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Annotated Engineering Report

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Annotation key

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ELECTROMAGNETIC ENERGY HARVESTER

As this example shows, the **title** of an engineering report should be concise and informative so that the reader can quickly discover what the report is about (Silyn-Roberts, 2012).

Nicholas Finch

May 2015

Note the inclusion of the **author's name** and the **date of submission** right at the beginning of the report. This information together with the title and the course name is placed on the title page.

EXECUTIVE SUMMARY

The **Executive Summary** is placed on a page by itself, immediately after the title page. Some reports begin with an Abstract rather than an Executive Summary. Check with your lecturer what is expected.

The **purpose** of the **Executive Summary** is to explain what the report is about: the purpose of the study, the experimental design, key results, and conclusions, including the need for future research.

This report explores the design of an electromagnetic energy harvester to produce power from vibrating machinery. Using a simplified experimental model, the effect of frequency, load resistance and coil parameters on the maximum electrical power was investigated.

Results were comparable with data in modern literature and indicated that a small amount of power can be produced. However, further research and development is required to optimise the energy harvester before it is fit for application.

The writer begins by **identifying the problem** the report is addressing.

Then, the writer outlines the **experimental design** and states what he investigated in the study. Note the use of the passive voice here to ensure that the focus is on the experimental model rather than the researcher.

In the second paragraph, the writer presents the **key results** compared to those in previous studies. Note that he only makes general reference to the literature, without providing citations.

In the last sentence, the writer points out **what research is required in the future**. It is important to make this sentence as specific as possible so that it is clear what other researchers could focus on.

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The **Table of Contents** follows the Executive Summary and enables the reader to get an **immediate overview** of **what** is included in the report and **where** each part is located.

Creating a **Table of Contents** can be done easily and automatically if you use **Heading Styles** as you write your report in Word. When you are ready to create your Table of Contents, you just need to click on 'Table of Contents' in the References tab.

TABLE OF CONTENTS

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LIST OF FIGURES

The **List of Figures**, **Tables** and **Equations** follows the Contents page. The List of Figures always goes before the List of Tables. As this example shows, these are an important part of engineering reports. Each is **numbered sequentially**, with a brief title and listed with its page number. When considering whether to use a Figure, Table or extended text, it is important to decide which communicates your message most clearly.

A variety of **Figures** are used in the form of **photos, diagrams, graphs** and **computer screen shots** to help the reader to understand the experimental design or results.

LIST OF TABLES

Several **Tables** are used as they are an **efficient means of presenting information**. As illustrated here, Tables can be used to compare different numbers and units.

LIST OF EQUATIONS

Equations form an integral part of this report as they **inform the experimental design**.

*Please note that these page numbers do not correspond to the page numbers used in this annotated version of the Report

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The **Introduction** gives the reader the opportunity to understand **what** the study is about, **why** it was done, and **how** it was carried out.

INTRODUCTION

The first sentence provides a **broad introduction** to the topic of the research and highlights the importance of it.

Small, low-power wireless sensors have applications across a wide range of industries. In order to fully utilise their wireless functionality, it is desirable to power them from a source that does not need replacing.

The second sentence **identifies the need for the research** and introduces the problem that needs to be solved.

The third sentence **states the purpose of the research**. (Note that this was also stated at the beginning of the Executive Summary).

This report considers the design of an electromagnetic energy harvester that could be used to power a wireless sensor attached to vibrating machinery. A shaker unit and a resistive load were used to model the machine vibration and sensor's power requirement respectively. The factors involved in maximum power generation were investigated.

In the last two sentences, the writer **describes the experimental design** that was used and then states exactly what was investigated. Note the switch to the **past passive** in the last two sentences, which report on the methods that were used and what was investigated.

Unlike other sections within this report, this section and the sub-sections within it are **not labelled** with a **conventional title**. Rather they are labelled with **headings that are appropriate** for this particular report. This section includes the **experimental procedure**, the **materials**, **theory**, and **reference** to the **literature**.

ELECTROMAGNETIC ENERGY HARVESTER

Physical Principle

In this paragraph, the writer outlines some **theory** behind the experiments.

According to the laws of electromagnetism, a changing magnetic flux through a conductor will induce a voltage in the conductor. In the case the magnetic field is produced by a permanent magnet, a flux change may be created by relative motion between the magnet and the conductor. If the conductor is then connected to a resistive load, a current will be able to flow and electrical power will be produced.

See how the writer skilfully uses two different **modal verbs** in this paragraph: The modal 'will' is used to state what is generally true and to make a **strong claim**. Conversely, the modal 'may' is used to make a **tentative claim**. The last sentence in the paragraph is in the form of the **conditional**. This means that 'a current will flow' and 'power will be produced' only 'if the conductor is connected to a restrictive load'.

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This paragraph introduces the **materials** used in the experiment.

The experiments described in this report feature permanent magnets attached to a vibrating cantilever as the transduction mechanism, and stationary wire-wound copper coils as the electromagnetic generator. A potentiometer was connected to the copper inductor to complete the circuit and thus allow the delivered power to be measured.

Note here the first example of **reduced relative clauses** in the report**.** If these clauses were written in full the sentence would say, "The experiments [that are] described in this report feature permanent magnets [that are] attached to …". Using such clauses helps keep the writing concise.

Here, the writer describes the **physical arrangement** of the experiment.

Experimental Setup

This paragraph is primarily written in the **past passive**. This enables the writer to focus on the **result of the action** rather than on who did it. If the third sentence, for example, was written in the **active** voice the focus would be on **who** did the action and would begin as follows: "The researcher placed the inductor coils approximately 1mm …"

The physical arrangement of the experiment is shown in Figure 1. As indicated, two permanent neodymium magnets were attached to a thin polypropylene cantilever, which was excited at its fixed end by a variable-frequency shaker unit. Inductor coils were placed approximately 1mm from the cantilever and were connected to external instrumentation to measure their electrical properties and generated voltage.

Note the way the writer refers to the **Figure** below by its **name** (Figure 1). Each time a Figure, Table or Equation appears the writer skilfully directs or 'signposts' to the reader what they need to look for in the Figure, Table or Equation to follow. The present tense is always used to do this.

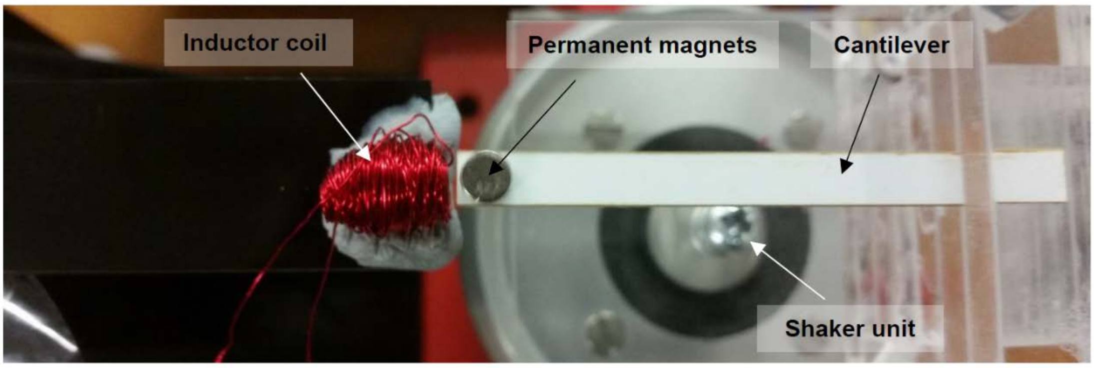

Figure 1 – Experimental setup showing the inductor coil, permanent magnets on the cantilever, and vibration-inducing shaker unit

Note that each **Figure** has a **title to describe it**. Titles for figures are placed below the figures.

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Note the first **reference to the literature** at the end of the sentence, where the number [1] appears. As is the convention in engineering, a **numbered referencing style** is used. The full reference for this citation can be found in the list of References at the end of the report.

The resistive load and shaker unit frequency for each of the four test coils were adjusted to determine the effect on the harvested energy. The construction of the cantilever and distance between the coil and magnets were not changed.

Note the continued use of the **past passive** here to report the methods used in the study.

Extracting Maximum Power

Mathematical analysis shows there are three main parameters that affect the power extracted by the energy harvester [1]. These are outlined in Table 1.

See how the writer **introduces the Table** in the sentence immediately before it appears. To be more concise, this sentence could also be written as follows: "See Table 1."

Table 1 – Parameters influential on the power obtained from the energy harvester

Parameter	Meaning	Has effect on	Ideal value
Mechanical damping	Parasitic damping of the cantilever motion due to friction and interaction with the coil's core	Cantilever motion (responsible for the change in magnetic flux)	Low
Magnetic flux density	Strength of the magnetic field	Maximum voltage induced in the conductor	High
Electrical damping	Electromagnetic damping of the cantilever due to magnetic interaction with the coil	Electromagnetic force (transforms mechanical to electrical energy)	High

See how the writer **interprets the content of the table** in the paragraph, which immediately follows it. Describing what you place in a Table is very important as it enables the reader to understand why you have placed it there and to follow your reasoning.

On the surface, it appears quite straightforward to adjust the parameters to maximise power output. However, significant nonlinear coupling between each factor makes manipulation of one term without affecting another extremely difficult. For example, the electrical damping should ideally be equal to the mechanical damping in order to match

Here the writer skilfully **links his argument** by using two **transition signals**: "However" indicates a contrasting thought (from appearing to be "quite straightforward" to being "extremely difficult"); "For example" indicates that an illustration is being given (of something that is "extremely difficult" to achieve).

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damping losses and achieve maximum power [1]; however, it also is desired to have one term very large and the other very small.

Note how the writer skilfully incorporates the first **Equation** into a sentence. He used the Styles formatting tool (in Word) to create the equation so that it automatically appears in the List of Equations at the beginning of the report.

The instantaneous output power of the energy harvester can be calculated as

$$P_e = F_{em}v = (D_{em}v)v \qquad (1)$$

where Fem is the electromagnetic force acting against the permanent magnetic field, v is the velocity of the cantilever tip, and Dem is the electromagnetic damping expressed by Equation 2 [2]. A full description of all terms is given in Appendix A.

Here the writer directs the reader to the **Appendix.** As this example shows, appendices are sequentially labelled with letters of the alphabet and contain **non-essential information,** which provides further clarification of a point, in this case 'a full description of all terms'.

$$D_{em} = \frac{1}{R_L + R_c + j\omega L_c}\left(\frac{d\Phi}{dt}\right)^2 \qquad (2)$$

See how the writer has used the **present simple tense** throughout this section. This tense is used here to present established knowledge and describe the existing situation.

It is this relationship that forms the basis of the problem for maximising power: there is a difficult compromise between increasing the damping to increase the electromagnetic force, and reducing the damping to increase the change in magnetic flux. The coupling between the damping factors and magnetic flux in the physical system means that a suitable balance has to be found.

An additional consideration for output power is the load resistance connected to the coil. By modelling the generator as an AC voltage source, ideal inductor and resistor in series, it is apparent that the impedance of the load must match that of the coil in order to receive maximum power. Figure 2 demonstrates this equivalent circuit.

Note the way the writer skilfully **links** one paragraph to another with the **transition signal** "An additional consideration".

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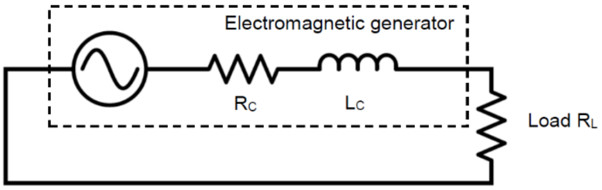

Figure 2 – Equivalent model of the electromagnetic generator and connected load

Transduction Mechanism

Material Properties

The simple static deflection test represented in Figure 3 was performed to calculate the elastic modulus of the polypropylene cantilever. By adding a small mass to the tip of the beam and measuring its displacement, the modulus can be expressed as

$$E = \frac{3\delta I}{m_T g L^3} \qquad (3)$$

where the definition of each term is described in Appendix B. Using Equation 3, the modulus was calculated as 2.847 GPa. This value is similar to 1.5-2 GPa estimations of polypropylene [3], but is slightly larger due to its sandwiched composite structure.

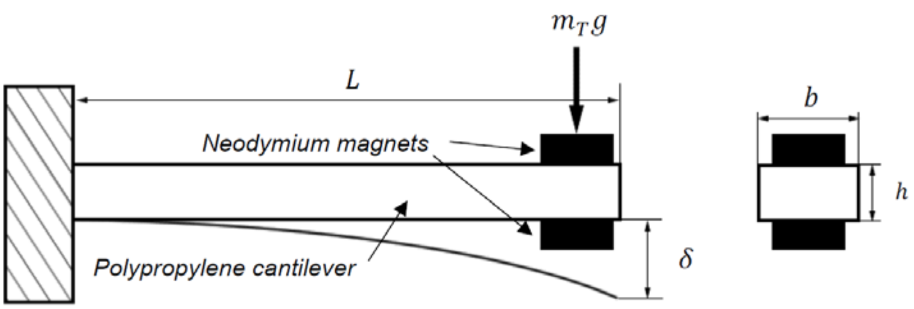

Figure 3 – The cantilever dimensions and deflection test force loading

The density and Poisson's ratio of polypropylene, as well as the characteristics of neodymium, were obtained from existing data [4][5]. These material properties are given in Appendix C.

Magnetic Characteristics

The magnets had a large flux density of approximately 0.25 Tesla each. Neodymium also has high coercivity, so the opposing magnetic field from the generator would not depole the magnets.

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Simulated Frequency

A computer model was created in ANSYS to calculate the natural frequencies of the cantilever (and thus the excitation frequencies at which tip displacement was maximum). By simulating a vertical acceleration at the fixed end and allowing the other end to oscillate, the frequencies of the cantilever were determined. As displayed in Figure 4, the lowest of these natural frequencies was approximately 13 Hz.

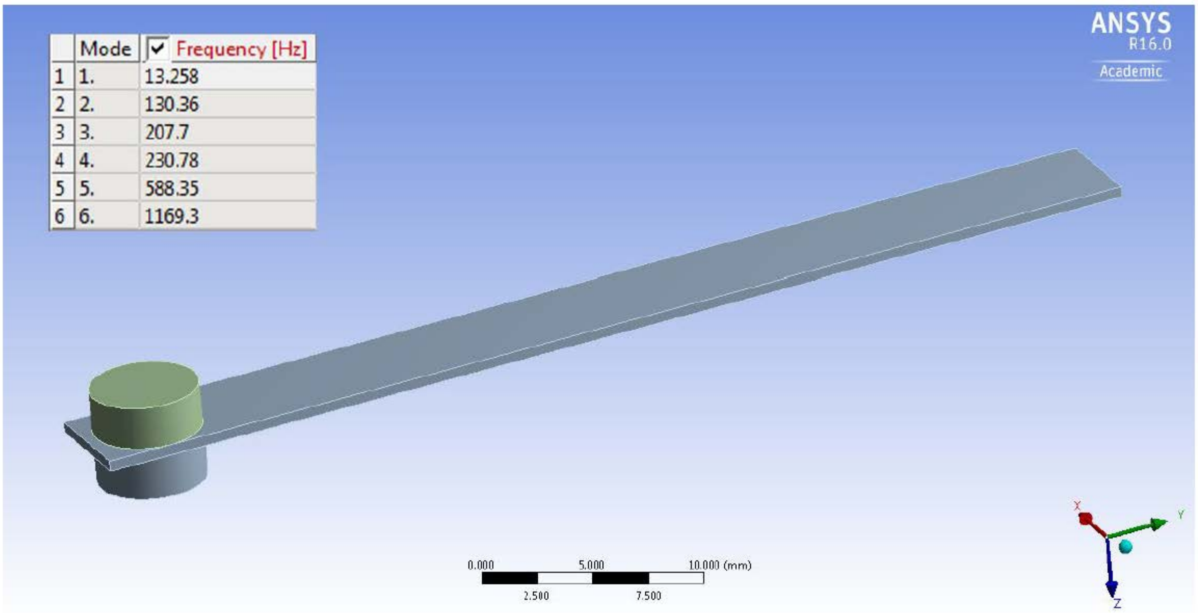

Figure 4 – ANSYS modelling of the cantilever to calculate its resonant frequencies

The higher frequencies found by the computer model correspond to different vibrational modes of the cantilever. As power is inversely proportional to the frequency, these modes were not considered and the beam was only excited at frequencies below 30 Hz.

Actual Frequency

By varying the frequency of the shaker unit and observing the vibrational magnitude of the cantilever, the resonant frequency of the physical system was found to be around 13.5 Hz, where peak-to-peak amplitude was estimated as 10 mm. Placing the coils near the tip also affected the resonant frequency of the system, as the magnetic interaction increased the effective stiffness of the beam. A comparison of these different responses is displayed in Table 2. All frequency tests were performed with the coils oriented horizontally.

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Table 2 – Resonant frequencies for different cantilever systems

Cantilever system	Approximate resonant frequency (Hz)	
	No load	5Ω load
Simulation	13	-
No coil connected	13.5	-
Short coil (ferrite-core)	15	15.8
Long coil (ferrite-core)	15	15.5
360 turn coil (air-core)	14	14.2
250 turn coil (air-core)	14	14.2

Electromagnetic Generator

Construction

The two ferrite-core coils used were commercially manufactured, similar to the inductor shown in Figure 5 (b). The other two air-core coils were made manually by looping 33SWG copper enamelled wire around circular metal shafts, which were lightly greased to allow the coil to be removed easily after winding. One of the air-core coils in mid-construction is shown in Figure 5 (a).

Images for Figure 5(a) and (b) appeared here in the original report, but are not included in this version.

Figure 5 – Construction method of the air-core inductor coils (a) and a typical ferrite-core inductor (b)

Although the windings of the manually-constructed coils were less uniform than manufactured ones, rough physical dimensions (and therefore electrical properties) could be controlled. This allowed the relative effect of each term on the electromagnetic damping and thus the power produced by each coil to be investigated. The measured characteristics are listed in Table 3.

Table 3 – Measured dimensional and electrical properties of the two air-core coils

Coil	No. of turns	Diameter (mm)		Thickness (mm)	Wire Length (mm)	Resistance (Ω)	Inductance (mH)
		Inner	Outer				
1	360	1	9	18	4200	2.42	0.074
2	250	3	10	12	5000	2.79	0.13
3	-	-	-	-	-	2.24	0.6458
4	-	-	-	-	-	8.75	2.12

Coil 1 was made with less wire, a smaller cross-sectional area and longer thickness in order to have a lower resistance and inductance [6] (reducing the denominator of

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Equation 2), and coil 2 was made with a larger cross-sectional area to increase the flux linkage (increasing the numerator of Equation 2). Coils 3 and 4 in the table are the long and short ferrite-core, respectively.

Inductor Core

Adding a core with a high permeability to the inductor strengthens the magnetic field interactions between the coil and the permanent magnets. This increases the flux linkage and allows for greater electromagnetic forces. However, it also introduces additional mechanical damping through hysteresis and eddy current losses in the core.

RESULTS

The **Results** section describes what **was found or observed** in the study. Data are presented pictorially in this report in figures.

Each of the four coils was tested at load resitances ranging from 1-10 Ω. The RMS voltage was measured and the power was calculated as per Equation 4. The experimental results are shown in Figure 6.

The **figures** contain all the **detailed data,** and the **accompanying text** in the Results identifies the **trend** in the data. Note that any interpretative observations will be made in the Discussion.

$$P_{RMS} = \frac{V_{RMS}^2}{R_L} \qquad (4)$$

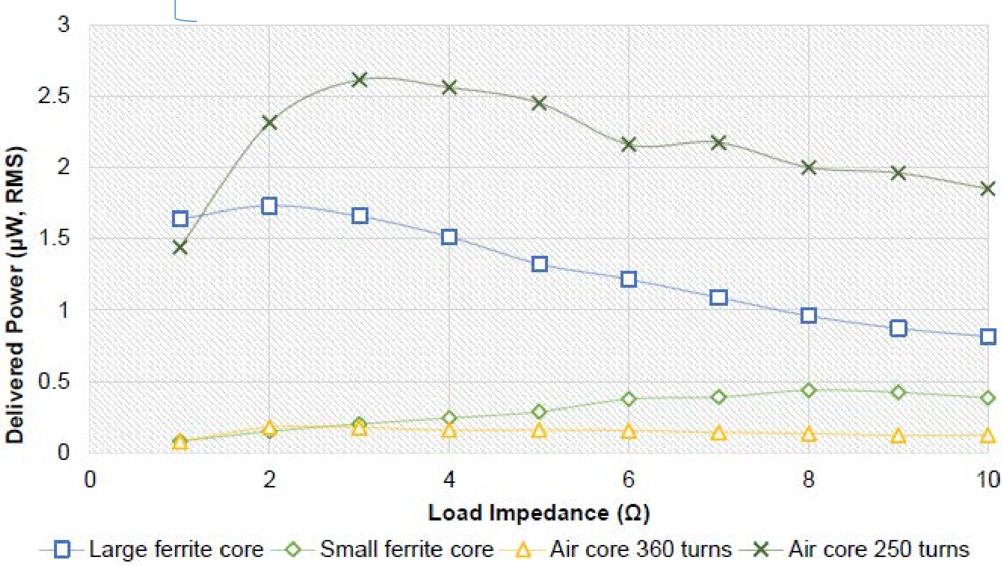

Figure 6 – Output power against load impedance for each coil

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This Results section is **well-written** because the writer **explains** what is going on in the preceding Figure and **guides** the reader in noticing what is **important** within it. Someone reading this passage critically would be able to compare their interpretation of the Figure with the writer's.

Note the extensive use of the **simple past tense** in the **Results** where actions or events completed in the past are reported.

The 250 turn coil delivered 2.6 μW, the most power out of all the coils, and about 50% more than the next best coil. The 360 turn coil delivered the least amount of power, with a maximum output less than 0.25 μW. The larger ferrite-core coil performed better than the smaller one, with a peak power of 1.75 μW compared to 0.5 μW.

All coils produced maximum power at a load close to their own impedance, at around 8 Ω for the short ferrite-core and between 2-3 Ω for the other three coils.

See how the writer uses the **active voice** throughout this and the following paragraph. Using the **active voice** enables the writer to focus on the *doer* or *performer* of the action, namely the "250 turn coil" and the "360 turn coil" rather than the *result* of the action, the output. In contrast, if the passive voice were used, the focus would shift to the *result* of the action and it would not be clear what *performed* the action: "2.6 μW were delivered ...."

In the last part of the Results, the writer switches to the **passive voice**. The passive enables him to focus on the *result* of the action rather than on *who* did it. If the writer used the active voice in the final sentence, it would draw unnecessary attention to himself: "I/The researcher show the coil itself in Figure 8."

Each coil exhibited a similar response to variations in the shaker unit frequency, with a peak voltage generated at one frequency and very little voltage produced at other frequencies. The measured voltage against frequency for the 250 turn coil is shown in Figure 7, with a peak voltage at 14.2 Hz. The coil itself is shown in Figure 8.

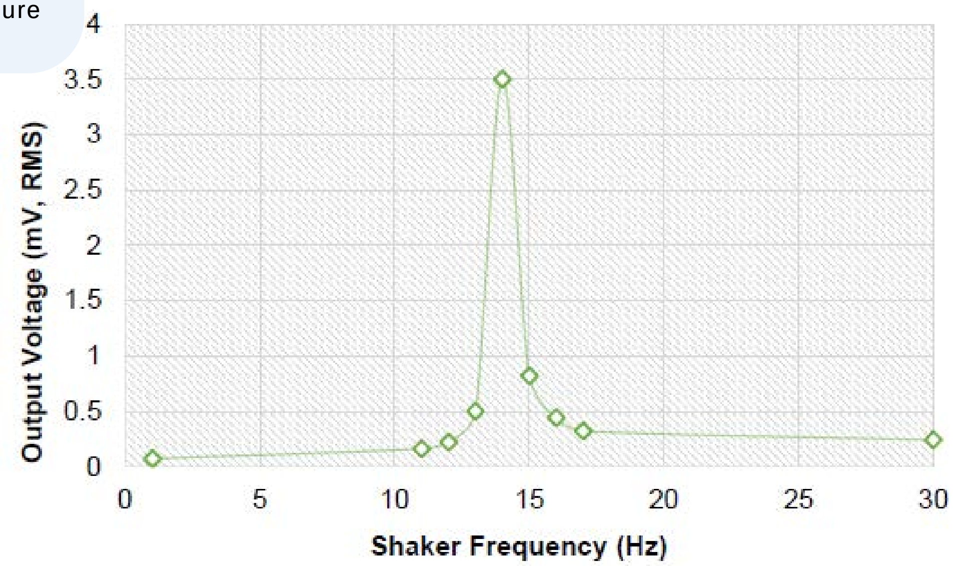

Figure 7 – Output voltage in response to cantilever excitation frequency

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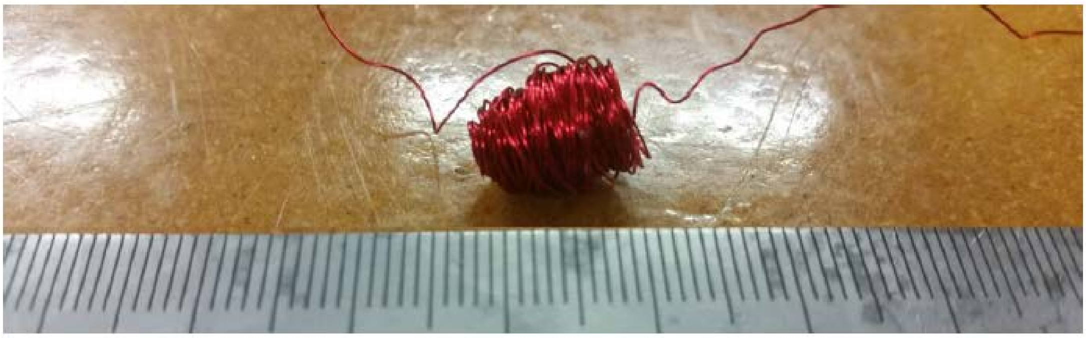

Figure 8 – The 250 turn air-core coil (with mm ruler for scale)

DISCUSSION

The average power output from each of the coils was in the order of microwatts. This amount of power is typical of electromagnetic energy harvesters, but the inductor design could still be improved to further increase power extraction; relatively similar electromagnetic systems have been recorded to deliver a significantly larger 46μW [7]. The results demonstrate that slight changes to the coil parameters cause significant variation in output power.

The dependence of maximum power on the impedance of the load is clear from Figure 6. When the resistance is too low, not enough voltage is developed across the load, and when it is too high, not enough current is drawn. As expected from theory, maximum power occurs when the load impedance matches that of the coil.

Due to the low operating frequency, the inductance of the coils had very

> As this example shows, the **focus** of the writer in the Discussion is on **interpreting his results in relation to the purpose** of the investigation. In this case, the purpose can be found in the last sentence of the introduction: "The factors involved in maximum power generation were investigated."

> The **Discussion** section is perhaps the most challenging to write. In this section the writer needs to interpret his/her results in relation to the objectives of the study. Also, the writer may mention the limitations of a study and explain how the research has moved understanding about the research area forward (cf. Bates College, 2011).

> Here is an excellent example of the writer **referring back** to the results (Figure 6) as he **interprets them** in relation to the objectives of the study.

> See how the **present tense** is used to interpret the Results throughout this paragraph and present well-accepted facts.

> Note how the writer skilfully uses **parallelism** in this sentence to contrast the different levels of resistance. In other words, the **same grammatical pattern of words** is used, which makes it easier for the reader to follow the argument.

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little impact on the electromagnetic damping (as per Equation 2). This meant that the low-inductance construction of the 360 turn coil did not improve its power output.

Conversely, the variation in magnetic flux linkage had a significant effect on the results. This is shown by the power obtained by the 250 turn coil – the greater cross-sectional area of this inductor increased the change in magnetic flux, increasing the electromagnetic damping (as per Equation 2) and therefore increasing the power. The shorter thickness of the coil also meant that more of the turns were closer to the stronger part of the magnetic field (in contrast to the thicker 360 turn coil).

Although the ferrite-cores for the other two coils increased magnetic interaction, they also caused more mechanical damping and limited the velocity of the cantilever. This had an overall effect of reducing the rate of change of flux and lowering the maximum power. The short coil was especially ineffective, as its large impedance also reduced electrical damping, further reducing the maximum output power. However, it is useful to note that while more mechanical damping decreases peak power, the bandwidth of the frequency and load increases, thus increasing the energy harvester's versatility to different operating conditions.

Ideally, an inductor core should have high permeability (to support a magnetic field), low coercivity (to reduce hysteresis when being magnetised) and a high resistance (to reduce eddy current losses) [8]. The soft ferrite cores used in the two test coils exhibit these properties, but still increase the mechanical damping of the system. This damping effect increases at higher frequencies (and when the coil is oriented horizontally), as energy loss occurs for each change in the direction of the magnetic field. Manganese, a paramagnetic material [9], could be used as an alternative core to increase the field strength without introducing losses. Unlike iron-based compounds, it does not retain its magnetisation and therefore will not contribute to damping through hysteresis.

As the coils were oriented horizontally, the electrical AC frequency was effectively twice that of the cantilever vibration (as the coil was cut twice for each pass of the magnets), and the output voltage was a distorted sinusoidal waveform. It is expected that this orientation of the coil generates more power than when they are vertical, as the rate of change of flux is greater. However, this theory was untested.

More work is required before the energy harvester can be implemented as a power source for a wireless sensor. Besides further improvement of the coil

As can be seen here, the writer acknowledges the **limitations** of the study and **possibilities for further research** in the Discussion section.

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parameters, development into the rectification of the output power is also necessary in order to extract useful electrical energy from the harvester. From testing, it was observed that different coils and loading affected the damping and increased the resonant frequency of the cantilever; further investigation into this physical coupling should be carried out and the energy harvester tuned in order to produce maximum power at the resonant frequency of the vibrating machinery.

> Note the switch made between the **past passive** and **simple past** in this sentence. The writer begins in the passive "It was observed" to avoid having to refer to himself as a researcher, but then switches to the past simple to put the focus on *what* carried out the action (i.e., the "different coils and loading").

> See how the writer skilfully comments on some key results before highlighting the need for further research related to these. It is usual to highlight the **need for further research** in the Discussion.

CONCLUSIONS

> The **Conclusions** section gives the writer the chance to sum up the main findings of the research.

> As this example shows, the Conclusions section does not need to be written in paragraph form, but rather as a list of **bullet points**. Using such a format keeps this section short and to the point.

- The maximum power output was achieved with a short air-core coil, delivering 2.6 μW to a 3 Ω load at the resonant frequency of 14.2 Hz.

> Each **conclusion** is drawn from the Results or Discussion. This first conclusion, for example, is drawn from the Results on page 13 of this version of the report.

- Very little power was able to be extracted when operating outside the resonant frequency of the cantilever and without a matched load impedance.

> Note the use of the **past tense** in the first three conclusions, which report on the **overall outcomes** of the study.

- The greatest influence on the energy harvester output was the rate of change of flux linkage. This was best increased by increasing the cross-sectional area of the coil, and reducing mechanical damping.

> See how the writer skilfully uses **parallelism** in the second part of this sentence where he reports two different results. In other words, he uses the same **grammatical pattern of words**: "increasing the cross-sectional area of the coil and reducing mechanical damping".

- Designing coils for maximum power is extremely difficult, and experimentation is necessary to observe the complex relationship between the electrical, mechanical and magnetic elements of the system.

> Note the switch to the **present tense** in this last Conclusion. The present tense is used first to describe the **current state** (is extremely difficult) and then to describe the **possibilities for future research**.

> See how the writer uses the **'booster' or 'intensifier'** "extremely" to make a very strong claim to end the Conclusions and sum up the research.

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The **referencing style** used in this paper lists each reference sequentially according to the order it was first mentioned in the body of the paper. Although not used in this report, the Chicago and Vancouver numbered styles are most commonly used in the University of Auckland's School of Engineering. Check which referencing style you should use in the assignment guidelines.

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It is usual practice to put **non-essential information,** which provides further clarification of a point in an **Appendix**. **Appendices** are **sequentially labelled** with letters of the alphabet. Placing the information here means that unnecessary space is not used within the body of a paper (Bates College, 2011).

APPENDICES

Appendix A – Definition of Equation 1 and 2 Terms

Parameter	Definition	Value
δ	Vertical displacement of cantilever tip	$0.014\ m$
$m_T g$	Total force at tip due to the magnets and added mass	$0.0498\ N$
L	Horizontal length of cantilever	$0.050\ m$
b	Cantilever width	$0.005\ m$
h	Cantilever thickness	$0.0005\ m$
I	Second moment of area about the neutral axis, equal to $(bh^3)/12$	$5.21 \times 10^{-14}\ m^4$
E	Young's Modulus of elasticity (calculated)	$2.847\ GPa$

Appendix B – Definition and Values of Equation 3 Terms

Term	Definition
P_e	Electrical power output
F_{em}	Electromagnetic force opposing magnetic field
D_{em}	Electromagnetic damping
v	Cantilever tip velocity
R_L	Load resistance
R_c	Coil resistance
L_c	Coil inductance
ω	AC frequency

Appendix C – Material Properties for Polypropylene and Neodymium

Material Property	Polypropylene	Neodymium
Density (kg/m^3)	1533.3	7500
Young's modulus (GPa)	2.85	160
Poisson's ratio	0.45	0.24

Annotation key

Tentative claims	Strong Claims	Transition signals	Specialised vocabulary

Engineering Reports

Background to this engineering report

The above engineering report was written by a student in the final year of his degree at the University of Auckland based on a piece of experimental work he carried out for a MECHENG course.

Sections of an Engineering Report

There are many different ways to structure an engineering report; the structure chosen depends on the type of report (e.g., general report, design report) (Silyn-Roberts, 2012). This report, based on a piece of experimental work, includes the following sections: Title page, Executive Summary, Table of Contents, List of Figures, List of Tables, List of Equations, Introduction, Electromagnetic Energy Harvester (a specific title for this particular report), Results, Discussion, Conclusions, References, and Appendices.

Because there are several different types of engineering reports, it is vital that you follow the course guidelines about expectations of the sections to be included, referencing style, formatting and length of each section. Below is a brief overview of each section of an engineering report based on experimental work:

Title page

The Title page takes up the first page of an engineering report. Information placed on this page includes the title of the report, the course name, the writer's name, and the date (month, year).

Executive Summary

The purpose of the Executive Summary is to explain what the report is about: the purpose of the study, the experimental design, key results, and conclusions, including the need for future research.

Table of Contents

The Table of Contents enables the reader to get an immediate overview of what is included in the report and where each part is located.

List of Figures, Tables, and Equations

The List of Figures, Tables and Equations follows the Contents page. The List of Figures is always placed first. Each Figure is numbered sequentially with a brief title and listed with its page number.

Introduction

The Introduction gives the reader the opportunity to understand what the study is about, why it was done, and how it was carried out.

Title will vary for this section (Electromagnetic Energy Harvester)

Unlike the other sections, this section and the sub-sections within it are not labelled with a conventional title, but rather with headings that are appropriate for the particular report (cf. Silyn-Roberts, 2012). This section may include the experimental procedure, the materials, theory, and reference to the literature.

Results

The Results section describes what was found or observed in the study. Key data are presented pictorially, for example, in line graphs.

Annotation key

Tentative claims	Strong Claims	Transition signals	Specialised vocabulary

Discussion

The Discussion is perhaps the most challenging to write because the writer needs to interpret the results in relation to the objectives of the study. They can also compare their results to what has been found in the literature, possibly drawing on new literature not previously mentioned. Further, the writer needs to explain how the research has moved understanding about the research area forward and may mention the limitations of the study (cf. Bates College, 2011).

Conclusions

This section gives the writer the chance to sum up the main findings of the research.

References

This section comprises a list of all references referred to in the research paper.

Appendices

It is usual practice to put non-essential information, which provides further clarification of a point in an Appendix. Appendices are sequentially labelled with letters of the alphabet. Placing the information here means that unnecessary space is not used within the body of a paper (Bates College, 2011).

Distinctive language features of engineering research reports

Engineering reports have a number of distinctive language features, which are outlined below:

Parallelism

One distinctive feature of well-written engineering reports is the use of parallelism, which means that the same grammatical pattern is used in lists or comparisons. The writer skilfully uses parallelism in this report, which makes it easier for the reader to follow the argument; e.g.,

(1) It is this relationship that forms the basis of the problem for maximising power: there is a difficult compromise between increasing the damping to increase the electromagnetic force, and reducing the damping to increase the change in magnetic flux.

gerund	noun phrase	infinitive	noun phrase	conjunction
increasing	the damping	to increase	the electromagnetic force	and
reducing	the damping	to increase	the change in magnetic flux	

(2) Ideally, an inductor core should have high permeability (to support a magnetic field), low coercivity (to reduce hysteresis when being magnetised) and a high resistance (to reduce eddy current losses) [8].

Noun phrase	infinitive	noun phrase
high permeability	(to support	a magnetic field)
low coercivity	(to reduce	hysteresis when being magnetised)
a high resistance	(to reduce	eddy current losses)

Pronoun usage

A further feature is related to the use of personal pronouns (e.g., I, he, we). Check with your lecturer whether it is appropriate to use these because in some cases they can be used. No pronouns, however, are used in this report. Rather, the writer uses passive voice to avoid any need of mentioning his role in carrying out the study; e.g.,

(1) A computer model was created in ANSYS to calculate the natural frequencies of the cantilever ...

(2) From testing, it was observed that different coils and loading affected the damping and increased the resonant frequency of the cantilever

Annotation key

Tentative claims	Strong Claims	Transition signals	Specialised vocabulary

Specialised vocabulary

Another feature of well-written research reports is that specialised vocabulary is correctly used. As you can see in the following two sentences, the writer has correctly used three different forms of the root word "magnet":

> According to the laws of electromagnetism, a changing magnetic flux through a conductor will induce a voltage in the conductor. In the case the magnetic field is produced by a permanent magnet, a flux change may be created by relative motion between the magnet and the conductor.

Indeed, in each case the writer has used the correct form of the word (i.e., noun, adjective) and used it within appropriate collocations; that is, with words that frequently combine together; i.e.,

> the laws of electromagnetism (noun)
> magnetic flux (adjective)
> magnetic field (adjective)
> permanent magnet (noun)
> between the magnet and the conductor (noun)

Given the importance of correctly using specialised vocabulary, you may find it useful to build a glossary and focus on learning these words so that you are familiar with their meaning, the words they collocate with, and the various forms of the word.

Expressing an opinion or the author's "voice"

As you can see in the above report, it is possible for the writer to position themselves and express their opinion through their choice of language. Writers can make tentative claims by using "hedging" devices (e.g., appears, slightly) or strong claims (e.g., extremely) when they are certain about the point they are making. Further, writers can comment on something striking, unexpected or of interest to the reader by using adverbs (e.g., ideally).

Tentative claims

Tentative claims or "hedging" are made most frequently in the Electromagnetic Energy Harvester section of this report. The writer uses hedging devices here because he needs to interpret the results of his study in light of previous research and he may be less certain of the claim he is making. The writer either uses adverbs (slightly), verbs with a weak meaning (appear), or modal verbs (could, may) to express uncertainty:

> Adverb
> This value is similar to 1.5-2 GPa estimations of polypropylene [3], but is slightly larger due to its sandwiched composite structure.
>
> Verb
> On the surface, it appears quite straightforward to adjust the parameters to maximise power output.
>
> Modal
> In the case the magnetic field is produced by a permanent magnet, a flux change may be created by relative motion between the magnet and the conductor.

Strong claims

The writer makes strong claims by using adverbs (e.g., extremely, very, especially) and adjectives (e.g., significant, greatest) that have a strong meaning. These adverbs and adjectives are sometimes referred to as "boosters" or "intensifiers". Some strong claims are made in the Electromagnetic Energy Harvester section; e.g., However, significant nonlinear coupling between each factor makes manipulation of one term without affecting another extremely difficult.

The majority of strong claims, however, are made in the Discussion and Conclusions sections of this report where the writer interprets the results; e.g.,

Due to the low operating frequency, the inductance of the coils had very little impact on the electromagnetic damping (as per Equation 2). [Discussion]

The short coil was especially ineffective, as its large impedance also reduced electrical damping, further reducing the maximum output power. [Discussion]

Designing coils for maximum power is extremely difficult, and experimentation is necessary to observe the complex relationship between the electrical, mechanical and magnetic elements of the system. [Conclusions]

Another way to express the writer's voice

It is possible for writers to make subjective comments when interpreting the results in the Discussion by using words (e.g., obvious[ly], surprising[ly], ideal[ly]) and phrases (e.g., it is useful to note, in particular). Although not done often, the writer of this report skilfully makes a couple of subjective comments in the Discussion:

Ideally, an inductor core should have high permeability (to support a magnetic field), low coercivity (to reduce hysteresis when being magnetised) and a high resistance (to reduce eddy current losses) [8].

However, it is useful to note that while more mechanical damping decreases peak power, the bandwidth of the frequency and load increases, thus increasing the energy harvester's versatility to different operating conditions.

Verb usage

This engineering report is characterised by frequent shifts in tense (past, present) and voice (active and passive). The perfect aspect is only used in the Discussion. Detailed analysis of verb usage can be found in the annotated comments in the body of the paper. A few general comments are given here.

Verb tenses

Executive Summary

The present tense is used to:

Describe the problem the report is exploring:
This report explores the design of an electromagnetic energy harvester to produce power from vibrating machinery.

Highlight the need for further research:
However, further research and development is required to optimise the energy harvester before it is fit for application.

The past tense is used to:

(1) Report on the methodology used
Using a simplified experimental model, the effect of frequency, load resistance and coil parameters on the maximum electrical power was investigated.

Annotation key

Tentative claims	Strong Claims	Transition signals	Specialised vocabulary

(2) Report overall results
Results were comparable with data in modern literature and indicated that a small amount of power can be produced.

Introduction

The present tense is used to:

(1) Give a broad introduction to the topic
Small, low-power wireless sensors have applications across a wide range of industries.

(2) Highlight the need for the current research
In order to fully utilise their wireless functionality, it is desirable to power them from a source that does not need replacing.

(3) State the purpose of the current research
This report considers the design of an electromagnetic energy harvester that could be used to power a wireless sensor attached to vibrating machinery.

The past tense is used to:

Describe the procedure that was used to collect the data
A shaker unit and a resistive load were used to model the machine vibration and sensor's power requirement respectively. The factors involved in maximum power generation were investigated.

Electromagnetic Energy Harvester

The present tense is used to:

(1) Describe the figures, tables, and equations; e.g.,
These are outlined in Table 1.

(2) Present well-established facts; e.g.,
Mathematical analysis shows there are three main parameters that affect the power extracted by the energy harvester [1].

(3) Describe the existing situation; e.g.,
An additional consideration for output power is the load resistance connected to the coil.

The past tense is used to:

Describe the experimental set up; e.g.,
As indicated two permanent neodymium magnets were attached to a thin polypropylene cantilever, ...

Results

The past tense dominates the results section where the writer presents the results of the study; e.g.,

All coils produced maximum power at a load close to their own impedance, at around 8 Ω for the short ferrite-core and between 2-3 Ω for the other three coils.

The present tense is only used to refer to the Figures; e.g.,

The experimental results are shown in Figure 6.

Annotation key

Tentative claims	Strong Claims	Transition signals	Specialised vocabulary

Discussion

There are frequent switches between the present and past tense in the Discussion. The present tense is used, for example, in the interpretation of the results;

> As expected from theory, maximum power occurs when the load impedance matches that of the coil.

The present tense is also used to acknowledge the need for further research:

> More work is required before the energy harvester can be implemented as a power source for a wireless sensor.

Reference to the past tense is made, for example, when referring to the results of the current study:

> Due to the low operating frequency, the inductance of the coils had very little impact on the electromagnetic damping (as per Equation 2).

Conclusions

The past tense is mainly used in the Conclusions where the writer sums up the main findings of the research; e.g.,

> The greatest influence on the energy harvester output was the rate of change of flux linkage.

The present tense, however, is used to describe the current state and the possibilities for future research:

> Designing coils for maximum power is extremely difficult, and experimentation is necessary to observe the complex relationship between the electrical, mechanical and magnetic elements of the system.

Active and passive voice

As evident in the above examples of verb tenses, both active and passive voice are used throughout this engineering report. The writer chooses whether to use the active or passive voice depending on what is being said and where the focus is to be.

When the active voice is used, the subject of the sentence is the *doer* or *performer* of the action, and the object is the *receiver* of the action. The active voice in the following example from the Results is used because the writer wants the focus to be on the *performer* of the action:

> All coils produced maximum power at a load close to their own impedance …

In contrast, passive voice is used in this section of the Results where there writer wants to focus to be on the *receiver* of the action:

> The measured voltage against frequency for the 250 turn coil is shown in Figure 7 …

You can see that the past passive is predominantly used where the experimental procedure is referred to because the focus is on the result of the *action* that has been completed, rather than on *who* carried it out:

> A shaker unit and a resistive load were used to model the machine vibration and sensor's power requirement respectively.

Annotation key

Tentative claims	Strong Claims	Transition signals	Specialised vocabulary

Aspect

The progressive aspect (e.g., It is starting) is not used at all in the report and the perfective aspect (e.g., It has started) is only used once. The present perfect passive is used in the Discussion to show that the action that took place in the past is still of relevance now:

> The amount of power is typical of electromagnetic energy harvesters, but the inductor design could still be improved to further increase power extraction; relatively similar electromagnetic systems have been recorded to deliver a significantly larger 46μW [7].

Reduced relative clauses

A further feature of engineering research reports is the use of reduced relative clauses. In this report such clauses are used in the Electromagnetic Energy Harvester, the Results, and the Discussion sections. Use of such clauses helps make the writing concise. Reduced relative clauses are in the passive voice and should not be confused with the simple past tense as this example illustrates:

> The soft ferrite cores used in the two test coils exhibit these properties. [passive voice]

The verb "used" in the above example is the non-finite *–ed* participle. If this clause had been written as a full relative clause, it would say:

> The soft ferrite cores that were used in the two test coils ...

In contrast, if this sentence had been written in the active voice, the verb "used" would be in the past tense:

> The researcher used the soft ferrite cores in the two test coils … [active voice]

Writing the above sentence in the active voice, however, would place unnecessary focus on the researcher carrying out the action.

Modal verbs

Modal verbs are used for a number of reasons which include:

(1) Expressing uncertainty; e.g.,
In the case the magnetic field is produced by a permanent magnet, a flux change may be created by relative motion between the magnet and the conductor.

(2) Making a strong claim; e.g.,
According to the laws of electromagnetism, a changing magnetic flux through a conductor will induce a voltage in the conductor.

(3) Expressing possibility; e.g.,
This report considers the design of an electromagnetic energy harvester that could be used to power a wireless sensor attached to vibrating machinery.

Manganese, a paramagnetic material [9], could be used as an alternative core to increase the field strength without introducing losses.

Annotation key

Tentative claims	Strong Claims	Transition signals	Specialised vocabulary

Developing a coherent argument

An important feature of a well-written research report is that it is coherent and well-structured. A variety of strategies can be used to ensure that the ideas are logically connected to one-another. One is to use "transition signals" such as "however" and "for example":

> On the surface, it appears quite straightforward to adjust the parameters to maximise power output. However, significant nonlinear coupling between each factor makes manipulation of one term without affecting another extremely difficult. For example, the electrical damping should ideally be equal to the mechanical damping in order to match damping losses and achieve maximum power [1]; however, it also is desired to have one term very large and the other very small.

Another feature is to use a pronoun such as "it", "this" or "these". If using a pronoun, however, check that the meaning is clear as in the following example where the pronoun "it" clearly represents "the energy harvester":

> However, further research and development is required to optimise the energy harvester before it is fit for application.

Otherwise, if the meaning of the pronoun is not clear, it is preferable to repeat the noun or noun phrase, or use a synonym or a noun phrase, as shown in this example:

> Using Equation 3, the modulus was calculated as 2.847 GPa. This value is similar to …
> [Noun phrase]

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