Optimum design of an Electromagnetic energy harvester from a vibration absorption system

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Abstract. This paper presents optimum design approach of an electromagnetic (EM) transducer in vibration absorber system during energy harvesting application. It is well known that when the natural frequency of absorber matches with excitation frequency, maximum amount of vibration energy transfer takes place. Here, an absorber system is represented by an equivalent single degree of freedom formulation. The amplitude reduction of primary system is the main concern along with maximum power output recovery from EM transducer. The effective objective function is formulated in terms of absorber parameters as well as the load resistance of EM circuit. Box complex optimization is implemented to obtain the optimal parameters. The optimum parameters obtained are employed and the output power harvested from the circuit is measured numerically. Results are presented for test case of the system subjected to base harmonic excitation.

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Second International Conference on Dynamics, Vibration and Control
NIT Durgapur (6-8th June 2018)

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Topics of Presentation

- Overview
- Objectives
- Brief back ground work
- Modeling and optimization formulation
- Results and discussion
- Conclusions
- References

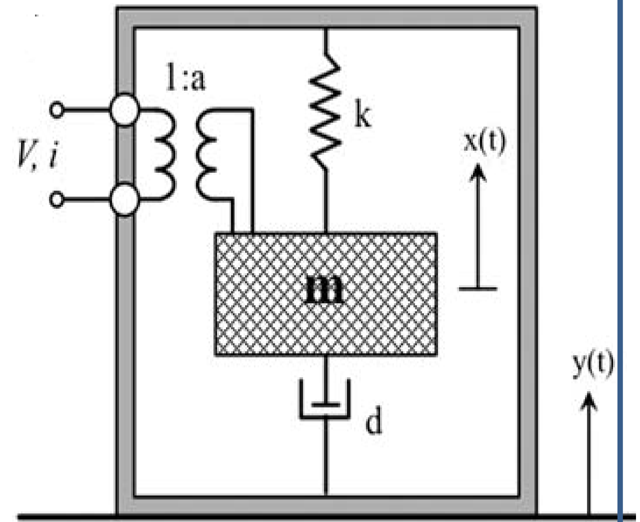
CoCo-80X vibration data collector

Overview

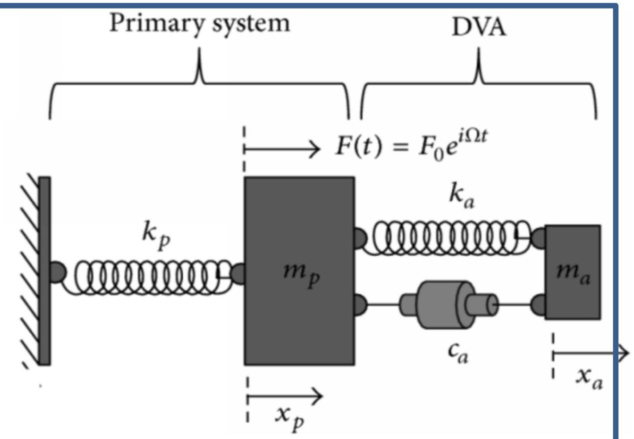
- There are several energy sources present in our environment, of which the most common ones include: vibration, thermal gradient, radiation and power (solar and EM fields).
- Mechanical vibrations are frequently employed among different sources of energy in harvesting process.
- For example, condition monitoring sensors are required to assess the vibration levels and simultaneously, they require some input voltage supplied through batteries.
- Design and fabrication of battery-less sensing modules performing tasks at a high duty cycles for long service times is now necessary.
- Energy harvesting transforms the ambient vibrational kinetic energy into useful electrical form.
- The most popular methods of energy conversion systems are: capacitive system, piezoelectric systems and electromagnetic system.
- Relatively EM system harvests higher energy levels (kW).

Inertial Vibration Harvesters

- Inertial vibration harvesters can be modeled as mass, spring and damper systems.
- Inertial harvesters are resonant devices that generate optimum power when the resonant frequency of the device matches the frequency of the vibration to be harvested.
- In addition to the forces associated with the mass, spring and damper, electromagnetic transducers have an additional Lorentz force due to the current induced in the coil, according to Faraday's law.
- The motion of a permanent magnet is used to induce a voltage across the terminals of a wire coil. This motion causes the magnetic flux through the coil which leads the induction of voltage. This voltage is used to energize an electrical circuit.



Dynamic Vibration Absorber



- A dynamic vibration absorber (tuned mass absorber) is a mechanical device designed for attaching to a primary dynamic structure in order to reduce its vibration or sound radiation.

•When properly tuned, the vibration energy can be transmitted efficiently from the primary structure to absorber system, reducing primary system's vibration amplitudes considerably.

•The classical absorber consists of a mass-spring system and its effectiveness is strongly limited to peak response.

•Den Hartog in early nineteenth century presented an approach for optimization in passive vibration absorbers.

•Adaptively tuned working frequency based absorbers on the other hand work by changing stiffness and mass parameters.

Energy harvesting from DVA System

- When energy harvesting circuit is attached to the absorber system, the motion of absorber mass is converted to some electrical form.
- The goal of minimizing the vibration amplitudes of primary system is achieved on one hand, while the electrical energy generation occurs on the other hand by transferring the absorbed displacements using a transduction circuit.
- To achieve proper output energy, the parameters of absorber system as well as electrical circuit are to be optimally designed.
- Several past researchers worked on this kind of study.

S.Faruque Ali and S.Adhikari, '**Energy Harvesting Dynamic Vibration Absorbers', J.Applied Mechanics, Tran.ASME, vol.80, pp.** 041004-1-9, 2013.

Brief past study

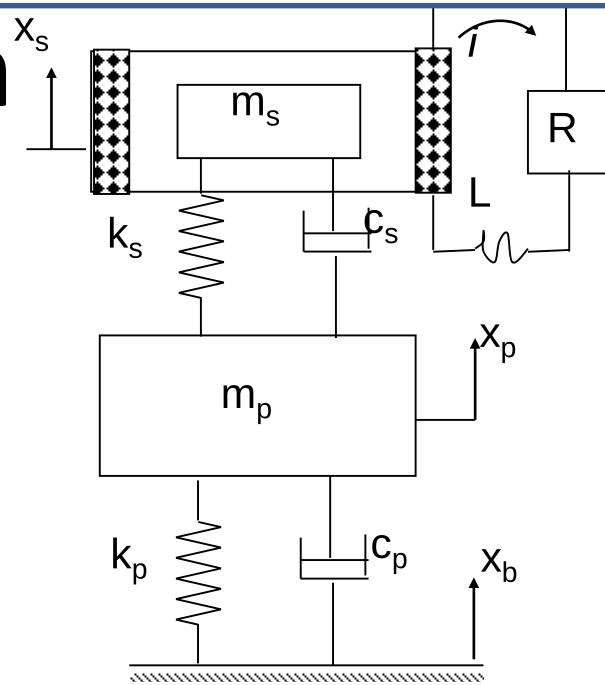
Authors	Year	Summary
Zhang et al.	2016	Employed EM energy harvester for renewable energy application in rail roads.
He and Daqaq	2015	Proposed simplified energy harvesting system model equations under white noise excitation
Jian and Chen	2016	Developed a generalized approach for piezoelectric and EM harvesting system with stochastic averaging approach.
Ali et al.	2013	Given concept of energy harvesting from vibration absorber via piezoelectric transduction
Madhav and Ali	2016	Proposed energy harvesting with piezoelectric circuit under random base excitation
Lee and Lin	2017	Introduced energy harvesting system with vibration absorber attached to a platform structure.
Kecik	2018	Developed an energy harvesting system from magnetic levitation environment.

Absorber system with EM circuit for energy harvesting was rarely utilized.

Objectives

- Present work, employs electromagnetic circuit in the energy harvesting system from a dynamic vibration absorber.
- Initially, the coupled structural and magnetic equations of motion are formulated and analyzed for harmonic base excitations.
- The optimum parameters of harvester and the absorber are predicted so as to achieve largest amount of energy from the harvesting circuit without loss of absorption ability.

Mathematical Formulation



- The coupled dynamic system is expressed by three ordinary differential equations as:

$$m_p \ddot{x}_p + k_p(x_p - x_b) + c_p(\dot{x}_p - \dot{x}_b) + k_s(x_p - x_s) + c_s(\dot{x}_p - \dot{x}_s) = 0$$

$$m_s \ddot{x}_s + k_s(x_s - x_p) + c_s(\dot{x}_s - \dot{x}_p) + \chi i = 0$$

$$L\dot{i} + Ri = \chi \dot{x}_s$$

Amplitude ratios in frequency domain

- By eliminating secondary mass displacement $X_s(s)$, the amplitude ratios are given as

$$\frac{X_p(j\omega)}{X_b(j\omega)} = \frac{b_2 j\omega}{m_p(a_1 b_2 - b_1 a_2)}$$

$$\frac{I(j\omega)}{X_b(j\omega)} = \frac{a_2 j\omega}{m_p(a_1 b_2 - a_2 b_1)}$$

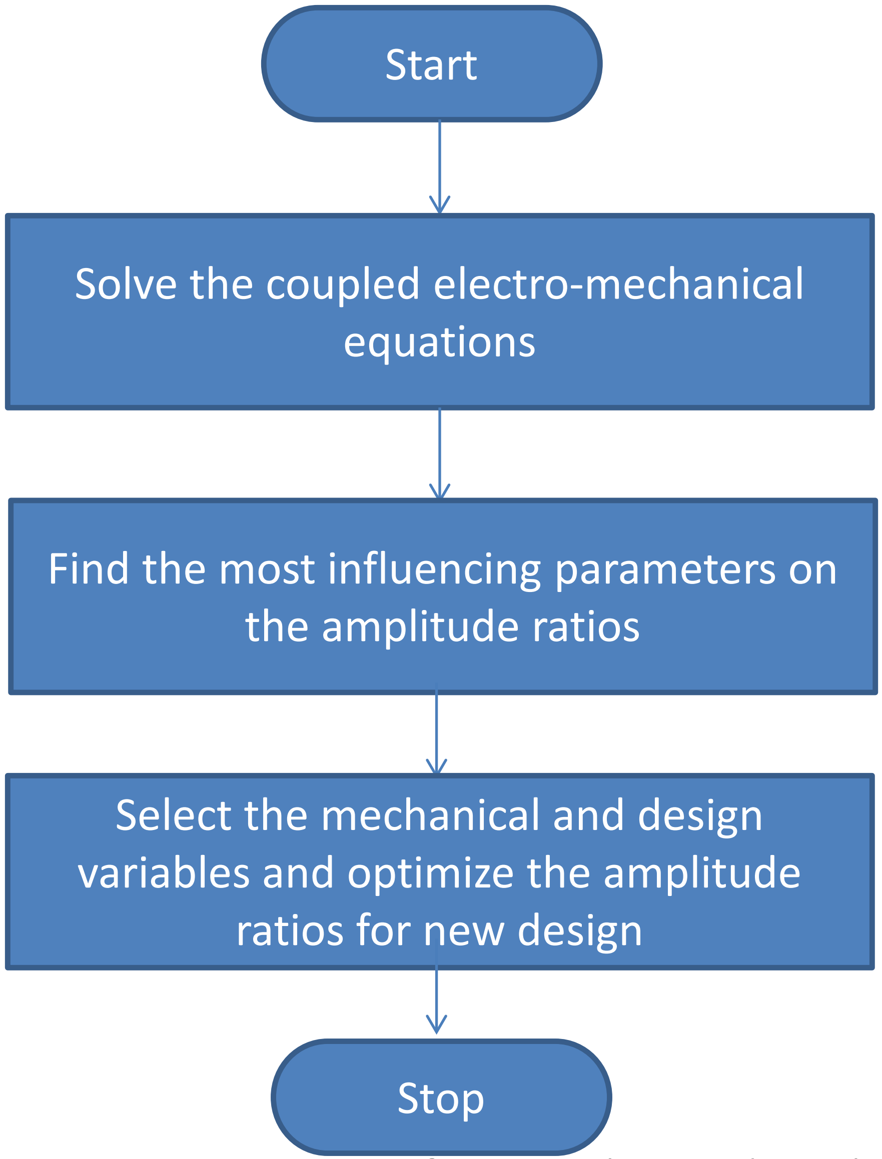
$$a_1 = -\omega^2 + \omega_p{}^2 + 2\xi\omega_p j\omega + \omega_s{}^2\mu + 2\xi_s\omega_s\mu$$

$$b_1 = (\omega_p{}^2 + \omega_s{}^2\mu + 2\xi_s\omega_s\mu\frac{L}{R}\left(\frac{j\omega+\theta}{j\omega}\right)$$

$$a_2 = \omega_s{}^2 + 2\xi_s\omega_s j\omega$$

$$b_2 = (-\omega^2 + \omega_s{}^2 + 2\xi_s\omega_s)\frac{L}{R}\left(\frac{j\omega+\theta}{j\omega}\right) + \frac{\chi}{m_p\mu}$$

Methodology

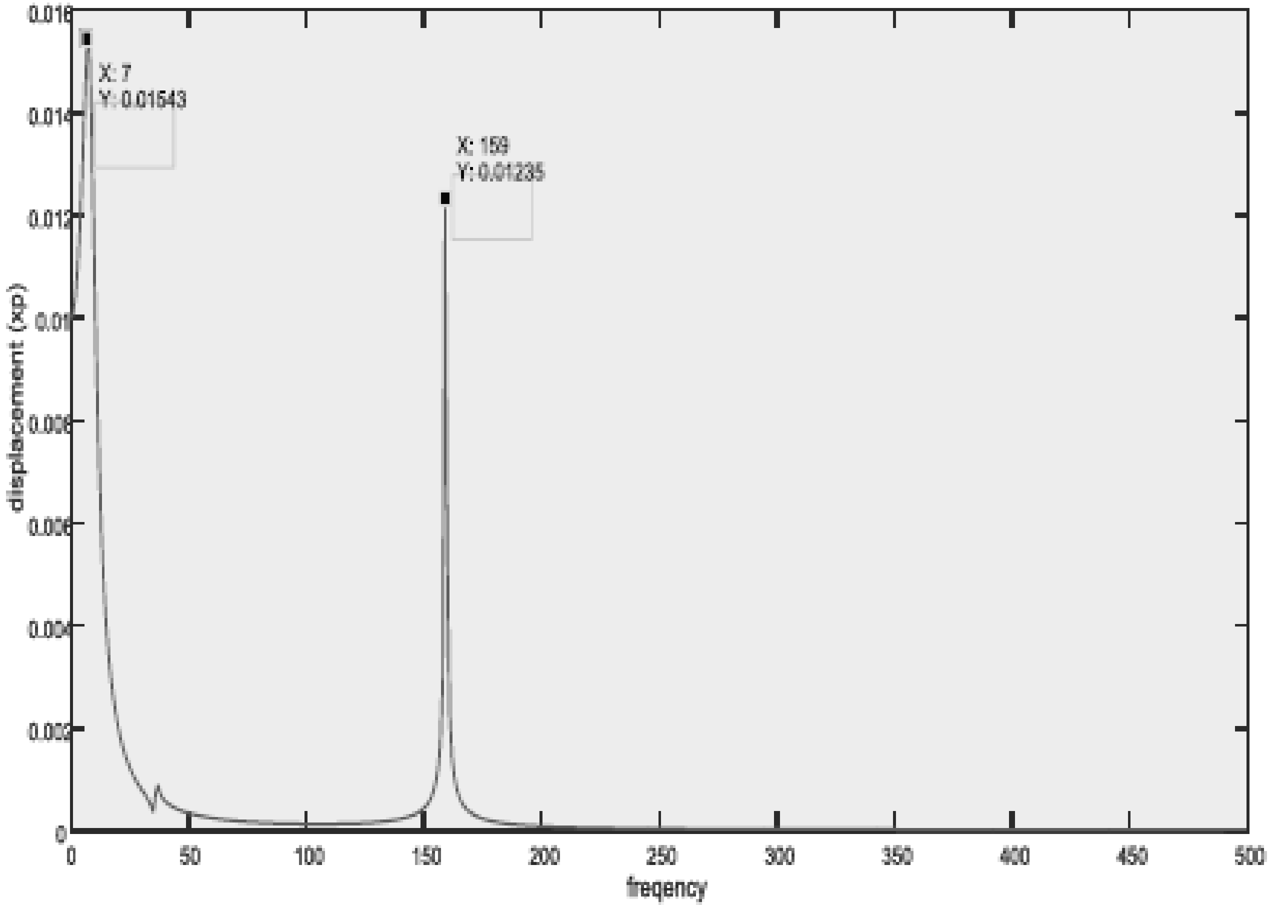


Results and input data

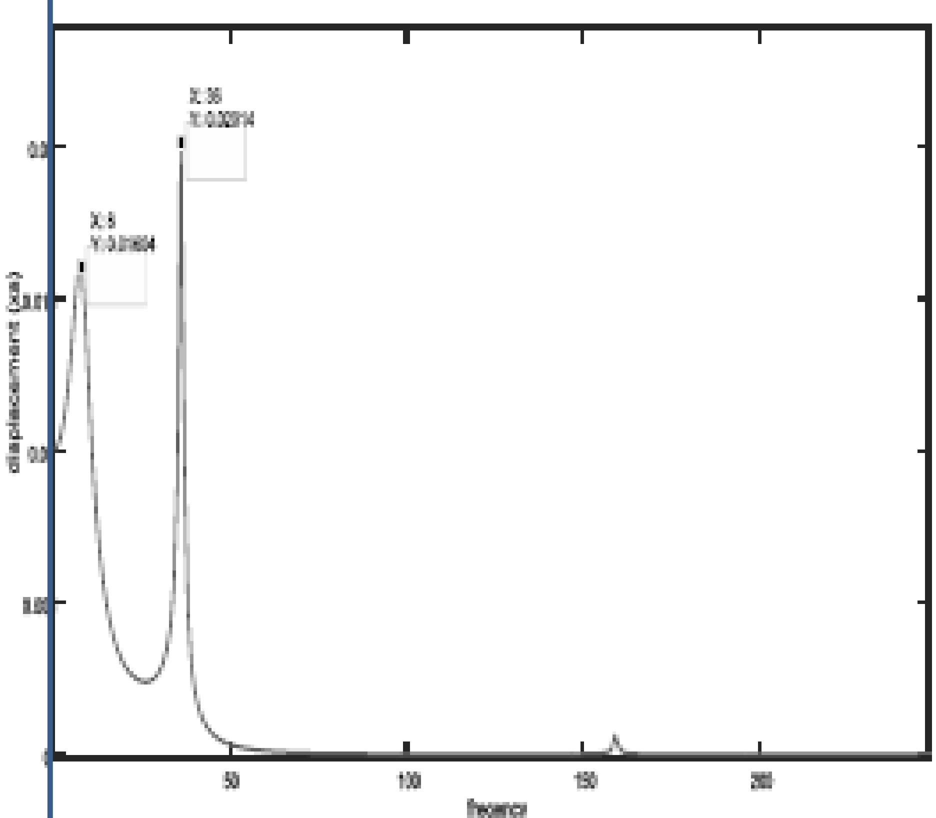
Parameter	Symbol	Value
Primary mass	m_p	527.9 kg
Primary damping	c_p	395 N s/m
Primary stiffness	k_p	623.5 N/m
Absorber mass	m_s	17.6 kg
Absorber damping	c_s	0.054 N s/m
Absorber stiffness	k_a	350 N/m
Total resistance	R	500 ohms
Inductance	L	1.46 Henries

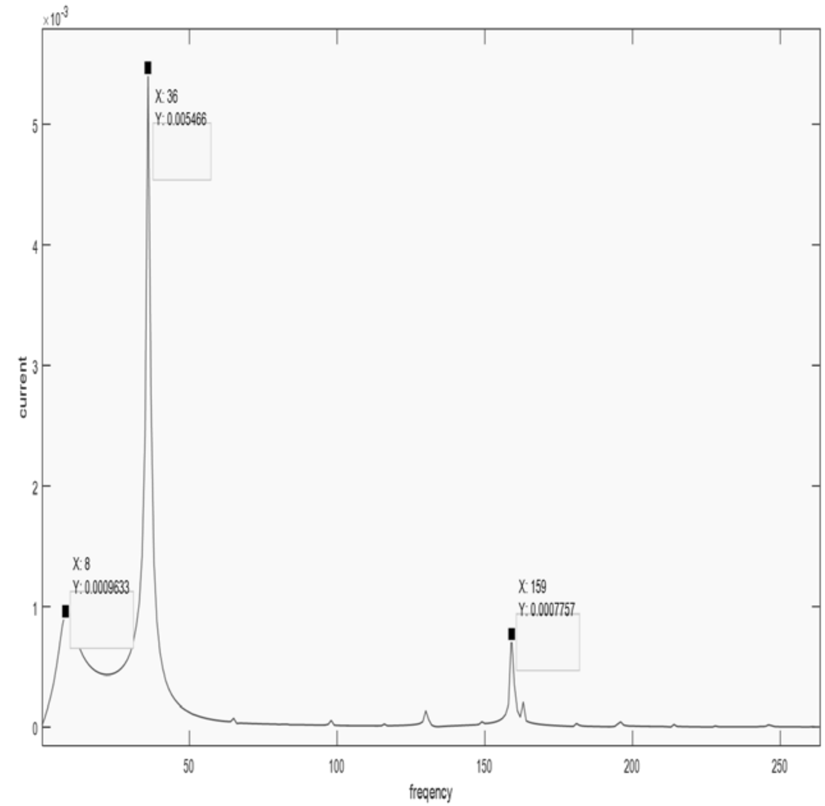
Matlab program is developed to solve the coupled differential equations in time domain with all zero initial conditions.

Frequency response of primary mass



Secondary mass and current spectra





Experimental set-up

- An experimental work is conducted to know the output coming from the circuit.
- A 12V, 300 mA DC motor is used as a generator of electricity.
- As shown in Fig. 4.8, it is connected to a horizontal rotor via a jaw coupler and the rotor is made to revolve. A multimeter is used to measure the output current at different speeds of operation..

Optimization methodology

- Maximize $f_i(X)$

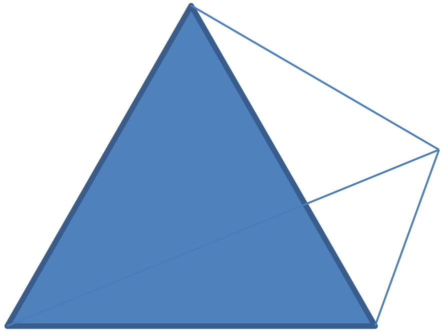
  Subject to $g_j(X) \leq 0$

  where X is a solution vector with d decision variables.

  When a feasible solution is not dominated by any other solution in the solution space, it is said to be non-dominated solution. A set of all non-dominated feasible solutions are called Pareto-optimal set. The corresponding objective function values are called Pareto font.

Box-Complex Optimization Method

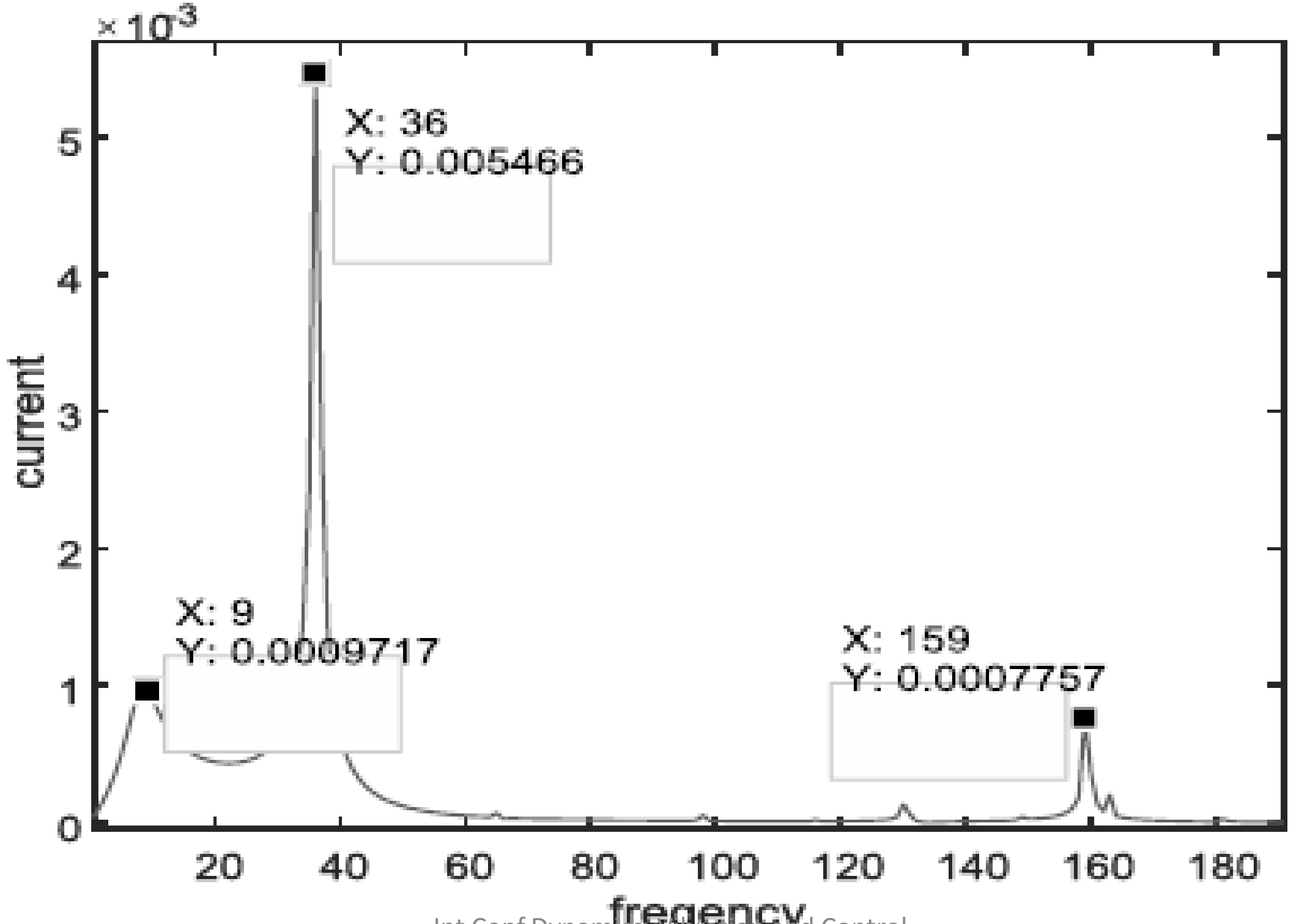
- Box (1965) complex method is based on regular geometric complex of n+1 (if n>2) vertices.
- Each vertex is evaluated for its objective function value and the worst of them is projected through the centroid of the remaining vertices.



Optimization Analysis

- The constant parameters considered are m_p=527.9 kg, c_p=395 N-s/m, k_p=623.5 N/m, L=1.46 H,
- By simultaneous maximization of circuit current *i* and minimization of x_p, using Box-optimization scheme,
- the following set of design parameters were obtained: $m_s = 29.081$ kg,
- $c_s = 4.5981$ N-s/m,
- k_s= 614.858 N/m,
- R = 2829 ohms.
- Here, it is assumed that the coupling parameter χ is constant (=30) even the magnetic flux changes continuously.

Solution of equations with optimum design



Conclusions

- Design and analysis of electromagnetic energy harvester from a base excited model was presented.
- A dual objective two degree of freedom vibration absorber with energy harvesting capability was designed and simulated for harvesting electrical power.
- The tuned vibration absorber was successfully reducing the primary vibrations and at the same time produce an electrical output.
- The current generated was lower without absorber as only a fractional percentage of displacement was transferred to generate the current.
- The constrained multi-objective solution given more interesting results of power harvested in the system.
- An experimental work is necessary to validate the outcomes.

Some References

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