An evaluation method of modal damping for silver/graphene nanoparticle on vibration based electromagnetic energy harvester

N. Ismail[1] and M.A. Salim[1,2,*]

[1)] Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2)] Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

[*]Corresponding e-mail: azli@utem.edu.my

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ABSTRACT – This paper presents an evaluation model of modal damping for graphene and silver nanoparticles on vibration based electromagnetic energy harvester. The conductive inks were printed on aluminum plate was tested by impulse waveform with vibration base system shaker and data physic. Modal damping test was done to evaluate and determined the damping coefficient of graphene and silver conductive ink. Damping test shows that damping coefficient of graphene conductive ink is higher than silver conductive ink.

1. INTRODUCTION

The project of electromagnetic energy harvester is using same concept as self-inductance which involve mechanical vibration on graphene and silver conductive ink. Vibration Energy Harvesting is the concept of converting the kinetic energy inherent in vibrations to electricity as the mechanical vibration is main focus in energy harvester, overall damping coefficient too plays an important role in harvesting and dissipation of energy and also transferring the energy from vibrating base into the system. This is shown that energy flow through the damper is positive when $\omega>\omega n$ and $\omega<\omega n$ when the energy flow is negative, but is zero when $\omega=\omega n$. Stephen said that mechanical component of the overall damping cannot offer more energy than it dissipates and author also present experimental result done by William et al that the function of the device in a vacuum is beneficial [1]. Maximum power is gain from the environment when the device is excited with frequency that equal to the undamped natural frequency, irrespective of the damping ratio.

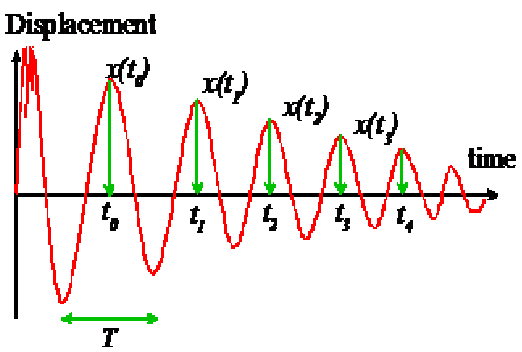

Fig. 1.1 Damping oscillation graph

The objective of this study is to investigate the damping coefficient of graphene and silver nanoparticle conductive inks.

2. RESEARCH METHODOLOGY

2.1 Sample preparation

Firstly, samples of graphene nanoplatelets and silver flakes filled epoxy conductive ink was fabricated. Graphene nanoplatelets (900439) with surface area of 500 m2/g and molecular mass of 12.01 g/mol and silver flakes (327077-50G) with diameter 10.49 g/cm supplied by sigma Aldrich. The materials acted as the filler element, epoxy as the binder and hardener were used. Then, the conductive ink was printed on aluminum plate as the base as fig. 2.1 and fig. 2.2 below.

Fig. 2.1 Graphene conductive ink sample for damping test

Fig. 2.2 Silver conductive ink sample for damping test

2.2 Damping experiment

Damping test was set with vibration test system shaker (rate force 18N) that has frequency range of 2 to 20 000 Hz and has 65g of maximum acceleration sine, and paired with Quattro data physic and power source amplifier.

Accelerometer sensor was placed on top of conductive ink to measure the acceleration force act on it. Damping test was done with impulse waveform to get the damping decay of aluminum plate, and conductive inks with aluminum plate. From the experiment the data obtained will be calculated with equation (1), (2), and (3) to obtain the damping coefficient.

The period of oscillation, T

$$T = \frac{t_n - t_0}{n} \tag{1}$$

Logarithmic decrement

$$\delta = \frac{1}{n}\log\frac{x(t_0)}{x(t_n)} \quad (2)$$

where x(tn) is the displacement at the nth peak, from T and δ obtain earlier, natural frequency, ωn and damping coefficient, ζ can be deduce as follow;

Damping coefficient

$$\zeta = \frac{\delta}{\sqrt{4\pi^2+\delta^2}} \quad (3)$$

Natural frequency, ωn

$$\omega_n = \frac{\sqrt{4\pi^2+\delta^2}}{T} \quad (4)$$

3. RESULT AND DISCUSSION

Damping test was done to identify damping coefficient of graphene and silver conductive ink. Firstly, damping test was done on aluminum plate only and the result then was compared with damping coefficient of aluminum plate printed with graphene and silver conductive ink. Tables below is the data analysis to obtain the average of damping and error bar that state the acceptance limit of the raw data. The test was done to measure the magnitude decay of the material from $T(x_0)$, $T(x_1)$ until $T(x_n)$ over time as in figures below.

3.1 Result of aluminum plate damping

Figure 3.1 show the graph of magnitude decay over times for the aluminium plate with error bar represent upper limit and lower limit at each time points. T(x0) at 45.7 ms has 7.1% of acceptance upper limit and 12.3% of acceptance lower limit, 6.5% and 12.1% for T(x1) at 48.0 ms, 8.2% and 12.6% for T(x2) at 50.4 ms, 12.5% and 16.1% for T(x3) at 52.7 ms, and 18.5% and 24.4% for T(x4) at 54.7 ms.

Table 3.1 Data of damping test for aluminum plate

	Time (ms)	N_1 (Hz)	N_2 (Hz)	N_3 (Hz)	N (Hz)
$T(x_0)$	45.7	22.8	23.2	19.0	21.7
$T(x_1)$	48.0	14.3	14.2	11.8	13.4
$T(x_2)$	50.4	9.29	8.97	7.51	8.6
$T(x_3)$	52.7	7.83	7.20	5.84	7.0
$T(x_4)$	54.7	4.80	4.29	3.06	4.1

Damping coefficient of the aluminum plate was calculated by using equation (1), (2), (3), and (4) which is 0.02897 and the natural frequency is 2.7937 KHz. This result will be compared with the damping coefficient of graphene conductive ink with aluminum plate and silver conductive ink with aluminum plate to get true value of graphene and silver conductive ink's damping coefficient

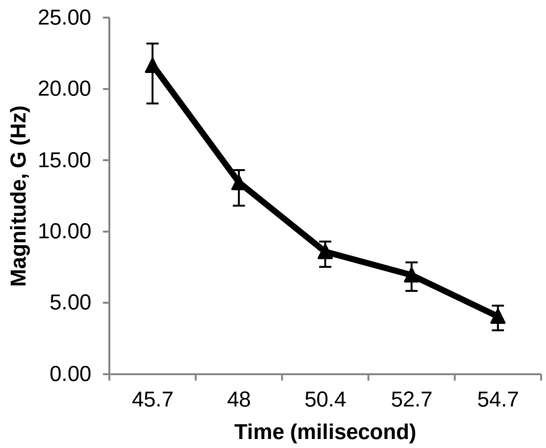

Figure 3.1 Graph of magnitude vs time for aluminum plate damping test

3.2 Result of graphene conductive ink with aluminum plate damping

Figure 3.2 show the graph of magnitude decay over times for the aluminum plate with error bar represent upper limit and lower limit at each time points. T(x0) at 45.7 ms has 16.7% of acceptance upper limit and 30.6% of acceptance lower limit, 14.3% and 27.6% for T(x1) at 47.7 ms, 16.8% and 31.9% for T(x2) at 49.6 ms, 11.9% and 17.9% for T(x3) at 51.6 ms, and 25.7% and 37.2% for T(x4) at 52.7 ms.

Table 3.2 Data of damping test for graphene conductive ink with aluminum plate

	Time (ms)	N_1 (Hz)	N_2 (Hz)	N_3 (Hz)	N (Hz)
$T(x_0)$	45.7	29.9	29.2	17.8	25.6
$T(x_1)$	47.7	20.2	20.0	12.8	17.7
$T(x_2)$	49.6	12.3	12.5	7.29	10.7
$T(x_3)$	51.6	3.38	3.20	2.48	3.0
$T(x_4)$	52.7	2.14	2.40	1.20	1.9

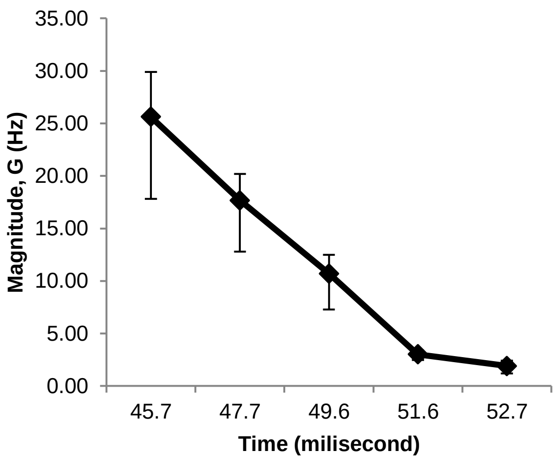

Figure 3.2 Graph of magnitude vs time for graphene conductive ink with aluminum plate

Damping coefficient for the graphene conductive ink after exclude the damping from aluminum plate is 0.01585 and the natural frequency is 3.594 KHz.

3.3 Result of silver conductive ink with aluminum plate damping

Figure 3.3 show the graph of magnitude decay over times for the aluminum plate with error bar represent upper limit and lower limit at each time points. T(x0) at 46.1 ms has 24.2% of acceptance upper limit and 14.1% of acceptance lower limit, 29.0% and 15.5% for T(x1) at 48.0 ms, 48.0% and 27.5% for T(x2) at 50.4 ms, 62.5% and 39.0% for T(x3) at 52.3 ms, and 48.4% and 25.9% for T(x4) at 54.7 ms.

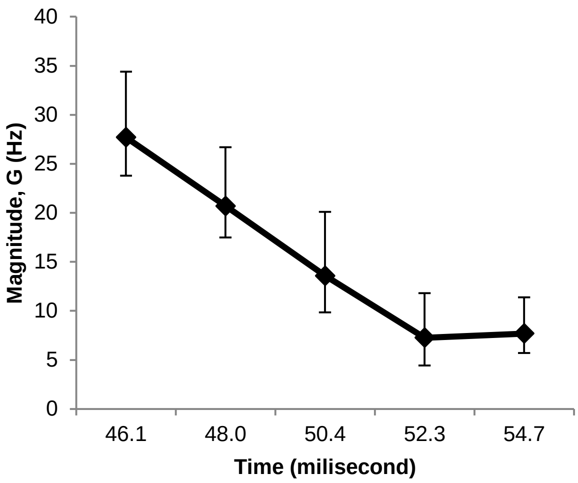

Figure 3.3 Graph of magnitude vs time for silver conductive ink with aluminum plate

Table 3.3 Data of damping test for silver conductive ink with aluminum plate

	Time (ms)	N_1 (Hz)	N_2 (Hz)	N_3 (Hz)	N (Hz)
$T(x_0)$	46.1	34.4	24.9	23.8	27.7
$T(x_1)$	48.0	26.7	17.9	17.5	20.7
$T(x_2)$	50.4	20.1	10.8	9.85	13.6
$T(x_3)$	52.3	11.8	5.54	4.43	7.3
$T(x_4)$	54.7	11.4	5.69	5.96	7.7

Damping coefficient for the silver conductive ink after exclude the damping from aluminum plate is 0.00654 and the natural frequency is 2.9231 KHz.

4. SUMMARY

Damping is a system to measure the energy dissipation in a vibrating system that was crucial in a major role in assessing the serviceability limit states. In addition, damping test is important because damping is most difficult dynamic properties to predict at design stage or to be predicted from the physical properties which is different from the properties of mass and stiffness.

This study was examined the damping coefficient for graphene and silver conductive ink that used to determine the power output and power dissipate inside the system. This is because the power that enters the system is equal with energy that dissipates or absorbed by the damper with the time rate of change of the sum of kinetic and strain energies.

From the results obtained, damping coefficient of aluminium plate is 0.02879 and it was compared with graphene and silver conductive ink damping coefficient to get the true value of damping coefficient of this two conductive ink which damping coefficient for graphene conductive ink is 0.01585 and for silver conductive ink is 0.00654. If the samples were applied with vibration, the higher damping material will diminish the response and absorb the energy, then delays the motion so the time taken to complete one cycle increases slightly.

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