Experiment on Wave Energy Conversion Device

Signal Processing

Processing Wave Gauge Signals

1. Wave gauge data from LabView are converted to a workable signal matrix using MatLab.

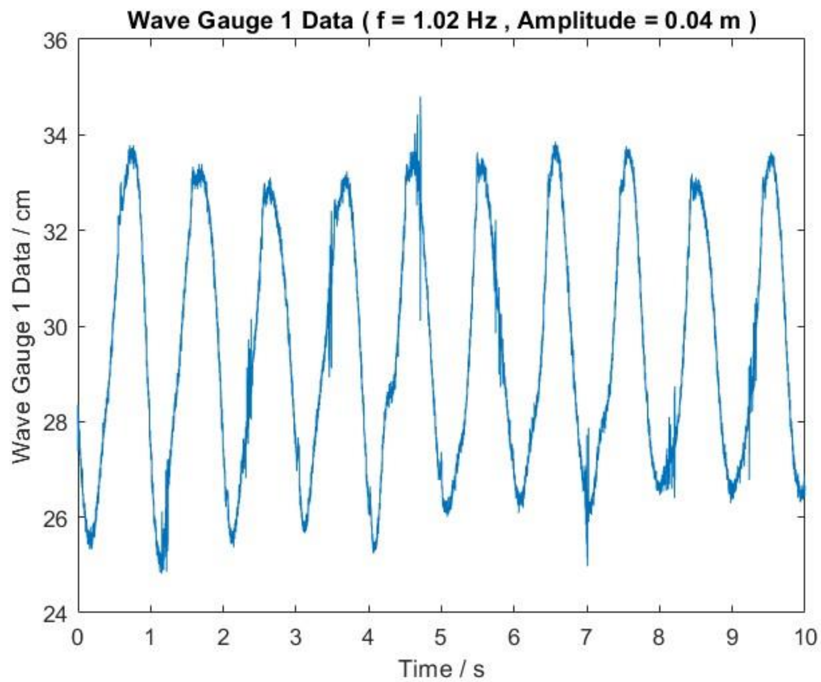

Figure 1 : Wave gauge data 1

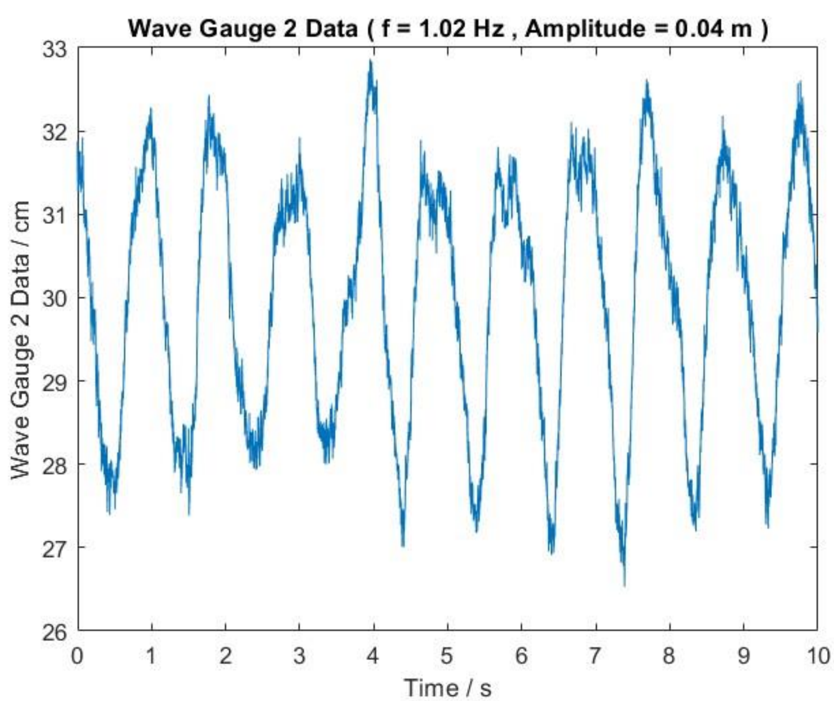

Figure 2 : Wave gauge data 2

2. The wave forms were smoothed using 'Curve Fitter' function in MatLab. Wave Forms also averaged to remove the DC offset of the data.

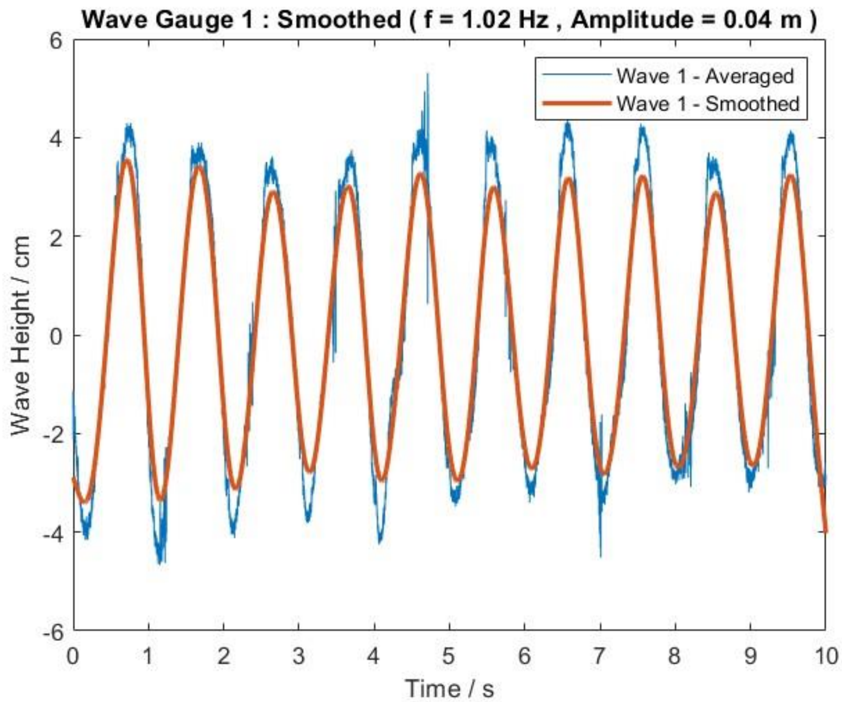

Figure 3 : Averaged and smoothed wave forms for wave gauge 1

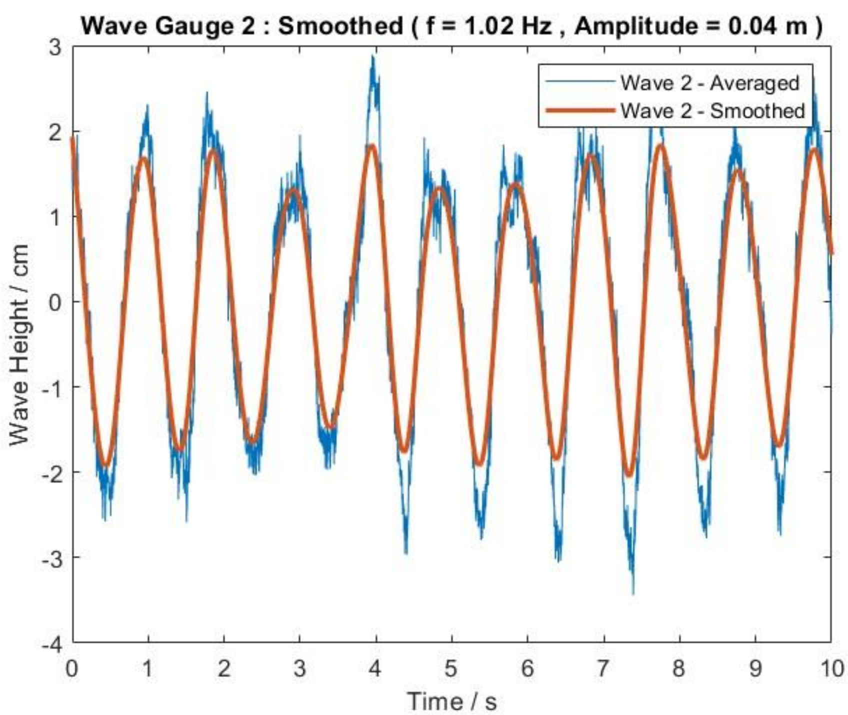

Figure 4 : Averaged and smoothed wave forms for wave gauge 2

3. A portion of the signal with complete cycles were selected for the Fourier analysis.

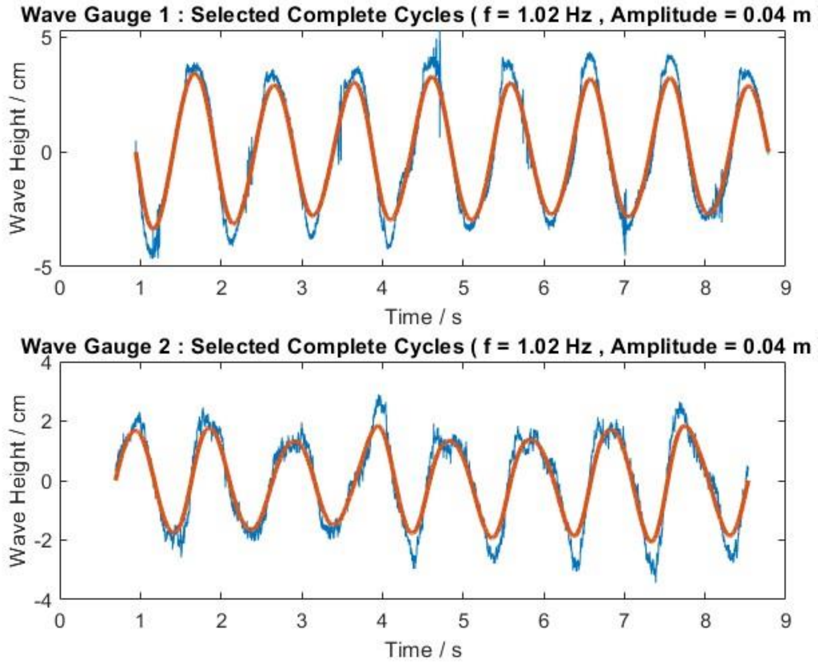

Figure 5 : Selected wave signals for Fourier analysis

4. Fourier analysis was performed and the noise was filtered. The component with the highest power in the 'Power Spectral Diagram (PSD)' was selected. Note that the 'X' value of the max power of the power spectral diagram is closer to the 'wave frequency preset' of the wave generator.

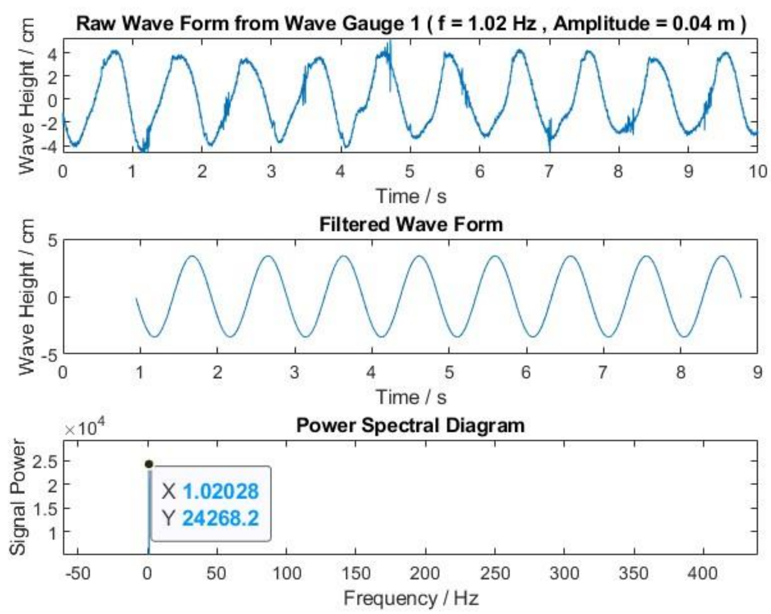

Figure 6 : FFT and noise filtration of wave gauge 1 data

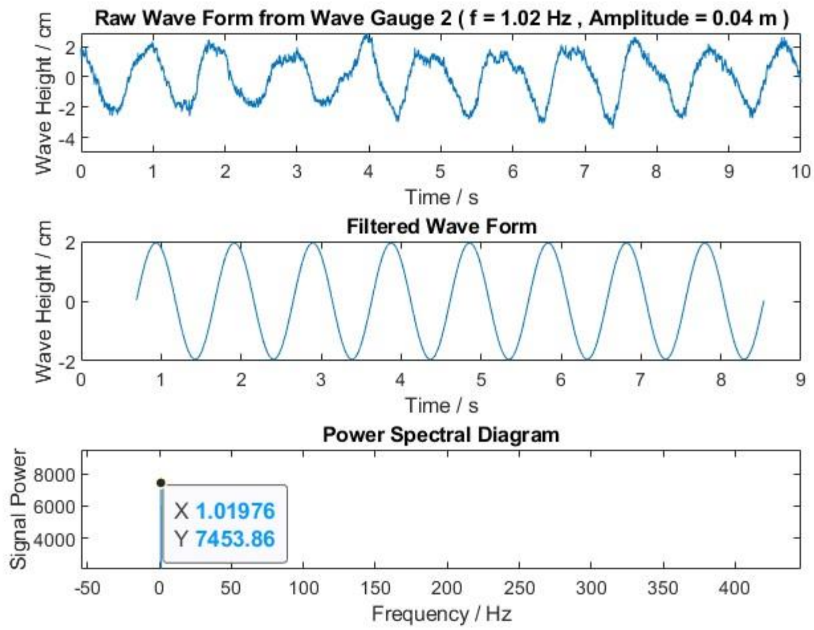

Figure 7 : FFT and noise filtration of wave gauge 2 data

Processing angle sensor data

1. A potentiometer was used as the angle sensor to measure the flap angle. Potentiometer data from LabView are converted to a workable signal matrix using matlab.

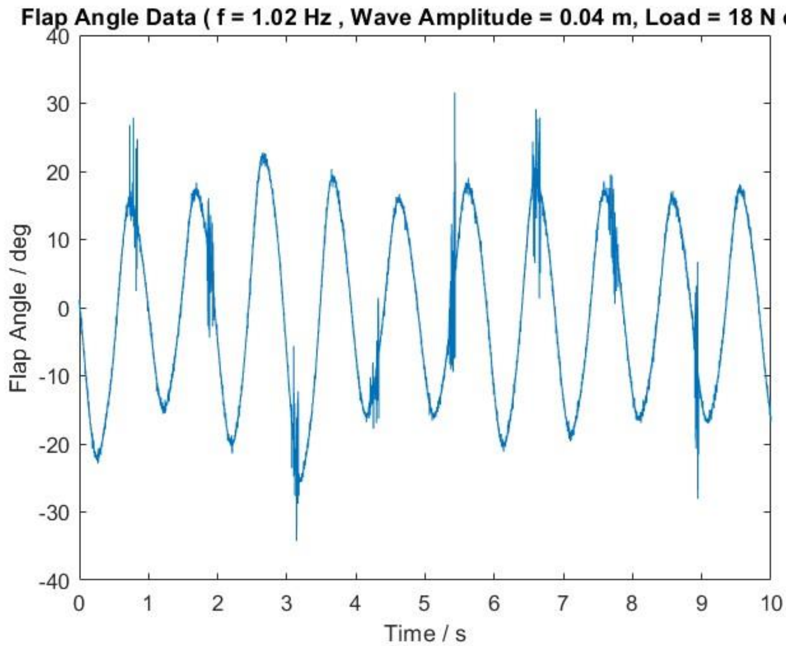

Figure 8 : Flap angle data

2. The wave forms were smoothed using 'Curve Fitter' function in MatLab. Wave Forms also averaged to remove the DC offset of the data.

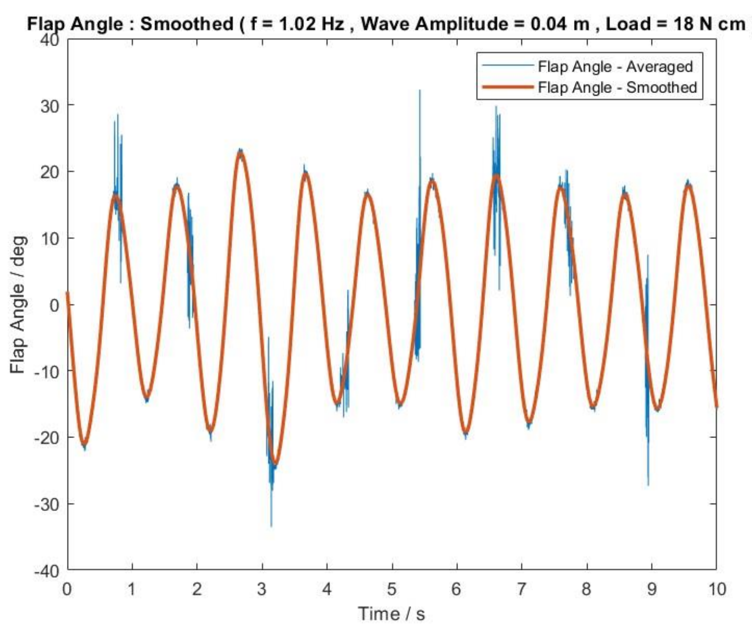

Figure 9 : Flap angle data

3. A portion of the signal with complete cycles were selected for the Fourier analysis.

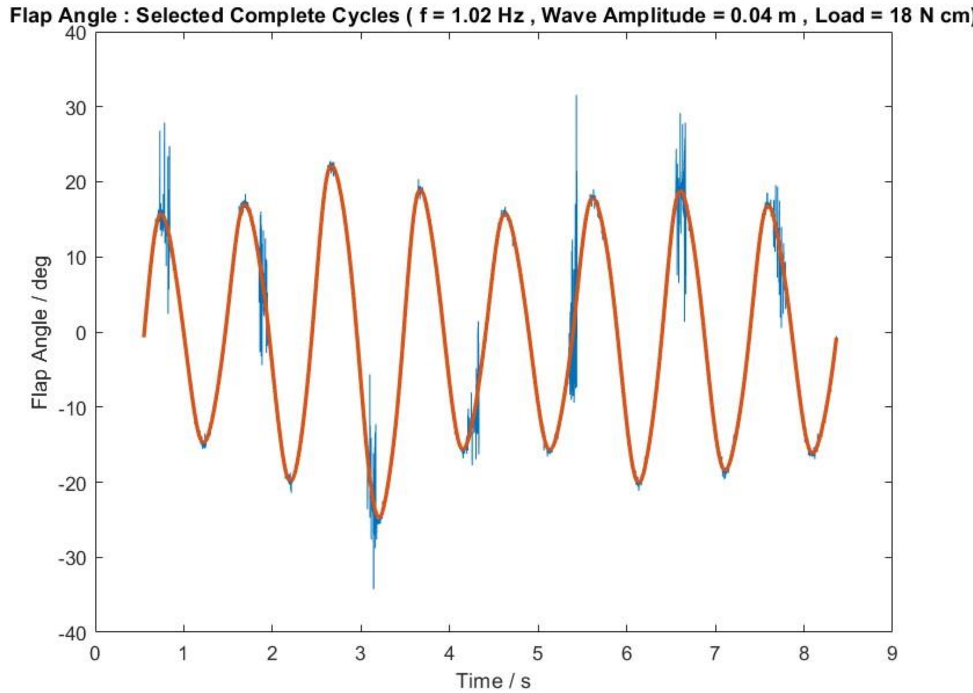

Figure 10 : Flap angle selected complete cycles

4. Fourier analysis was performed and the noise was filtered. The components with the 5 highest powers in the 'Power Spectral Diagram (PSD)' was selected. Since flap angle is not purely sinusoidal 1st 5 components of the PSD is selected to include all the important frequencies of the furrier analysis.

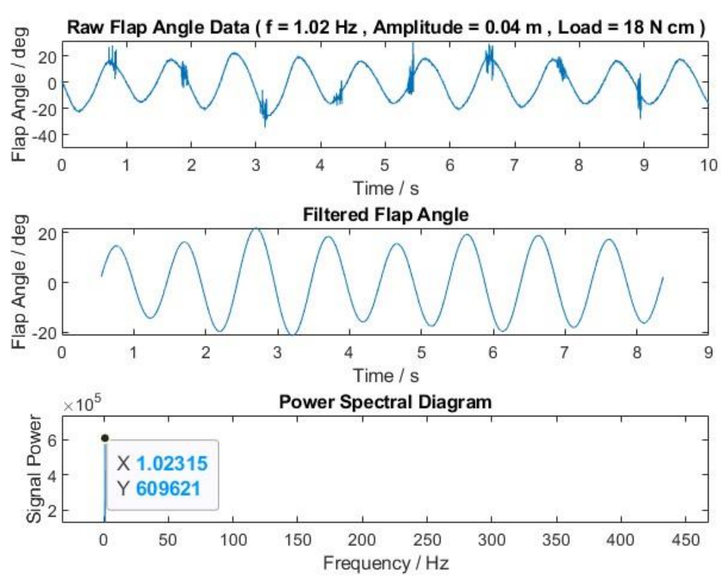

Figure 10 : FFT and noise filtration of flap angle

Processing Torque Sensor Signals

1. A strain gauge was used as the torque sensor to measure the torque acting on the flap. Torque sensor data from LabView are converted to a workable signal using matlab.

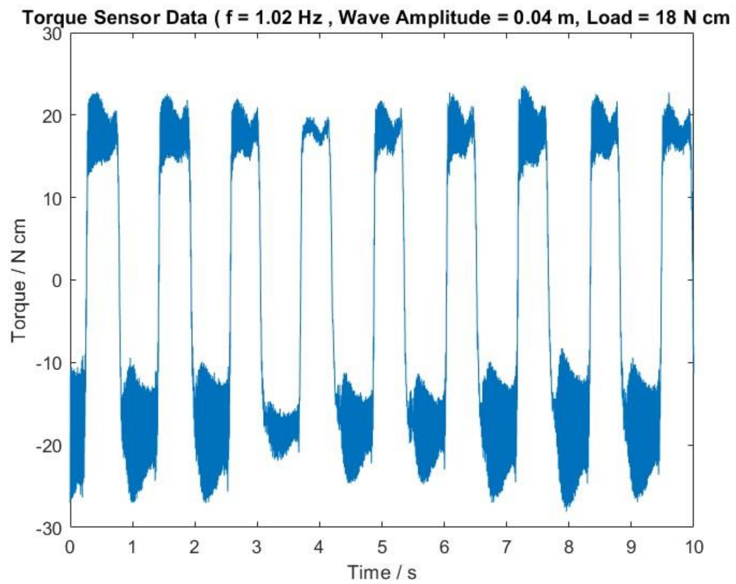

Figure 11 : Torque sensor data

2. The wave forms were smoothed using 'Curve Fitter' function in MatLab. Wave Forms also averaged to remove the DC offset of the data.

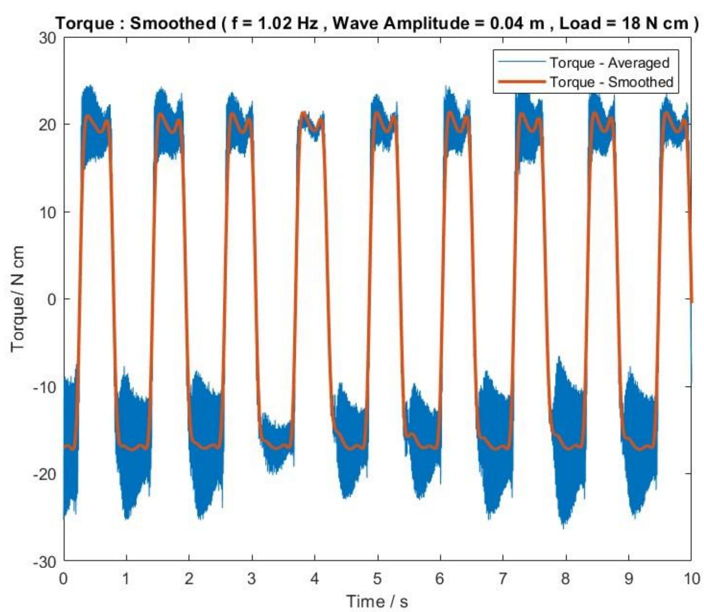

Figure 12 : Torque data smoothed

3. A portion of the signal with complete cycles were selected for the Fourier analysis.

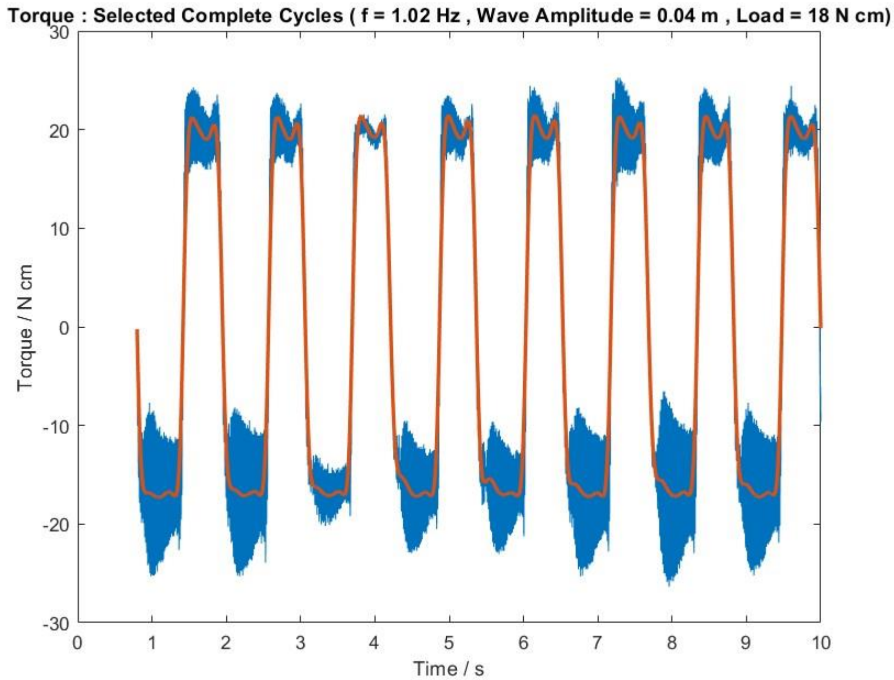

Figure 13 : Torque selected complete cycles

4. Fourier analysis was performed and the noise was filtered. The components with the 5 highest powers in the 'Power Spectral Diagram (PSD)' was selected. Since torque is not purely sinusoidal 1st 5 components of the PSD is selected to include all the important frequencies of the furrier analysis.

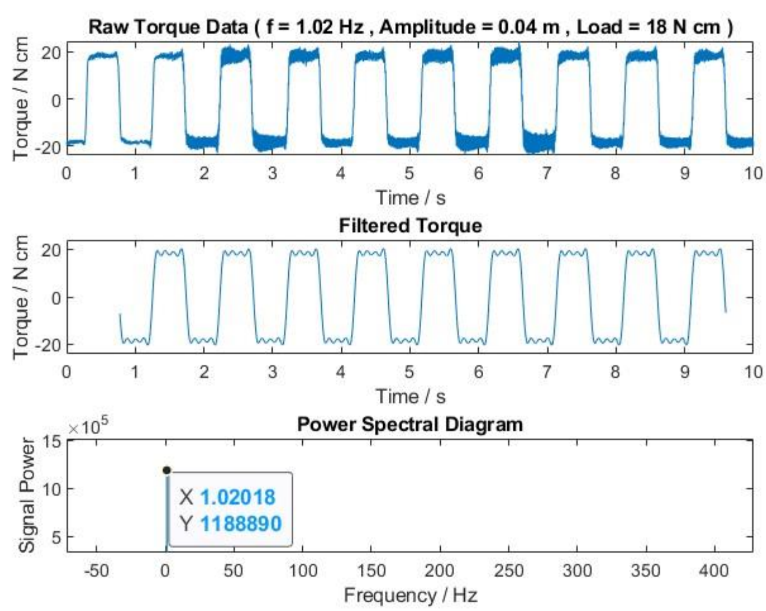

Figure 14 : FFT and noise filtration of torque sensor data

Calculations

Energy Harvested by the Device

1. Filtered angle signal was converted into radians and differentiated in terms of time and the velocity were calculated.

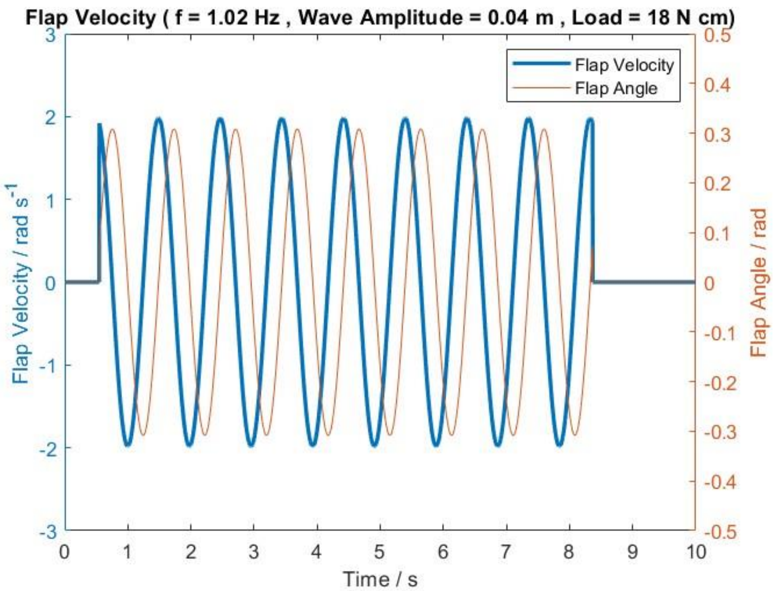

Figure 15 : Variation of flap velocity

2. Velocity was multiplied by torque and instantaneous power was calculated.

$$Power = Torque * Velocity$$

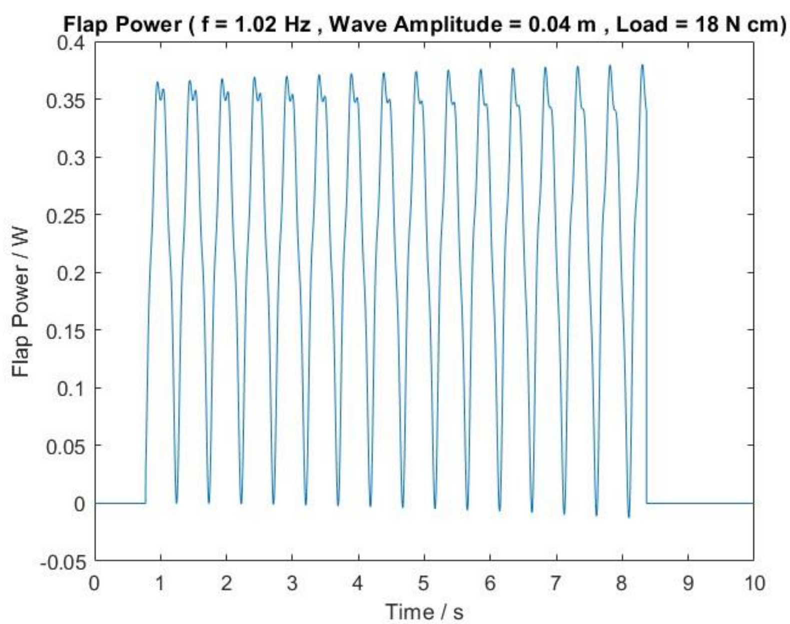

Figure 16 : Variation of flap power with time

3. The amount of energy harvested by the device was calculated by the integration of the power curve with time. To find the area under the power curve trapezium method was used.

$$Energy\ Harvested\ by\ the\ Device = \int Power.dt$$

Energy Supplied by the Wave

1. Using dispersion relationship the wave length (λ) was found. An iteration method was used to find 'λ'.

$$\lambda = \frac{gT^2}{2\pi}\tanh\left(\frac{2\pi d}{\lambda}\right)$$

Here,

$\lambda = \text{Wave Lenght}$
$g = Gravitational\ Acceleration$
$T = Wave\ Period$
$d = Water\ Depth$

2. Phase speed (c) was calculated using the following equation. Here, wave period (T) was calculated before.

$$c = \frac{\lambda}{T}$$

3. The wave type of the wave is determined by (d/ λ) ratio. If (d/ λ) ratio is between 0.05 and 0.5 the wave falls to intermediate wave type.

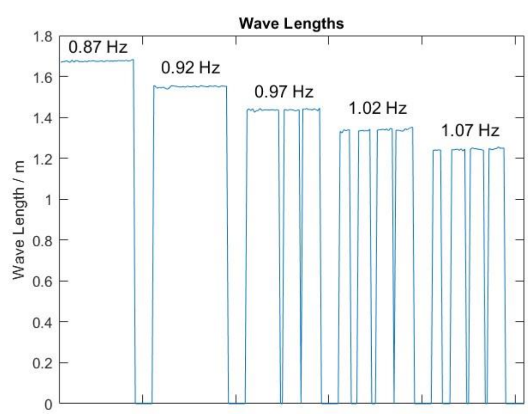

Figure 17 : Wave length for different frequencies

Here,

$d = 0.03\ m$
$\lambda(\max) \approx 1.7\ m$
$\lambda(\min) \approx 1.2\ m$

$(d/\lambda)(\min) = \frac{0.03\ m}{1.7\ m} = 0.017$

$(d/\lambda)(\max) = \frac{0.03\ m}{1.2\ m} = 0.025$

4. Assuming all the wave lengths falls under transitional waves, the wave power was calculated using the below equation.

$$Wave\ Power = Mean\ Energy\ Density * Group\ Velocity$$

$$P = \left[\frac{1}{8}\rho g H^2\right] * \left[\frac{1}{2}c(1+G)\right]$$

Here,

$$Group\ Velocity\ (c_g) = \left[\frac{1}{2}c(1+G)\right]$$

$$G = \frac{2kd}{\sinh(2kd)}$$

$$Wave\ Number\ (k) = \frac{2\pi}{\lambda}$$

$$Wave\ Height\ (H) = \frac{Wave\ Amplitude}{2}$$

5. The amount of energy supplied by the wave is calculated by the product of wave power and time duration. Here, the 'time duration' is the time duration which the flap provided a non-zero output power.

$$Energy\ Supplied\ by\ the\ Wave = Wave\ Power * Time\ Duration$$

Device Efficiency

1. Device Efficiency is calculated by the below equation.

$$Efficiency = \frac{Energy\ Harvested\ by\ the\ Device}{Energy\ Supplied\ by\ the\ Wave} * 100\%$$

Results

Wave Probe Results

1. Frequencies calculated by wave probe data vs Nominal frequency of the wave generator

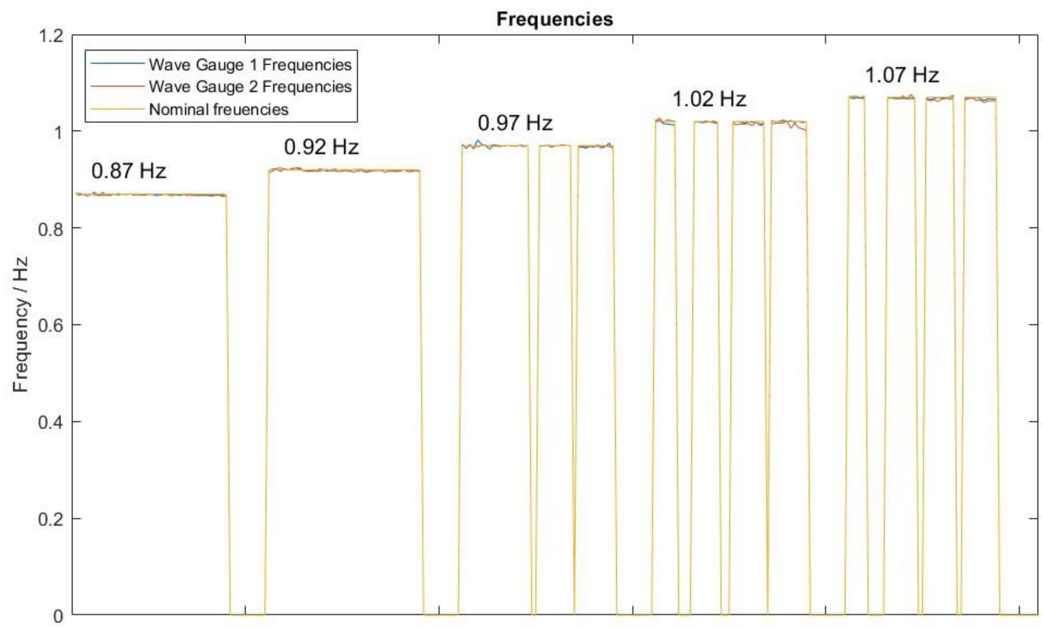

Figure 18 : Calculated frequencies vs Nominal Frequency

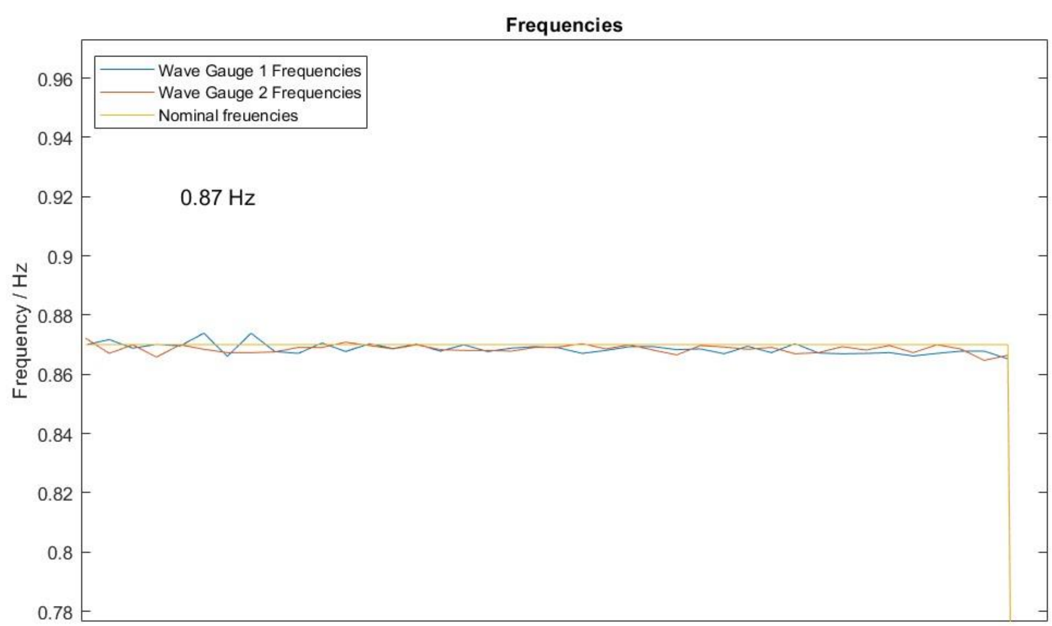

Figure 19 : Comparison of Calculated frequencies vs Nominal Frequency

2. Amplitudes calculated by wave probe data vs Nominal amplitudes

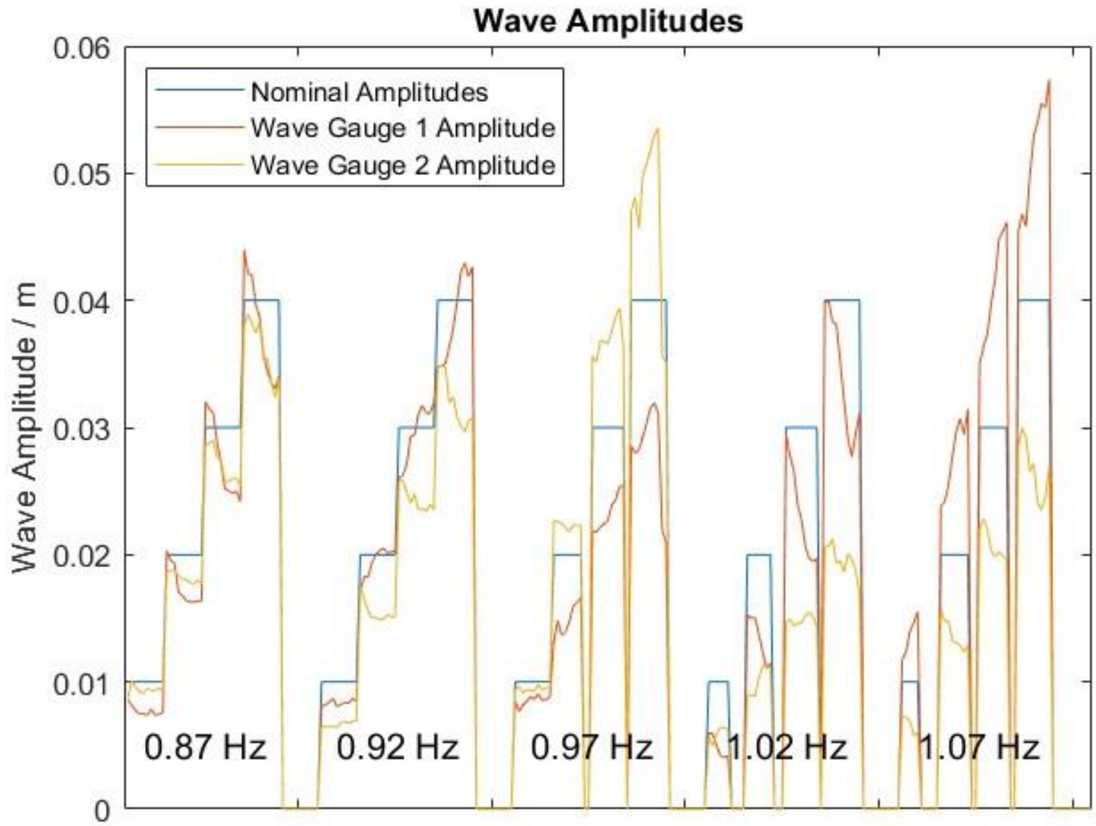

Figure 20 : Distribution of amplitudes

Since amplitudes calculated from wave gauge data are unreliable, the wave power was calculated using only the nominal amplitude from the wave generator.

Device Energy Results

1. Device energy distribution for different frequencies

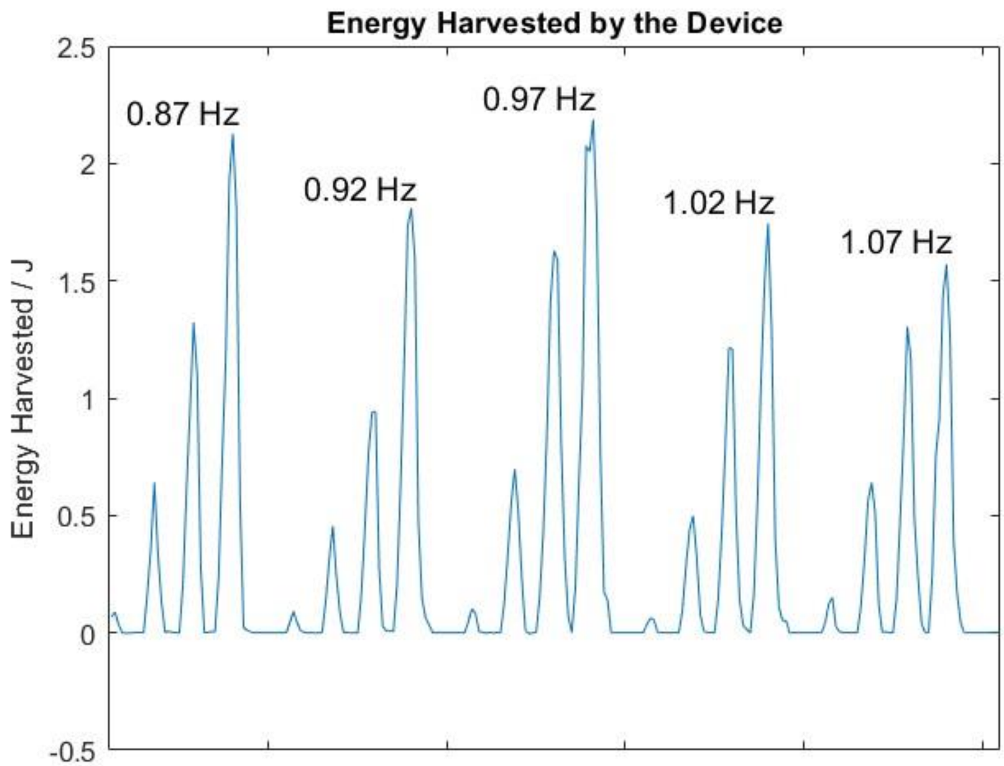

Figure 21 : Device Energy Distribution

2. Device energy variation with load. For frequency of 0.87 Hz

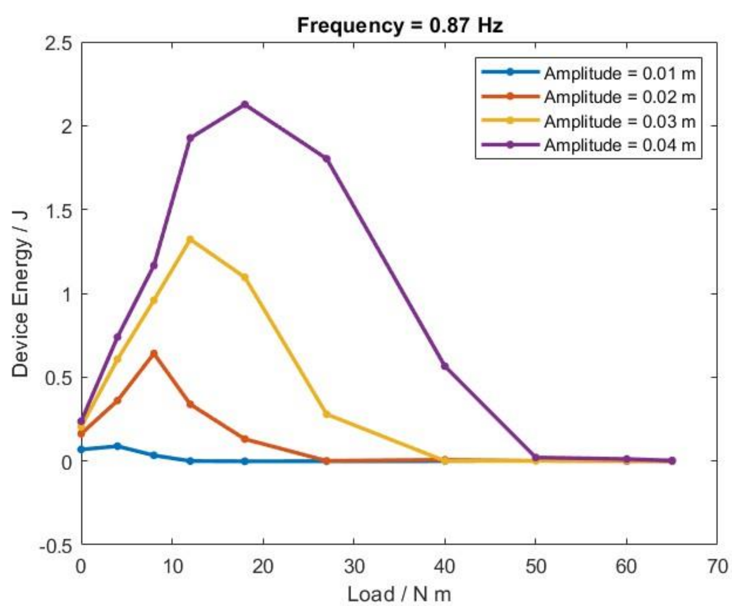

Figure 22 : Device energy variation for 0.87 Hz

3. Device energy variation with load. For frequency of 0.92 Hz

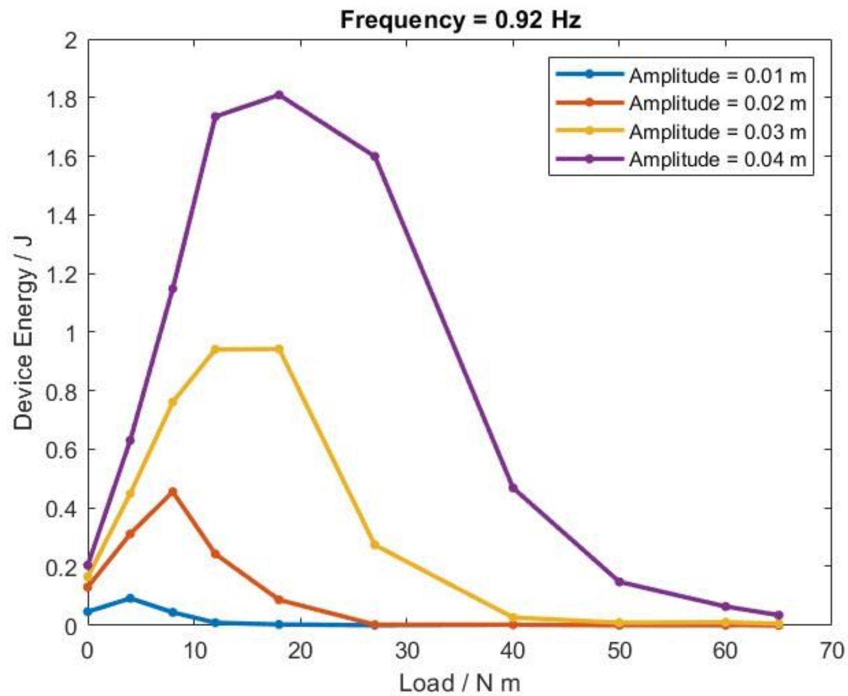

Figure 23 : Device energy variation for 0.92 Hz

4. Device energy variation with load. For frequency of 0.97 Hz

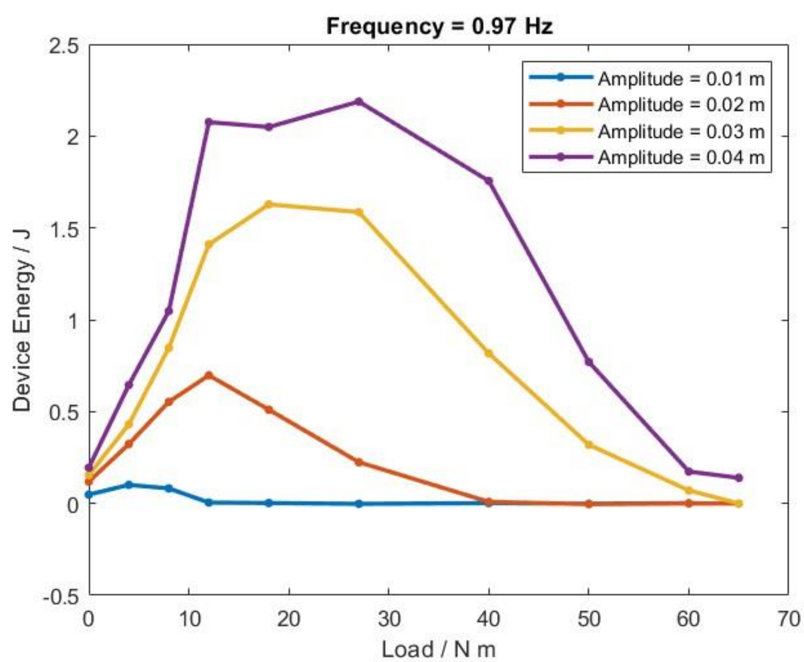

Figure 24 : Device energy variation for 0.97 Hz

5. Device energy variation with load. For frequency of 1.02 Hz

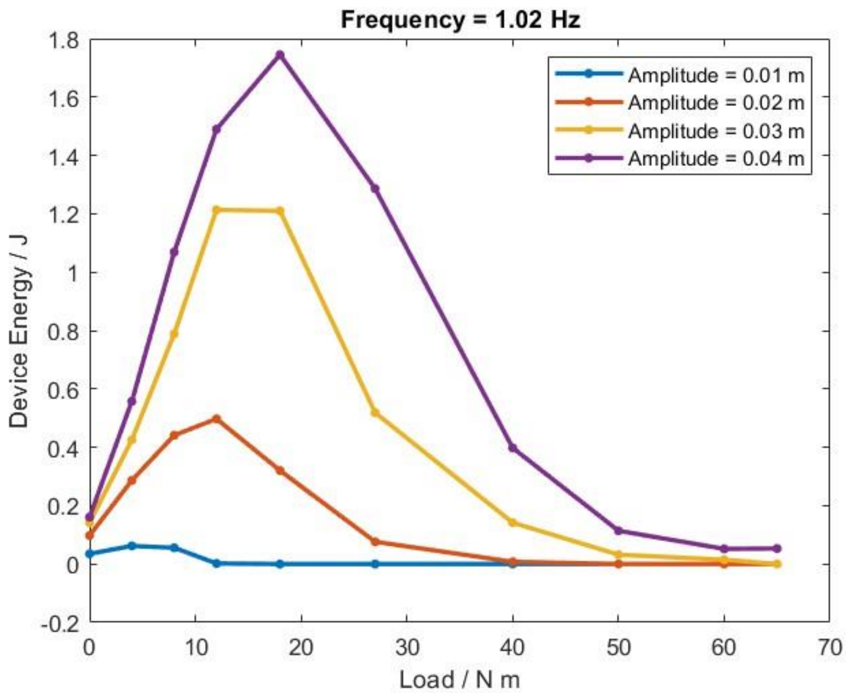

Figure 25 : Device energy variation for 1.02 Hz

6. Device energy variation with load. For frequency of 1.07 Hz

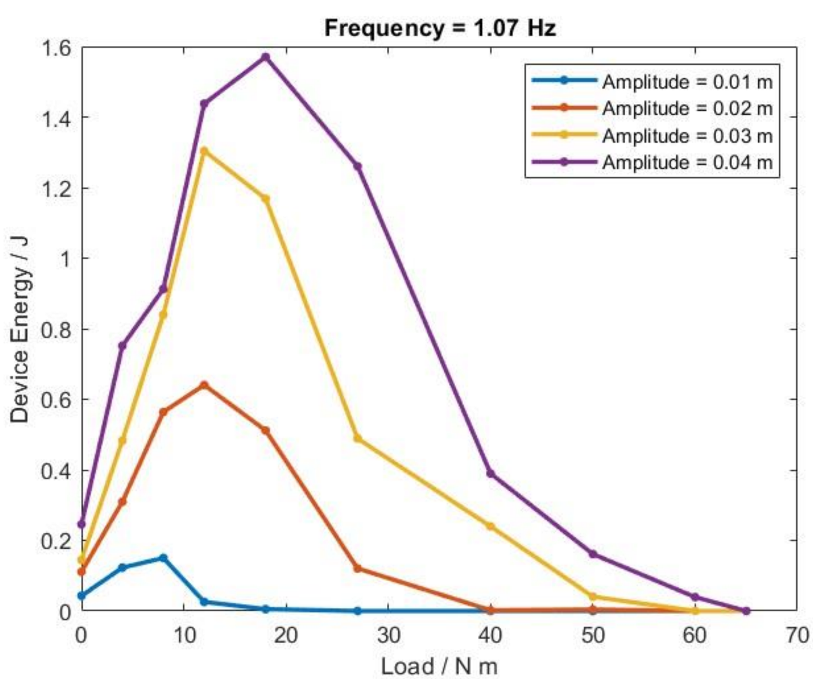

Figure 26 : Device energy variation for 1.07 Hz

Efficiency Results

1. Efficiency distribution for different frequencies

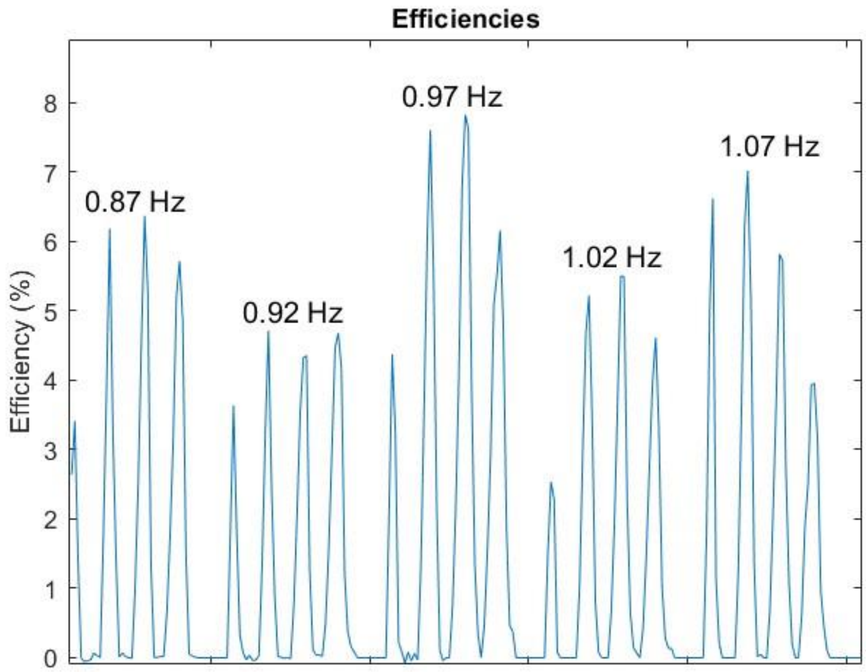

Figure 27 : Efficiency Distribution

2. Device energy variation with load. For frequency of 0.87 Hz

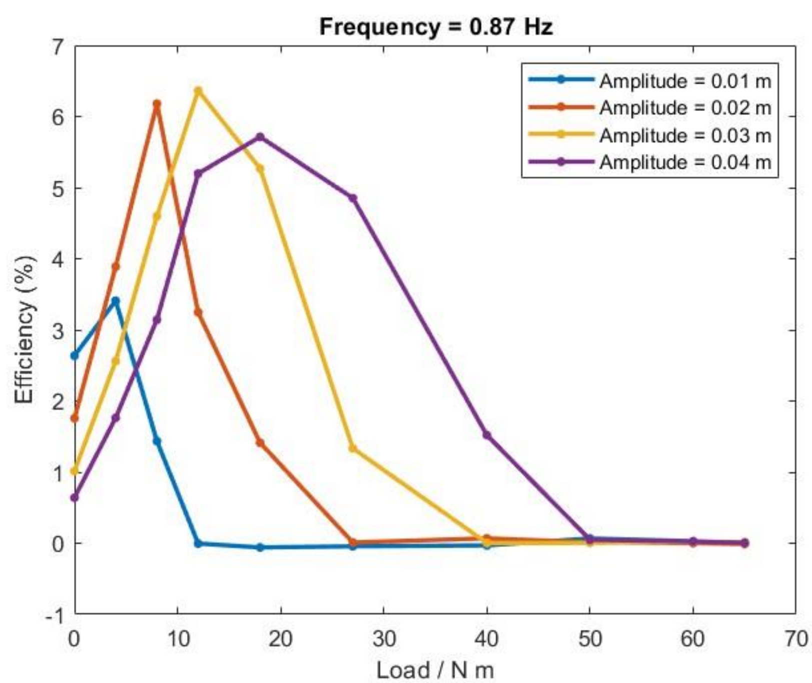

Figure 28 : Device energy variation for 1.07 Hz

3. Efficiency variation with load. For frequency of 0.92 Hz

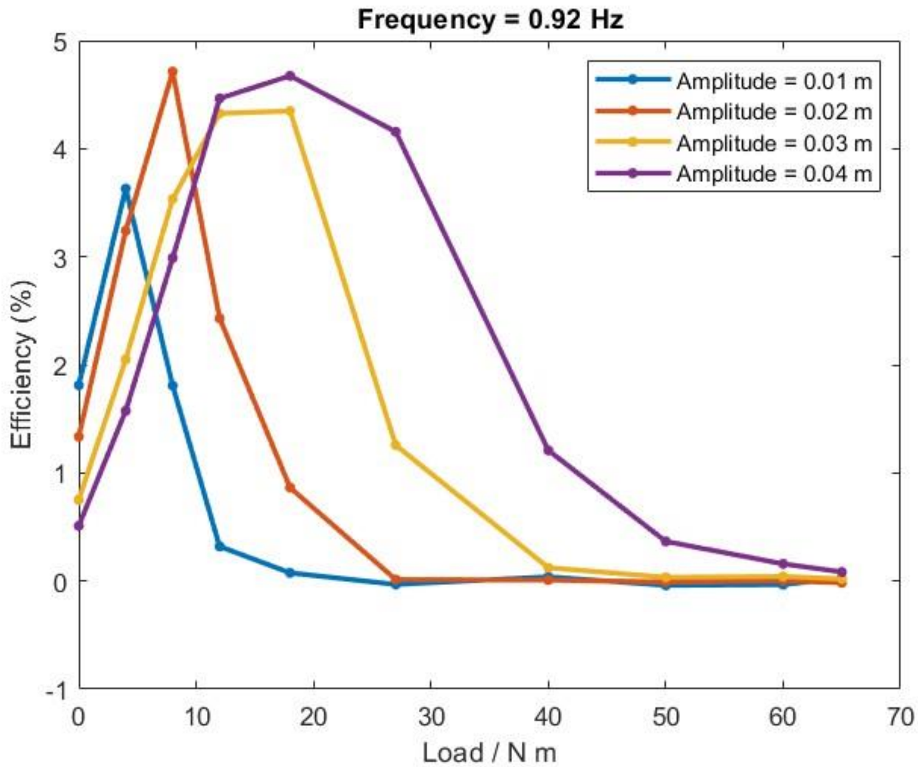

Figure 29 : Efficiency variation for 0.92 Hz

4. Efficiency variation with load. For frequency of 0.97 Hz

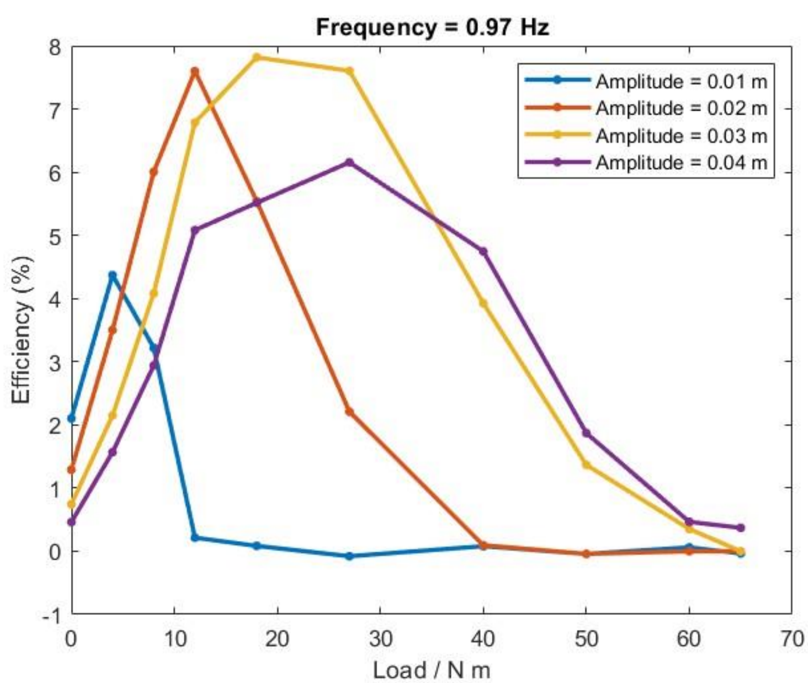

Figure 30 : Efficiency variation for 0.97 Hz

5. Efficiency variation with load. For frequency of 1.02 Hz

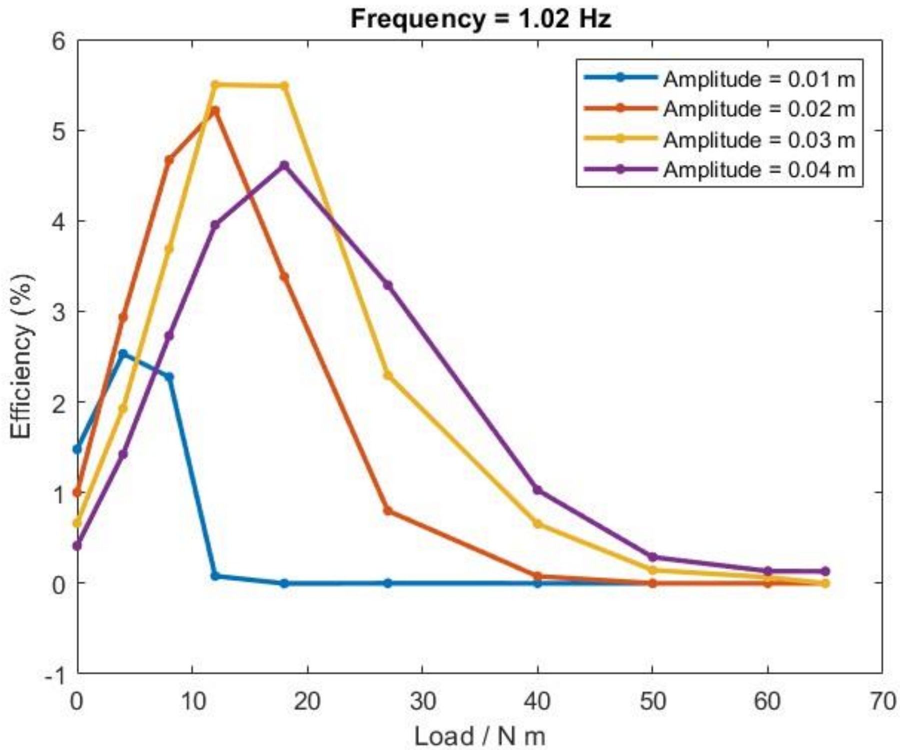

Figure 31 : Efficiency variation for 1.02 Hz

6. Efficiency variation with load. For frequency 1.07 Hz

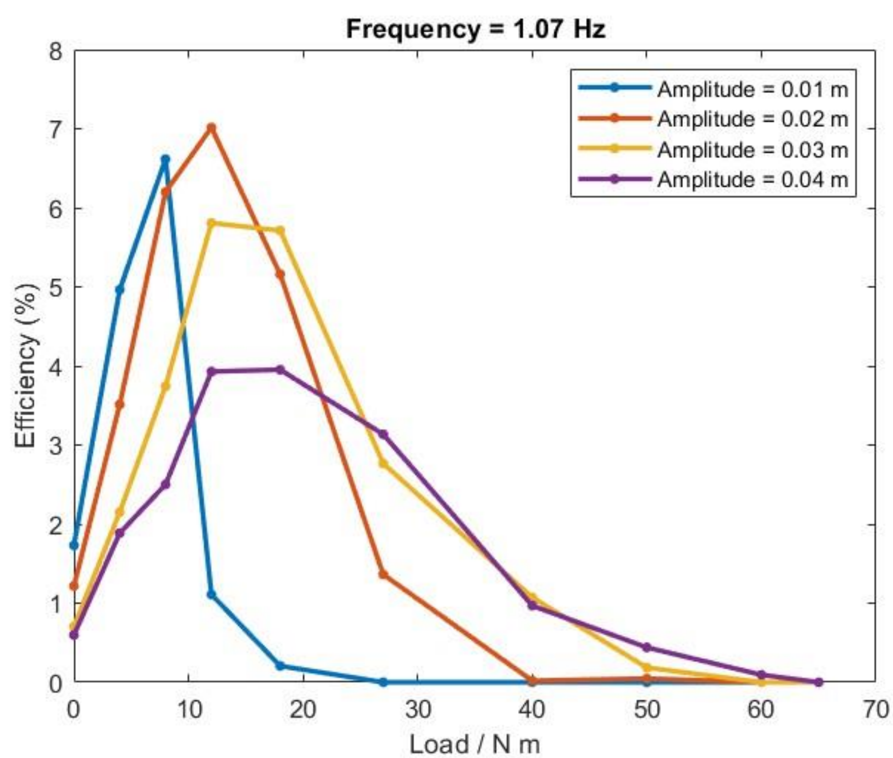

Figure 32 : Efficiency variation for 0.97 Hz