers to measure the response of ECM for arterial pulse sensor [22, 23]. The experimental result has verified the proposed benchmarks.

This paper organized as follows: section 1 introduces the background of this research which is about the introduction of arterial pulse sensors using ECM and how the background of the test device is made to determine the frequency response of the ECM that is used as an arterial pulse sensor. Section 2 introduces the material and the method used in designing arterial pulse test devices, the material consists of low-frequency loudspeaker and low-frequency amplifiers. The method describes how to operate the arterial pulse test device. The Results and Discussion are discussed in section 3. And the last, section 4 presents the Conclusion.

2. MATERIAL AND METHOD

To implement the proposed test device, some components are realized to this test device such as the loudspeaker with low-frequency characters, the amplifier without distortion and has high linearity and measurement device i.e. oscilloscope and vector network analyzer. The detailed components of the overall system are explained as follows.

2.1. Low-frequency loudspeaker

Commonly, the existing speaker has a frequency response in the range between 20 Hz to 20 kHz, however, in this study, the proposed speaker is designed to satisfy the frequency range of 0.5-10 Hz. Figure 2 shows the schematic equivalent circuit of the proposed speaker. The proposed speaker consists of two components, i.e: the electrical and the mechanical component. The electrical component is composed by the moving coil, while the mechanical component consists of diaphragm and spring.

According to Figure 2, the mathematical model of the loudspeaker can be derived as follows:

$$Sp(\omega) = j\omega L + Re + \frac{1}{j\left(\omega Cm - \frac{1}{\omega Lm}\right) + \frac{1}{Rm}} \tag{1}$$

where the loudspeaker impedance is represented by $Sp(\omega)$, the resistance of the loudspeaker coil is assumed by Re, the inductance of the loudspeaker coil is denoted by Le, the mass of diaphragm is represented by Cm, the spring diaphragm of the loudspeaker is related by Lm and the losses of spring diaphragm is represented by Rm. The parameters of the low-frequency loudspeaker are described in Table 1.

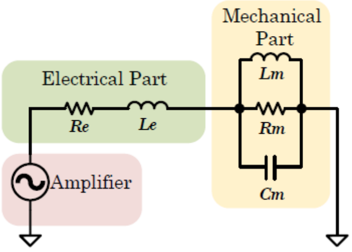

Figure 2. The Modeling of Loudspeaker

Table 1. The parameter of the loudspeaker modelling

Parameter	Description	Value
Re	Loudspeaker coil resistance	6.1 Ω
Le	Loudspeaker coil inductance	0.11 mH
Lm	Spring diaphragm of the loudspeaker	7.5 mH
Rm	Spring diaphragm losses	8.9 Ω
Cm	Diaphragm mass	306 µF
Amplifier	Class A Amplifier	1-1000 Hz

According to Figure 2, the loudspeaker has a resonant frequency. The resonant frequency is the relationship between the mechanical resonant frequency of the diaphragm and the moving coil represented in (2) as follows:

$$f_{res} = \frac{1}{2\pi}\sqrt{\frac{S}{M}} \tag{2}$$

where f_{res} is the resonant frequency of the loudspeaker, S is the stiffness of the spring compliance loudspeaker and M is the mass (weight) of all components moving on the loudspeaker. S is a notation for the loudspeaker stiffness system in centimetres per dyne which consists of a spider or spring system that positions the moving part again at the rest position. This moving part position can move forward or backwards from the rest position according to the signal given to the loudspeaker. The strength of this spring will determine how much force is given by voice-coil. The greater the value of S, the greater the force that the moving coil must be given. Whereas, M represents all components loaded from loudspeakers such as diaphragms, cones, and moving coils as well as included in this M component. Based on the aforementioned explanation, it can be concluded that the type of woofer loudspeaker has the character of S which is lower than other types of loudspeakers and M is greater than other types of loudspeakers.

To find out the force acting on the diaphragm of the loudspeaker provided by the voice coil, the combination of the electrical and mechanical domain must be incorporated and added. Magnetizing force to obtain a large force that affects the moving force of the loudspeaker represented in the following:

$$\begin{aligned} f &= Bli \\ e &= Blu \end{aligned} \tag{3}$$

where B is the magnetic field strength (T), I is the length of the conductor in the magnetic field (m), f is the force in Newton (N), u is the speed from moving the moving part loudspeaker (m/s), i is the current passing through the moving coil from the loudspeaker (A) and e is the voltage supplying moving coil from the loudspeaker (V). Mechanical quality factor and electrical quality factor are represented this following (4):

$$\begin{aligned} Q_{ES} &= 2\pi f_S C_m R_e \\ Q_{MS} &= f_S C_m R_m \\ f_S &= \frac{1}{2\pi\sqrt{C_m R_m}} \end{aligned} \tag{4}$$

where Q_{MS} represents the mechanical quality factor, Q_{ES} denotes the electrical quality factor and f_S is the resonance frequency.

2.2. Low-frequency amplifier

Since the audio amplifier [24] has a frequency response in the range frequency of 20-20 kHz, the amplifier is conditioned in the range frequency of 0.5-10 Hz. In this paper, the basic principle of the low-frequency amplifier using modified Class A is introduced. The schematics of the circuit are shown in Figure 3 and Figure 4. The proposed amplifier is composed by Darlington transistors and several passive components.

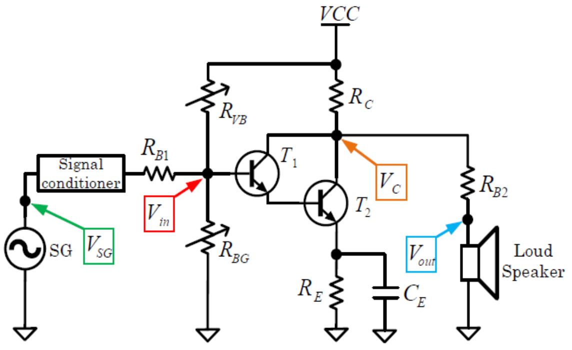

Figure 3. The proposed of low-frequency amplifier based class-A amplifier

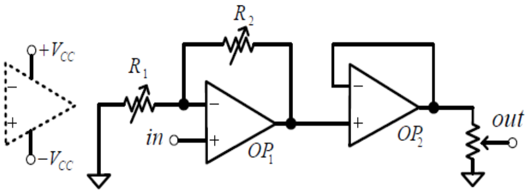

Figure 4. Signal conditioner

The parameters of the proposed amplifier are listed in Table 2. R_B is a resistor that acts as a buffer between the signal source and the main circuit such that it does not overload the signal generator, R_{VB} and R_{BG} is a voltage divider that provides voltage and current to the base of T_1 transistor, R_C is a resistor that regulates the current of Darlington transistors T_1 and T_2. R$_E$ is the resistor to compensate the deviation of Darlington transistors T_1 and T_2, C$_E$ is to compensate for the sine wave signal and the R_{B2} is the resistor to compensate between the loudspeaker and amplifier.

Table 2. The parameter of proposed amplifier

Parameters	Value
R_{B1}	100 Ω
R_{VB}	10 KΩ
R_{BG}	1 KΩ
R_c	8 Ω
R_E	24 Ω
R_{B2}	14 Ω
T_1	2N3035
T_2	2N3055
C_E	3.3 µF

To determine the voltage of amplifier affecting the force of loudspeaker, the force of motor using Ohm's law relating to a Lorentz actuator can be calculated. The motor voltage must be replaced by a short circuit to determine the impedance of a voltage source [25]. The force of loudspeaker which affecting the amplifier voltage can be described by

$$F = Bil = \frac{BV_s l}{R_c}[N] \tag{5}$$

where B is the flux density of the loudspeaker magnetic field around the coil in Tesla $[T]$. l is the length of the voice coil inside the magnetic field. To determine the dynamic response $T_{F,x}$ of the cone displacement x which related to mass m to drive the force of excitation F can be described by

$$T_{F,x}(\omega) = \frac{x}{F} = \frac{C_s}{-\frac{\omega^2}{\omega_0^2}+2j\zeta\frac{\omega}{\omega_0}+1} \tag{6}$$

where $\omega = 2\pi f$, ζ is damping ratio, C_s is compliance and the resonant frequency of mechanical part ω_0 is calculated by: $\zeta = \frac{c}{2\sqrt{km}}$, $C_s = \frac{1}{k}$ and$\omega_0 = \sqrt{\frac{k}{m}}$.

The resonant frequency of the mechanical part is called "eigenfrequency" [11] and denotes as f_0. The f_0 is equal to $\omega_0/2\pi$ called by fundamental resonant frequency. Around its the fundamental frequency, the loudspeaker actuator is matched with the force due to the displacement of the cone against the stiffness of the loudspeaker suspension. In this study, the loudspeaker resonant frequency f_0 is 193 Hz, but the loudspeaker is operated at a lower frequency in the range of 0.5-10 Hz by designing a special amplifier that is able to operate at a very low frequency such that can drive the motor force of loudspeaker. The complete description of the experimental setup of the low-frequency amplifier is later discussed in the following section.

2.3. Experimental setup

This study proposes a new test device for testing a performance of the ECM that operates in the frequency of arterial pulse region. In addition, test devices can be used for mechanical pulse emulator the same as the arterial pulse. To design the test device, the researchers conduct an experiment by measuring the impedance and gain of loudspeaker using a Bode-100 type vector network analyzer (VNA). Based on the experiment, it can be obviously seen that the loudspeaker impedance rate in the frequency range 0.5-10 Hz. In addition, the gain of the loudspeaker is also measured using this VNA in the frequency range 0.5-10 Hz.

To characterize the Class A amplifier, the output voltage on the amplifier is conditioned constant even though the input frequency is varied in the range of 0.5-10 Hz. This output voltage is then represented by displacement of the diaphragm of the loudspeaker. This displacement is then conditioned at a desired constant value by varying the input voltage of the signal generator. In order to verify the performance of the proposed test device, a novel class A power amplifier design and a low-frequency loudspeaker are verified in Figure 5. The test benchmark consists of several components i.e: signal generator, digital storage oscilloscope, power supply, Class A amplifier and loudspeaker. Each of those components has its function. The signal generator produces the sine wave. The Class A amplifier is supplied by the power supply, the loudspeaker generates the mechanical vibration driven from the Class A amplifier. To measure the amplitude response, digital storage oscilloscope (DSO) is connected to the terminal V_{in} and V_{out} of Class A amplifier. The experimental setup parameters are listed in Table 3.

The experimental setup of the proposed system is clearly shown in Figure 5, while the detailed test device is shown in Figure 6. The ECM stand is the ECM holder aiming to support and maintain the ECM position. ECM is the focus of research which is the main objective in this study. Soft silicon rubber is utilized to adjust mechanical coupling between the loudspeaker and ECM diaphragms. The description of the ECM system as an arterial pulse sensor is explained in detail in [3]. In this research, the main topic is the design of a test device to generate a mechanical signal such as human pulse arterial signals which the loudspeaker is conditioned in the frequency range 0.5-10 Hz with a displacement of 0-1.5 mm_{pp}.

Table 3. The parameter of experimental setup

Parameters	Specification
Power Supply	20 V DC
Function generator	KMOON, Dual-channel DDS signal Generator
DSO	Hantek MSO5074F, 4 channel DSO, 70 MHz

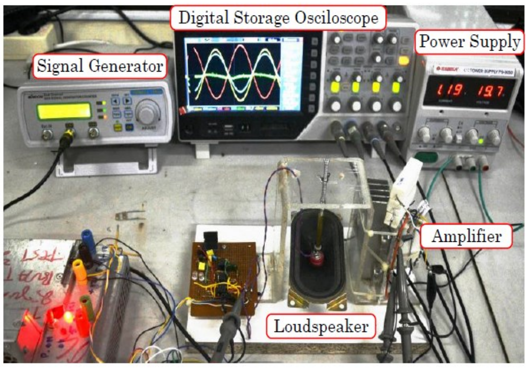

Figure 5. The photograph of the low-frequency response test device of the ECM

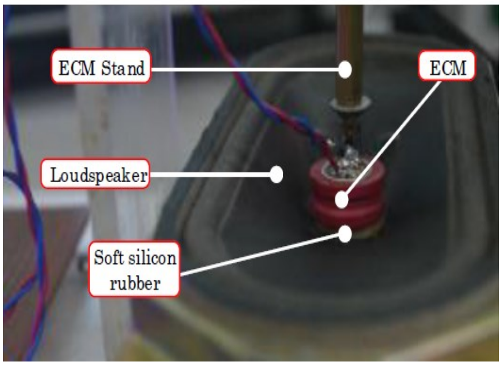

Figure 6. The configuration of loudspeaker and ECM

3. RESULT AND DISCUSSION

Figure 7 depicts the loudspeaker impedance measurement using VNA type Bode 100 from Omicron Lab. In this impedance measurement, the loudspeaker is stationary and there is no object hitching on this loudspeaker. Then, the VNA is set to kick the loudspeaker in the range 0.5-10 Hz. The frequency response of the loudspeaker is measured by VNA and shown in Figure 8. Based on the measurement, the loudspeaker has the impedance at about 7.09 Ω. Figure 8 shows the loudspeaker gain in the frequency range of 1-10 Hz. However, the loudspeaker gain tends to be constant at about 0.2477 in the frequency range of 3-10 Hz. In future, it can be interpreted in the frequency range of 310 Hz that this loudspeaker has a gain of 0.2477 dB.

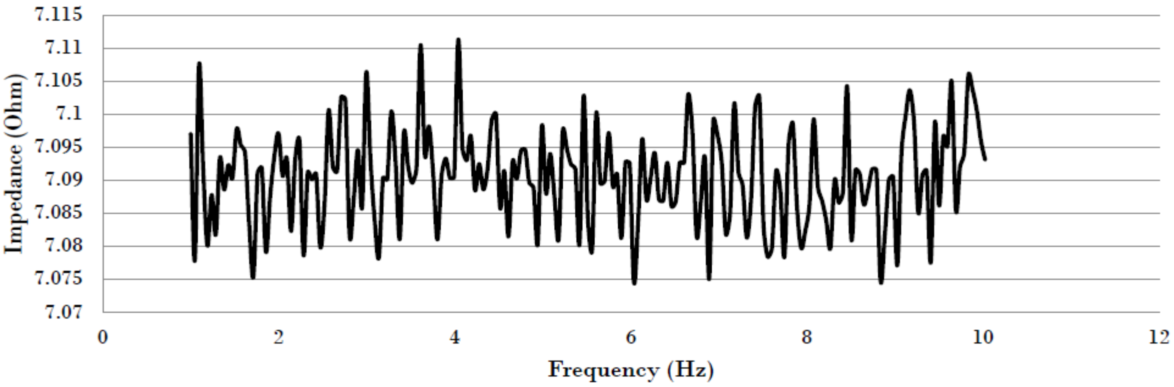

Figure 7. The loudspeaker impedance measurement using VNA

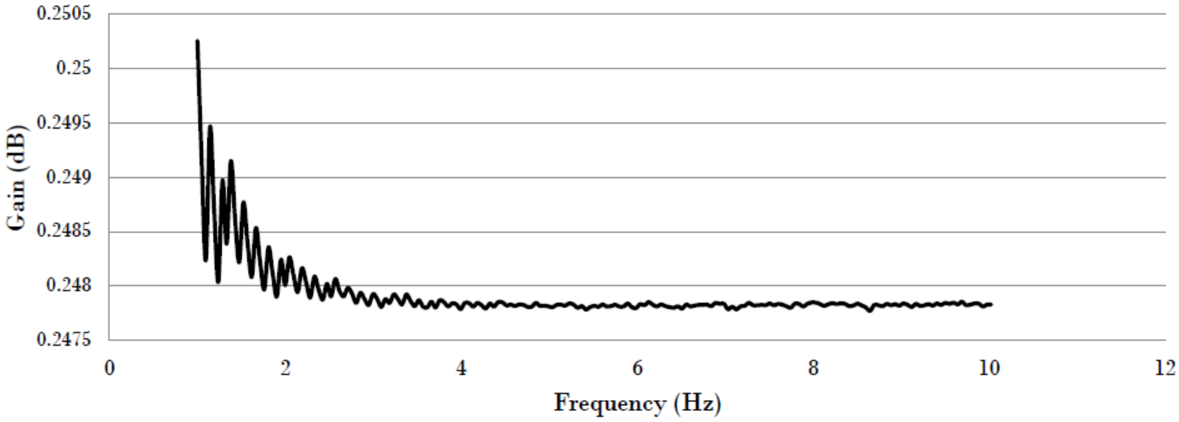

Figure 8. The loudspeaker gain measurement using VNA

The voltage ratio between the voltage signal generator which represented as V_{in} and the amplitude voltage at loudspeaker which denoted as V_{out} in every 0.5 Hz sampling is shown in Figure 9. It can be clearly seen that the ratio of the test device system tends to decrease when the frequency is getting higher. It implies that the test device system will require larger V_{in} if the frequency is raised. Figure 9 shows that the frequency response value is not fixed. Therefore, signal conditioners as shown in Figure 4 are added as shown in Figure 10 indicating the input voltage V_{in} from a signal generator in every 0.5 Hz. Figure 11 shows the frequency response after signal conditioners from Figure 10 are added. Consequently, the diaphragm displacement of the test device is stationary at the range 3.36 to 3.46 at the frequency range of 0.5-10 Hz as depicted by Figure 11. It can be clearly seen that the loudspeaker is operated at low frequencies and can be used as a test device.

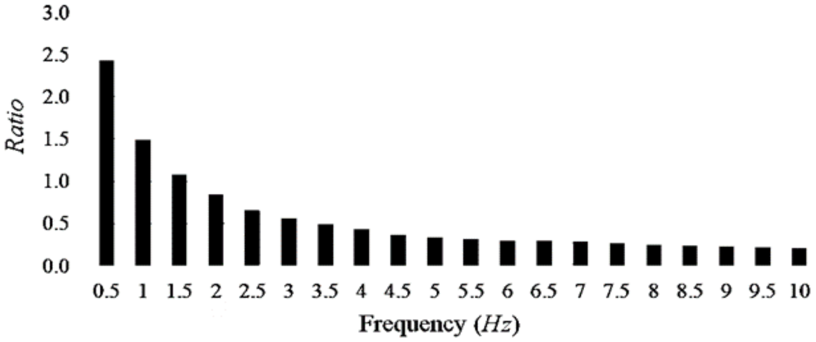

Figure 9. The voltage ratio between the voltage signal generator which represented as V_{in} and the amplitude voltage at speaker which denoted as V_{out} in every 0.5 Hz

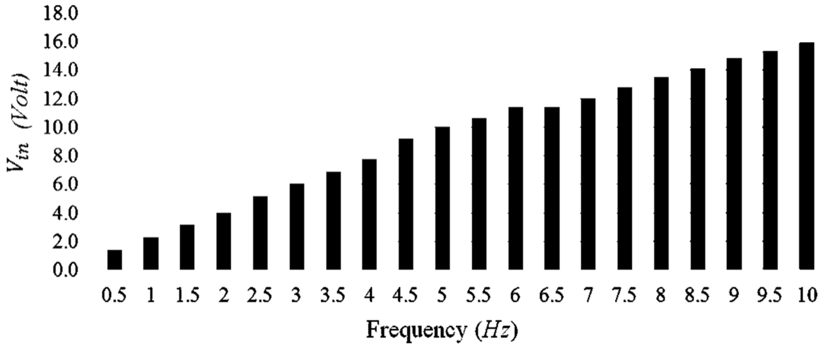

Figure 10. The voltage of the signal generator which denotes as V_in in every 0.5

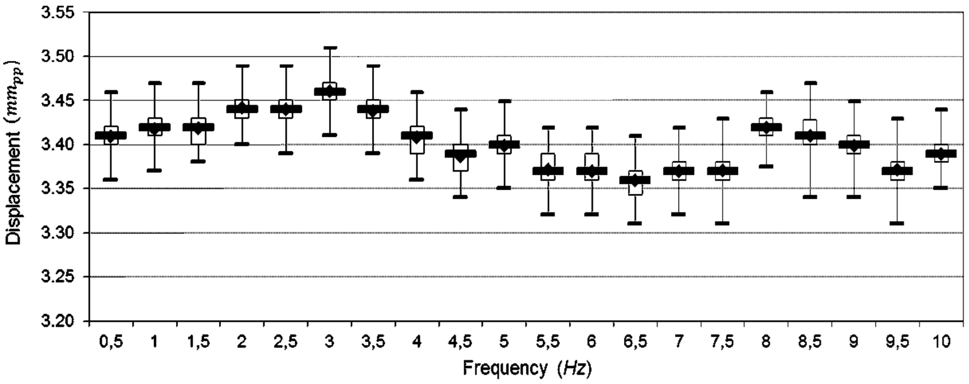

Figure 11. The diaphragm displacement of the loudspeaker in mm_{pp}

4. CONCLUSION

The low-frequency response test devices of ECM has been successfully implemented. The test device has been successfully verified with constant displacement. So the proposed test device is able to used as a low-frequency response test device.

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