VIBRATION SUPPRESSION OF FLEXIBLE BEAM USING ELECTROMAGNETIC SHUNT DAMPER

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ABSTRACT

In this thesis, the electromagnetic shunt damper was newly developed to passively suppress the vibration of the flexible cantilever beams. The electromagnetic shunt damper, which is electro-mechanically coupled with the flexible structures, simply consists of a coil, a permanent magnet, and an R-L-C circuit. The ends of the conductive coil are connected to the R-L-C series shunt circuit and the battery as well. The aim of electronic magnetic shunt damper is to achieve the damping effect. This effect is affected by the position of the conductor and magnet. The data was record by using the DAQ cable and Accelerometer. The position of the magnet which is at the bottom of the coil does not able to induce the damping effect. Since then it has been replaced by spherical conductor by placed inside the coil. Present results show that the electro-magnetic shunt damper can be successfully applied to reduce the vibration of the flexible structures. The vibration and damping characteristics of the flexible beams with the electromagnetic shunt damper were investigated by tuning the circuit parameters. The change in value of resistor, voltage, and capacitor were investigated towards the effect of damping characteristic. There are four different of resistor, three different of voltage, and three different of capacitors were employed to study this effect. The vibration of the flexible beam was reduced most with R= 1.5 Ohm, V= 9V, C = 2000 μF. With this tuning, the vibration of the flexible beam was reducing up to 91.6%. The data will be more significant if the disturbance employed on the aluminium plate in harmonic motions. This can achieve by using Mechanical Shaker machine. The magnet can use to induce the eddy current if the position magnet is placed inside the coil.

ABSTRAK

Dalam thesis ini, Pemirau Ayunan Elektromagnetik adalah kaedah terbaru untuk mengurangkan getaran batang julur fleksibel. Pemirau ayunan elektromagnetik diikat bersama batang julur fleksibel, yang terdiri dari lingkaran dawai, magnet kekal, dan litar R-L-C. Penghujung lingkaran dawai disambung kepada litar R-L-C dan juga bateri secara bersiri. Objektif pemirau ayunan elektromagnetik adalah untuk mewujudkan kesan ayunan pada batang julur fleksibel. Kesan ini dipengaruhi oleh kedudukan konduktor dan magnet. Maklumat telah dicatat dengang menggunakan kabel DAQ dan Accelerometer. Kedudukan magnet di hujung lingkaran dawai tidak mampu untuk mewujudkan kesan ayunan pada batang julur fleksibel. Oleh sebab itu, ia diganti dengan konduktor berbentuk silinder dan diletakkan di dalam lingkaran dawai. Hasil eksperimen menunjukkan susunan konduktor ini mampu untuk mengurangkan getaran pada batang julur fleksibel. Getaran dan sifat ayunan dikaji dengan menukar parameter litar RLC. Perubahan nilai rintangan, voltan, dan kapasitor dikaji kesannya terhadap sifat ayunan. Sebanyak empat jenis perlainan rintangan, tiga jenis berlainan voltan, dan tiga jenis berlainan kapasitor diuji untuk menguji kesannya terhadap sifat ayunan. Getaran paling berkurang apabila litar disambung dengan R= 1.5 Ohm, V= 9V, C = 2000 µF. Dengan tiunan ini, getaran batang julur fleksibel dikurangkan sehingga 91.6%. Data yang diperoleh akan lebih tepat jika getaran pada plat aluminium di hasilkan oleh getaran yang mempunyai ayunan yang harmoni. Ia boleh dicapai dengan menggunakan mesin penggegar mekanikal untuk menggantikan motor DC. Magnet berupaya untuk menghasilkan arus eddy jika posisi magnet tersebut diletak di dalam lingkaran dawai.

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CHAPTER I

INTRODUCTION

1.1 BACKGROUND

Vibrations accompany us everywhere and in most cases these vibrations greatly affects the nature of engineering design. The vibration properties of engineering devices are often limiting factors in their performance. Vibration can be harmful and should be avoided, or it can be extremely useful and desired (Tripathi, 2006). In order to solve this problem, so many complex systems including new sensors and actuators, various control strategies, and smart materials have been proposed until now. Recently, the smart materials including piezoelectric materials, shape memory alloy, ER and MR have been widely employed as actuators and sensors in the vibration control systems. However, those transducers additionally need power amplifiers, heaters, and signal processing units, resulting in the high cost. Also, the visco elastic materials can be passively used to reduce the vibration level of the operating systems, but it cannot work well in the unexpected environments like high or low temperature (Cheng, 2009).

The electromagnets have been widely used in the industrial fields of power generator, electric fan, loud speaker and propulsion train. Fung developed an electromagnetic actuator for the vibration control of a cantilever beam with a tip mass. Recently, Bae, Kwak and Inman developed a new eddy current damper system with a fixed copper conductive plate and flexible linkage attached to the tip of the beam (Cheng, 2009). Sodano introduced a new electromagnetic damping mechanism for the vibration suppression of a beam by using a conductive square. The non-noncontact vibration control systems using active eddy current were also studied by Sodano, proposed a magnetic actuator for use as a navigation system for capsule endoscopes.

The actuator is composed of a capsule dummy, a permanent magnet inside the capsule, and an external spiral structure (Cheng, 2009).

In this thesis, we present a new passive electro-magnet shunt damper (EMSD) for single mode vibration suppression of flexible cantilever beam. In electro-magnet shunt damper, the electric current is induced within a conductor when a coil moves through a non-uniform magnetic field or is in a region where there is a change in the magnetic flux.

1.2 PROBLEMS STATEMENTS

The electromagnetic shunt damper, which is electro-magneto-mechanically coupled with the flexible structures, simply consists of a coil, a permanent magnet, and an R-C circuit. The ends of the conductive coil, which plays a role of the inductance, L, are connected to the R-C series shunt circuit. The general modeling of the resonant shunting damper with the R-L-C series circuit is developed to consider the effect of the circuit parameters on the damping mechanism.

1.3 OBJECTIVES

i. To reduce the vibration of the flexible beams using eddy current
ii. To investigate the vibration and damping characteristic of the flexible beams with the electromagnetic shunt damper by tuning the circuit parameters.

1.4 SCOPE

The aim of this project is to investigate the characteristic vibration of the flexible beam by changing the parameter of Electromagnet Shunt Damper (EMSD). The parameter that we change is the value of resistor, voltage, and capacitor.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION TO EDDY CURRENT

There exist many methods of adding damping to a vibrating structure. However, very few can function without ever coming into contact with the structure. One such method is eddy current damping. This magnetic damping scheme functions through the eddy currents that are generated in a nonmagnetic conductive material when it is subjected to a time changing magnetic field (Sodano, 2005).

The magnitude of the magnet field on the conductor can be varying through movement of the conductor in a stationary magnetic field, by movement of a constant intensity magnetic source or changing the magnitude of the magnetic source with respect to a fixed conductor. Once the eddy currents are generated, they circulate in such a way that they induce their own magnetic field with opposite polarity of the applied field causing a resistive force (Sodano, 2005). Figure 2.1 shows the schematic of the generation of Eddy Current damper. The direction of the eddy current on the plate is depend on the magnetic intensity.

However, due to the electrical resistance of the conducting material, the induced currents will dissipated into heat at the rate of I^2R and the force will disappear. In the case of a dynamic system the conductive metal is continuously moving in the magnetic field and experiences a continuous change in flux that induces an electromotive force (emf), allowing the induced currents to regenerate. The process of the eddy currents being generated causes a repulsive force to be produced that is proportional to the velocity of the conductive metal. Since the currents are dissipated, energy is being removing from the system, thus allowing the magnet and conductor to function like a viscous damper (Sodano, 2005).

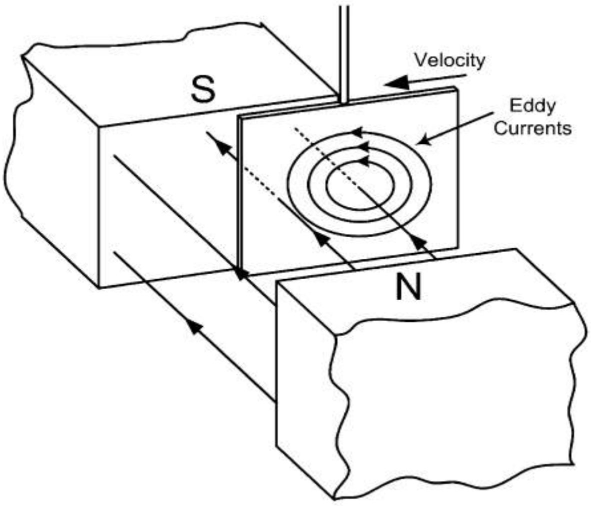

Figure 2.1: Schematic of the generation of Eddy Current damper.

Source: Sodano 2005

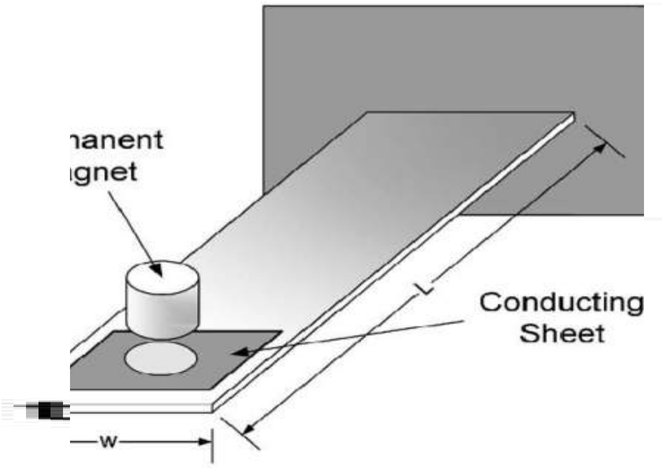

Figure 2.2: Cantilever beam in magnetic field generated by permanent magnet.

Source: Sodano, 2005

Figure 2.2 show the position of the magnet and the metal sheet on the cantilever beam. The magnetic field was induced between them where its can generated the damping characteristic. Figure 2.3(a) and (b) show the magnetic field and the eddy currents induced in the cantilever beam respectively.

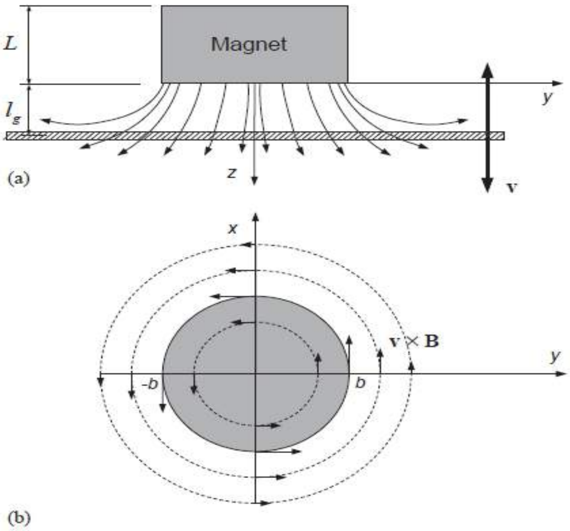

Figure 2.3: (a) Magnetic field and (b) the eddy currents induced in the cantilever beam.

Source: Sodano, 2005

This process causes the eddy currents to function like a viscous damper and dissipate energy causing the vibrations to die out faster. The use of eddy currents for damping of dynamic systems has been known for decades and its application to magnetic braking systems and lateral vibration control of rotating machinery has been thoroughly investigated. One of the most useful properties of an eddy current damper is that it forms a means of removing energy from the system without ever contacting the structure. This means that unlike other methods of damping, such as constrained layer damping, the dynamic response and material properties are unaffected by its addition into the system. Furthermore, many applications require a damping system that will not degrade in performance over time. This is not the case for other viscous dampers; for instance, many dampers require a viscous liquid which may leak over time. These two points are just a few of the many advantages offered by eddy current damping systems (Sodano, 2004).

2.2 PIEZOELECTRIC TRANSDUCER

Recently, the piezoelectric shunt damping has become a most popular technique for minimizing the vibration of the flexible structures, as the concept of smart materials and structures has been widely studied (Cheng, 2009). The piezoelectric patch plays a role in generating the electrical signal from the vibrating structures and can be treated as a capacitor in the circuit diagram (Chenga, 2009).

Piezoelectric shunt damping, which can be classified into a semi-active control method without the power amplifier and the signal processing unit, is a most popular technique for minimizing the vibration of the smart flexible structures (Cheng, 2010). However, those transducers additionally need power amplifiers, heaters, and signal processing units, resulting in the high cost. Also, the visco elastic materials can be passively used to reduce the vibration level of the operating systems, but it cannot work well in the unexpected environments like high or low temperature (Cheng, 2009). Figure 2.4 show the piezoelectric shunt circuit which is connected in parallel.

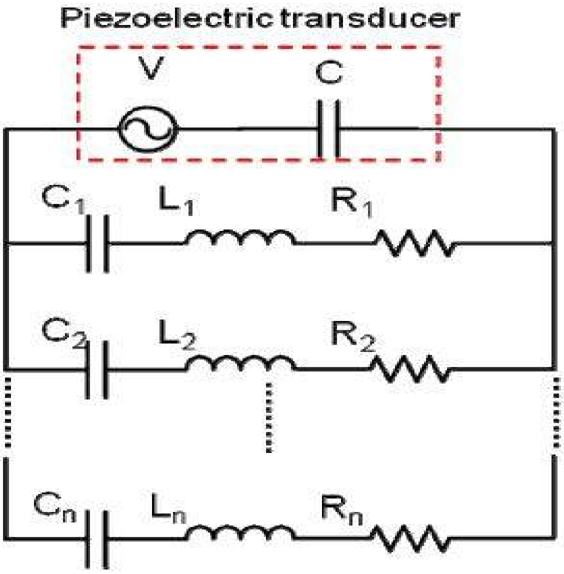

Figure 2.4: Piezoelectric Shunt circuit.

Source: Bae, 2007

2.3 INTRODUCTION TO ELECTROMAGNETIC SHUNT DAMPER

The electromagnetic shunt damper was newly developed to passively suppress the vibration of the flexible cantilever beams. The electromagnetic shunt damper, which is electro-mechanically coupled with the flexible structures, simply consists of a coil, a permanent magnet, and an R-C circuit. The ends of the conductive coil are connected to the R-C series shunt circuit (Cheng, 2009).

A conductive coil is bonded to the vibrating beam and a fixed permanent magnet is placed under the bottom of the coil. Both ends of the coil were connected to the multi-mode resonant shunt circuit. When the conductive coil dynamically moves through the magnetic field in line with the vibration of the flexible structures, a dynamic electric current can be induced in the coil due to the electro- magnetic coupling. The concept of the electromagnetic shunt damper is to transfer the kinetic energy of the vibration system to the electrical energy with the shunt circuit, which results in a reduction of the vibration of the base structures. On the basis of the current-flow method, the connected shunt circuit was designed to tune the multi-modal resonances of the structural system (Cheng, 2009). Figure 2.5 shows the schematic of series electromagnetic shunt damper.

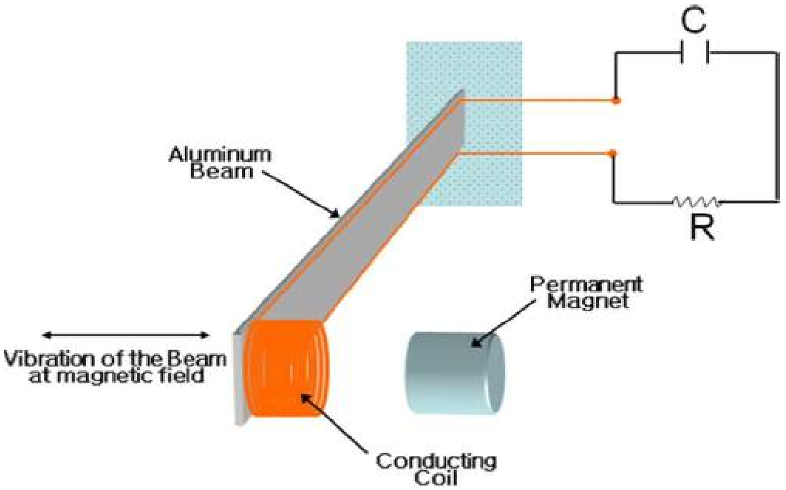

Figure 2.5: Schematic of series electromagnetic shunt damper.

Source: Cheng, 2009

2.4 INDUCTOR COIL

The approximate inductance of a single-layer air-core coil may be calculated from the equation 2.1 :

$$L = \frac{d^2n^2}{18d + 40l} \tag{2.1}$$

where L = inductance in micro henrys;
d = coil diameter in inches (from wire center to wire center);
n = number of turns;
l = coil length in inches.

This formula is a close approximation for coils having a length equal to or greater than 0.4 d. Inductance varies as the square of the turns. If the number of turns is doubled, the inductance is quadrupled. This relationship is inherent in the equation, but is often overlooked (Robert, 1997).

2.5 RLC CIRCUIT

The circuit consisting of an inductor, a capacitor, and a resistor connected in series is called an RLC circuit. The resistance of the resistor R represents all of the resistance in the circuit. .With the resistance present, the total electromagnetic energy U of the circuit (the sum of the electrical energy and magnetic energy) decreases with time because some portion of this energy is transferred to thermal energy in the resistance. Because of this loss of energy, the oscillations of charge, current and potential difference continuously decrease in amplitude, and the oscillations are said to be damped (McHutchon, 2013).

To see how an RLC circuit works, consider the circuit in Figure 2.6 with the capacitor initially charged. Since there is a conducting wire connecting the negative side of the capacitor to the positive, a current will begin to flow in the counterclockwise direction. As it does, several things happen (McHutchon, 2013). Figure 2.6 shows the RLC circuit which is the inductor, resistor, and capacitor are connected in series.

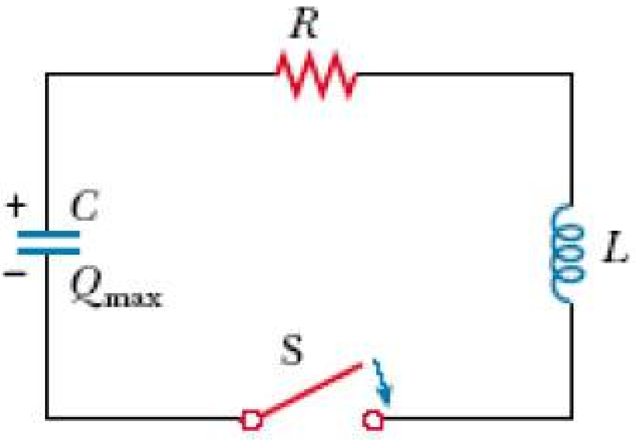

Figure 2.6: A series RLC circuit

Source: Hutchon, 2013

The first is that the resistor will begin to strip energy from the current and convert it to thermal energy. The second is that the current through the inductor will result in a magnetic field. However, since the current is transient (not constant), the magnetic flux through the inductor is not constant, resulting in an emf across the inductor, pointing in the opposite direction of the voltage across the capacitor (McHutchon, 2013).

Once the capacitor is discharged, the emf in the inductor, in trying to prevent the change in magnetic flux, will result in a current in the opposite direction. This causes an opposite charge to start building up on the capacitor. The negative charge will be on the upper plate. This transient current will continue to flow until the capacitor is charges and the magnetic flux through the inductor becomes zero. At this point, the capacitor current starts discharging and the current flowing in the clockwise direction

(McHutchon, 2013). Figure 2.7 shows the graph of charge versus time for damped RLC circuit. The charge is significantly decreased with time.

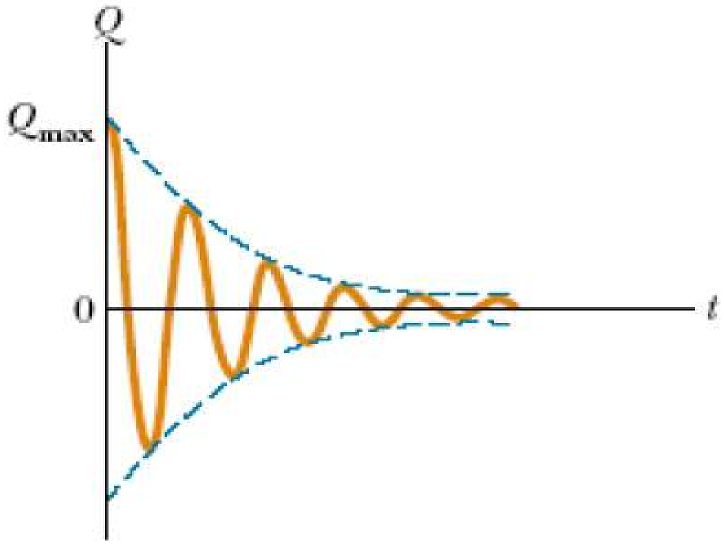

Figure 2.7: Charge versus time for the damped RLC circuit.

Source: Hutchon, 2013

2.6 SIGNAL PROCESSING

Vibration transducers convert this motion into an electrical signal. The electrical signal is then passed on to data collectors or analyzers. The analyzers then process this signal to give the FFTs and other parameters (Girdhar, 2004).

2.6.1 Fourier transform

Time domain consists of amplitude that varies with time. This is commonly referred to as filter-out or overall reading. Frequency domain is the domain where amplitudes are shown as series of sine and cosine waves. These waves have a magnitude and a phase, which vary with frequency (Girdhar, 2004).

The measured vibrations are always in analog form (time domain), and need to be transformed to the frequency domain. This is the purpose of the fast Fourier transform (FFT). The FFT is thus a calculation on a sampled signal (Girdhar, 2004). Figure 2.8 shows the different between time domain and frequency domain. The transform of time domain to frequency domain was called as Fourier transform.

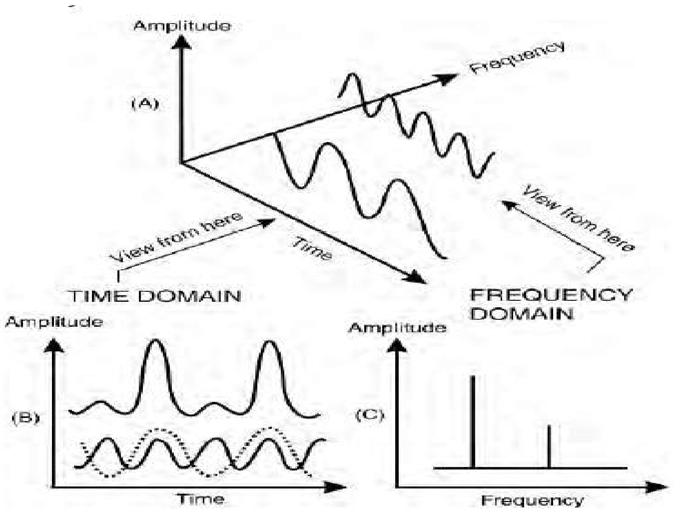

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Figure 2.8: Fourier transform

Source: Girdhar, 2004

2.7.2 Sampling rate

Sampling is the process of recording the amplitude of a wave at given instants, and then generating a curve from the recorded points. Thus, the collected discrete sampled data points (digital) are used to reconstruct the wave, which was originally in an analog form. If the reconstructed digital wave has to look similar to the original wave, how fast should we record the amplitude, or in other words, take samples so that the digitized wave is an exact replica of the original analog wave (Girdhar, 2004).

Figure 2.9 shows a case where the sampling rate is less than double the wave frequency. We can see that four sample intervals collected in 3 ms will result in a reconstructed wave (dotted) as shown in the figure. This wave is of a lower frequency and not at all a true representation of the actual wave (Girdhar, 2004).

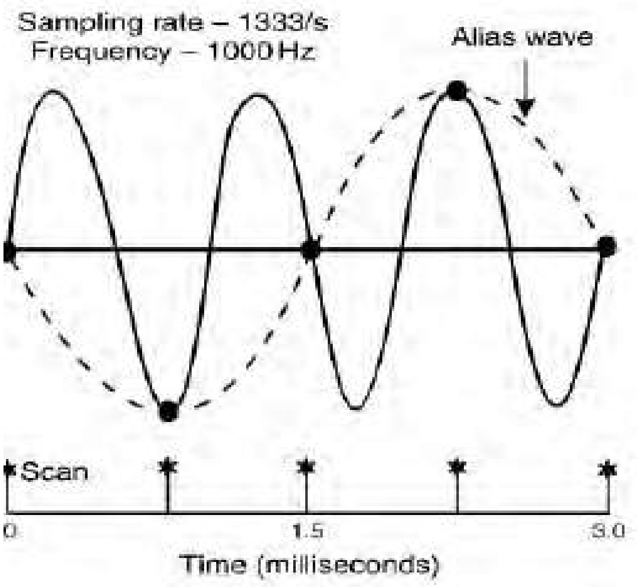

Figure 2.9: Example of undersampling

Source: Girdhar, 2004

This phenomenon of formation of a lower-frequency wave due to undersampling is called aliasing. All data collectors/analyzers have automatically selected built-in sampling rates to ensure that no aliasing occurs. In theory, there should be no vibrations with frequencies of more than half of this sampling rate (Girdhar, 2004).

However, this can never be ensured in practice. Therefore all analyzers are fitted with anti-aliasing filters. These are low-pass electronic filters, which allow low frequencies to pass but block higher ones. The filters remove all vibrations in the analog signal that have frequencies greater than half the sampling rate. These filters are automatically tuned to the proper values as the sampling frequency is changed (Girdhar, 2004).

2.7.3 Windowing

After the signal was digitized using an A/D converter, the next step in the process (before it can be subjected to the FFT algorithm) is called windowing. A ‘window’ must be applied to the data to minimize signal ‘leakage’ effects. Windowing is the equivalent of multiplying the signal sample by a window function of the same length (Girdhar, 2004).

When an analog signal is captured, it is sampled with fixed time intervals. Sampling fixed time intervals can cause the actual waveform to get truncated at its start and end. The results obtained can vary with the location of the sample with respect to the waveform’s period. This results in discontinuities in the continuous waveform. Windowing fills the discontinuities in the data by forcing the sampled data to zero at the beginning and at the end of the sampling period (Girdhar, 2004).

Figure 2.10 shows the effects of windowing. Windows can be thought of as a way to fill in the discontinuities in the data by forcing the sampled data to zero at the beginning and end of the sampling period (or time window), thereby making the sampled period appear to be continuous (Girdhar, 2004). Figure 2.10 show the principle of windowing. The windowing is useful to make the sample of the data show continuously.

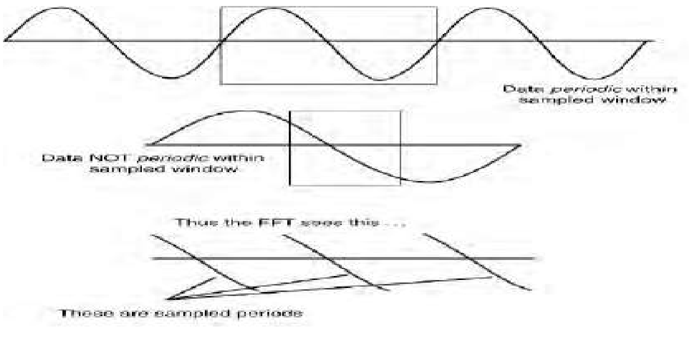

Figure 2.10: The principle of windowing

Source: Girdhar, 2004

The FFT algorithm sees the discontinuities as modulating (varying) frequencies and it shows as sidebands in the spectrum when none of these frequencies are actually present in the signal. The usage of windows also affects the ability to resolve closely spaced frequencies while attempting to maintain amplitude accuracy (Girdhar, 2004).

CHAPTER 3

METHODOLOGY

3.1 PROJECT FLOW

Figure 3.1 shows the project flowchart summary along the project was employed. After receive the project's title, the first thing to stress on was in define the problem statement, objective, and scope. To make these things clear up, the literature review on the related project's title was conducted.

The methodology was started by searching the apparatus to assemble the test rig. After the test rig is functioned, the study on DASYlab is needed in order to record and interpret the data from the experiment. The suitable DASYlab's code block is important to get the precise data.

The first experiment was employed and the data has been analyzed using Matlab to plot the graph. If the result doesn't achieve the objective, the work flow must be turning back to the searching the apparatus. This loop of work continues until achieved the first objective, which is to minimize the vibration of the cantilever beam.

The next experiment can be proceeding after achieved the first objective. The result has been analysis and discussed to find out the reason and the theory behind the data from the experiments.

Figure 3.2 and figure 3.3 shows the Gantt chart week 1-14 and week 15-28 respectively. For week 1-14, all the activities were done on the time except the task in assemble and testing the test rig. The problem was occurring due to the dispute over the disturbance for the flexible beam. It's happened because the barrier in operate the machine. This problem was dragged until week 16 by using another types of disturbance.

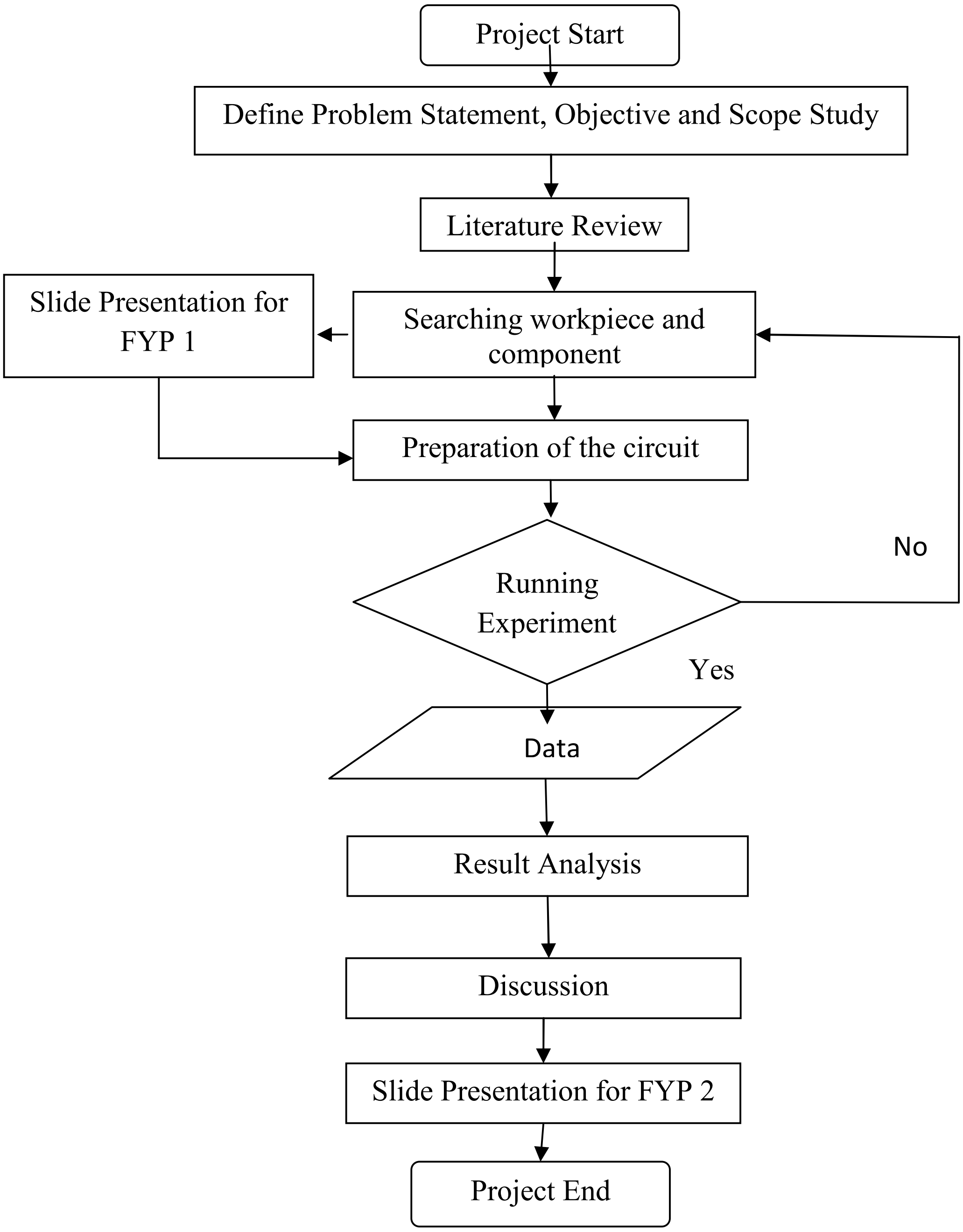

Figure 3.1: The project flow summary