DEVELOPMENT OF POLE-AND-KNIFE SPRINGS SYSTEM FOR HARVESTING OIL PALM FRUIT

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Mechanical Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"DEVELOPMENT OF POLE-AND-KNIFE SPRINGS SYSTEM FOR HARVESTING OIL PALM FRUIT"** was prepared by **LEE MIN KHUAN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Mechanical Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

Efficient harvesting of oil palm fruit is crucial for the industry's sustainability and profitability. Traditional manual harvesting methods have been used for many years, but they are tiring, time-consuming, and physically demanding. To address these issues, this project aims to develop a prototype for harvesting oil palm fronds more efficiently and reduce fatigue experienced by the worker. The developed prototype consists of a sickle with a specialized handle which provide hammering effect that helps to cut the frond and avoid the sickle get stuck problem. It’s also consists of mechanical spring to ensure the smooth cutting process that help to reduce fatigue of the harvester. The prototype was tested for its functionality and feasibility using a digital hanging balance to measure the force required to pull the frond and a stopwatch to record the time taken to cut off a single frond. The results show that the force required to pull the frond ranges from 5.07 kg to 7.01 kg, with an average force of 6.2 kg or 60.83 N. The time taken to cut off a single frond ranges from 4 seconds to 11 seconds, with an average of 7.2 seconds. In short, this project has successfully developed a prototype for harvesting oil palm fronds more efficiently and safely compared to traditional methods. The prototype has been tested for its functionality and feasibility, and the results show its potential for improving the harvesting process. Further field testing and improvements can be made to enhance the prototype's performance and effectiveness.

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LIST OF SYMBOLS / ABBREVIATIONS

k	spring rate, N/mm
G	slip modulus, MPa
d	wire thickness, mm
D	outer diameter, mm
L_c	length of the fully compressed spring, mm
L_n	maximum compressed length, mm
N	number of active coils

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Oil palm trees are a valuable source of oil, and harvesting their fruits is a crucial activity in the oil palm industry. Traditionally, harvesters use a long pole embedded with a sickle or knife to harvest the fruit bunches from tall oil palm trees, which can be physically demanding and result in waist pain for the harvesters.

This project report focuses on introducing a new idea for harvesting tall oil palm trees, which aims to reduce the energy consumption of harvesters and eliminate the discomfort they experienced. The new idea revolves around redefining the springs application and utilizing the mechanical advantage of the springs to make the harvesting process easier.

Locally, the cutlass or the chisel is used to cut the bunches and fronds from short trees within arm's height. However, when it comes to a tall tree, for example, 7m height, the harvesters will use a long pole embedded with a sickle or knife to harvest the fruit bunches, and the length of the pole depends on the average height of the tree in the plantation. This is the conventional harvesting method implemented in Malaysia. While the conventional harvesting method has been implemented in Malaysia, this project proposes a pole-and-knife springs system that can be a more efficient and effective alternative. The project report aims to provide an overview of the new idea, including its design, construction, and potential benefits. Ultimately, the goal is to improve the harvesting process of oil palm trees and enhance the productivity and welfare of harvesters.

1.2 Importance of the Study

Oil palm has become the world's leading economic crop due to its wide range of applications, including as a source of palm oil used in food and non-food products. For instance, palm oil has contributed to several health benefits, and it may help protect brain function, reduce heart disease risk factors, and increase vitamin A levels in certain people (Franziska Spritzler, 2022). Not only that, palm oil can also be the raw material for toothpaste, soap, washing powder, and cosmetics. Therefore, this fact has made palm oil much more popular and caused it to become the world's leading economic crop. Figure 1.1 roughly shows the palm oil production and consumption in Malaysia reported by Mohd. Izham Hassan, et al. (2021).

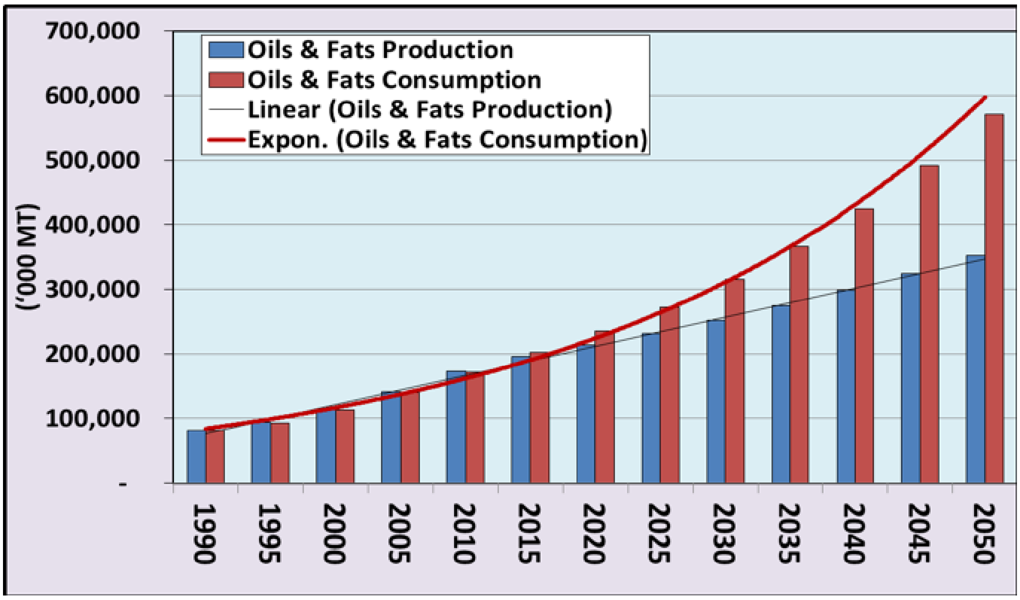


Figure 1.1: Palm oil production and consumption from year to year and forecasting chart (Mohd. Izham Hassan, Rina Mariati and Desmond Ng, 2021)

On top of that, the palm oil industry expands rapidly, and the demand for palm oil rises from time to time. This rapid expansion of the palm oil industry and increasing demand for palm oil has highlighted the need for efficient and safe harvesting methods that can keep up with market demands while ensuring the safety and well-being of harvesters (Thomas Baker et al., 2015).

The outcome of this study is expected to provide significant insight into the optimization of the harvesting activity of oil palm fruit with:

(I) The implementation of the spring mechanisms onto the existing pole-and-knife harvesting method.

(II) The implementation of spring mechanism onto the existing pole-and-knife harvesting method is expected to reduce the time and energy required during the harvesting process while improving the comfort and well-being of the harvesters,

which can lead to increased productivity and profitability for the palm oil industry.

1.3 Problem Statement

The problem statement for the current study on the development and implementation of pole-and-knife springs system can be summarized below:

Harvesting oil palm fruit is a laborious and energy-intensive task, with even cutting a single frond requiring a significant amount of force. The Journal of Oil Palm Research reports that the force required to cut off the oil palm frond requires a force of ranged from 80 N to 200 N, depending on the size and age of the frond (Razak Jelani et al., 1999). The time taken to cut off an oil palm frond using motorised cutter is within 6-10 s depending on the skills of the labour (Jelani et al., 2018).

(I) The proposed solution to this problem is to implement different variation of springs onto an ordinary pole-and-knife cutter used for oil palm fruit harvesting. The implementation of springs can provide a mechanical advantage that can response to an equal or larger force. However, the detailed mechanism of the proposed design needs to be tested and verified to determine its feasibility. It is questionable whether this implementation can lighten the harvester's energy and increase the harvesting process's efficiency.

(II) There are many configurations or types of a spring that can achieve its mechanical advantage, depending on what are the spring application or how the force is applied on the spring. Therefore, a question remains: What is the optimized type of spring that uses to implement onto the pole-and-knife cutter?

(III) While there have been some studies on improving the harvesting method of oil palm fruit, the studies implementing springs on ordinary pole and knife cutter in this field is not yet common.

1.4 Aim and Objectives

The primary objective of this project is to address the current inefficiencies in oil palm fruit harvesting by designing and developing an integrated pole-and-knife springs system cutter in Malaysia. The specific objectives of this project were:

(I) To develop an efficient pole-and-knife springs system cutter by balancing the applied force against the maximum load output.

(II) To evaluate the performance of the pole-and-knife springs system in terms of energy consumption and harvesting time effectiveness.

(III) To address the current issues of oil palm harvesting, namely inefficiency and lack of productivity, and improve the user experience for the workers.

Through these objectives, the project intends to contribute to the improvement of oil palm fruit harvesting methods while enhancing the safety and well-being of harvesters.

1.5 Scope and Limitation of the Study

The overall enhancements to the current oil palm fruit harvesting tool were the basis for determining the project's scope. Some new ideas can be made to the previous year's mechanism. The improvement to the current pole-and-knife system includes bringing in an effective and easy-to-use springs system, adding to ease the harvesting process and redesigning the structure of the pole-and-knife cutter so that it can be a good combination.

There are a variety of considerations that will play a vital role in the design of the oil palm fruit harvesting tool. Since this new idea this implementation onto the harvesting tool is rarely seen in oil palm industry, few researchers have studied it and finding relevant references has been challenging for researchers. One such factor is the field testing phase, which is essential to evaluate the tool's efficiency and effectiveness. However, it is challenging to locate oil palm trees in the area, and the tool's capability to harvest only 3-meter tall trees may limit its use for younger oil palm trees that are three to five years trees.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

From an agricultural point of view, harvesting is a crucial process of gathering the useful parts or in other words, mature crops from the field. Whereas, harvesting operation can be divided into two categories, namely hand harvesting and mechanized harvesting. In the oil palm industry, harvesting the oil palm fruits has always been a challenging task that has garnered significant attention over the years. Many approaches have been attempted to ease the process and increase the efficiency of oil palm fruit harvesting. Furthermore, many recent studies have focused on the implementing motorized machine, robotic arm or drone to solve the current issue, it indeed has their own advantages, however, these alternatives are not yet widely accepted by workers or employers due to its drawbacks and relatively costly as compared to the ordinary harvesting tool. Additionally, the implementation of mechanical spring onto the ordinary harvesting tool, which may provide significant mechanical advantages, has been overlooked in oil palm fruit harvesting.

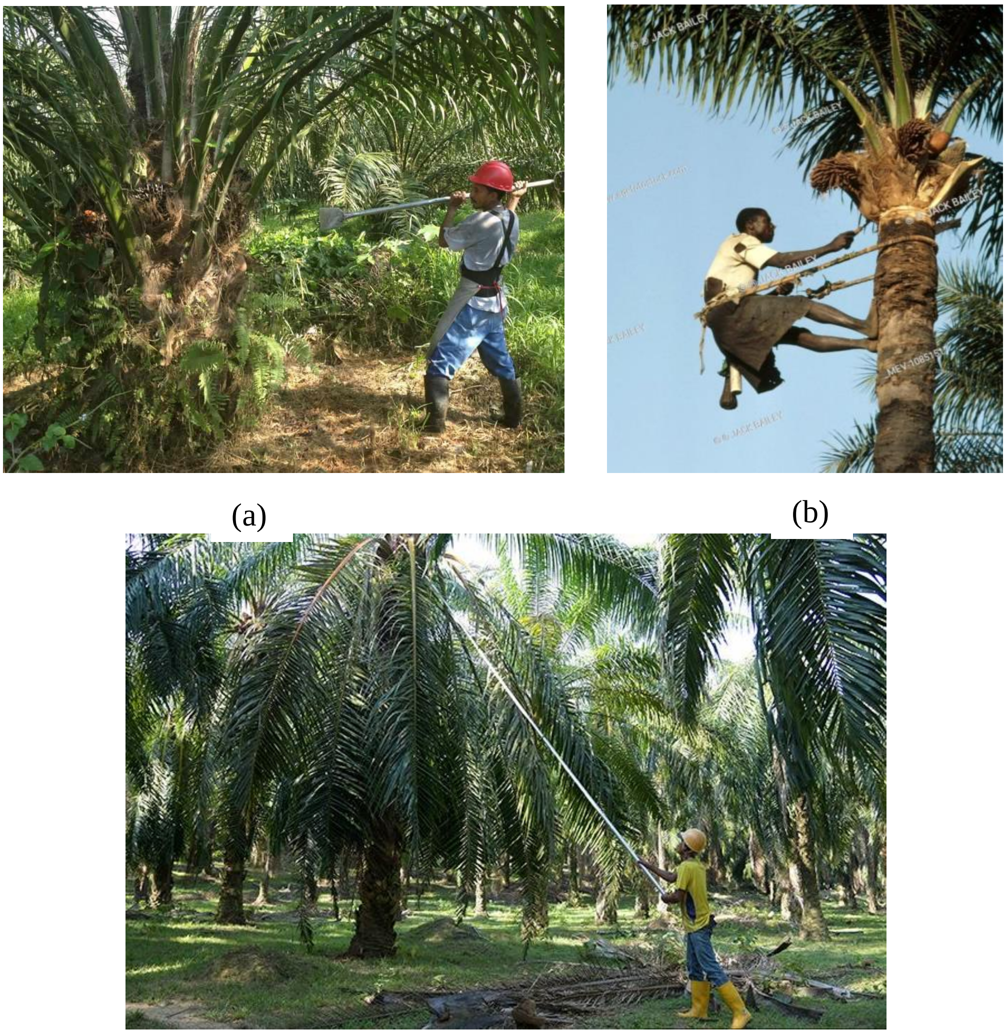
This chapter will review the harvesting tools currently in use on the plantation as well as the research of the most recent advancements of those harvesting tools. Not only that, and yet this chapter will also review the other applications that make good use of the mechanical springs, particularly cutter application. At the end, develop a pole-and-knife springs system is the main focus of this development project. Apply the knowledge of mechanical springs onto the ordinary pole-and-knife cutter and the proposed design will be tested in the field to evaluate its effectiveness in reducing human energy consumption, harvesting time, and labour costs.

2.2 Ancient tools used in oil palm harvesting

To harvest the fresh oil palm fruit bunches, harvesters should cut off the underlying palm tree’s fronds together with the oil palm fruit bunches, afterward it is allowed to fall freely on the ground (Owolarafe and Arumughan, 2007). Figure 2.1 shows how the oil palm fruits grow alternately on the treetop.

Figure 2.1: Close view of oil palm treetop with fruits (Donyanedomam, 2014)

Over the decade of years. There are various of tools developed to harvest the oil palm fruit. Adetan et al. (2007) had summarized several methods and tools used for oil palm fruits harvesting. Basically, the short trees with 3-5 years-old within arm-reach height are harvested using the tool called chisel or cutlass to cut the brunches and fronds. This is a relatively simple way of harvesting since the oil palm tree is still young and short. The chisel will aim at the target point at a high speed in order to cut off the fronds. The high speed of this action can provide a high momentum and enough energy to cut off the frond (Razak Jelani et al., 2008). Under other conditions, which the trees are very tall, above 9m in height, an aged method called rope-and-cutlass method is used. In this method, harvesters manually climb up the tree using the rope tied around the tree trunk, once when the harvesters climb up almost to the tree crown, harvesters use a cutlass or axes to cut the fronds and bunches. Besides, adult oil palm trees that beyond arm-reach height, rope-and-cutlass method is no longer suitable, on the contrary, the pole-and-knife method is employed. In this method, a sickle is attached at the end of the long pole, then the harvester stands on the ground and raises the pole and sickle to the tree crown to cut off the fronds and bunches. Figures 2.2 clearly shows how harvester harvest oil palm fruits using the method mentioned above.



(a) (b)

(c)

Figure 2.2: Harvester using chisel to cut the frond and bunch (a); harvester climbing tree to remove bunches of fruit (b); harvester cutting off fronds and bunches using a long pole (c) (Leonix Peter, 2018) (Anon, 2021) (Jack Bailey, n.d.)

In short, to harvest young tree it is relatively simple and safe since it is within human arm-reach height. However, when the oil palm trees become taller, rope-and-cutlass or pole-and-knife is utilized. These two methods are more common in oil palm plantation nowadays. Anyhow, these two methods have its own limitations, and the harvesters will put themselves in danger where harvesters climb up the tress to cut down the bunches. There will be the risks of accidental falls and being bitten by insects. On the other hand, the pole-and-knife method found it difficult to be comfortably used for harvesting tall trees due to the bending of long and heavy pole. This results in controlling the pole and engaging the stalks of the fronds and bunches becomes very difficult. Besides, the harvesters' skill and safety are also a critical problem in harvesting activity (Aramide and Adeyemi, 2015).

2.3 Advanced Harvesting Tools (Related studies)

An article established by Adetan, et al. (2007) had commented that the research effort and direction should preferably toward to improve the pole-and-knife method. This is due to the pole-and-knife method being more swift, effective, and secure than the rope-and-cutlass method. Therefore, there are several advanced harvesting tools or method being developed to solve the puzzle.

2.3.1 Modified pole-and-knife method

A work carried out by Adetan, et al. (2007) had an idea that improved design of the harvesting pole. This article also had carried out a field test which include the rope-and-cutlass method, conventional pole-and-knife method and the modified pole-and-knife method, to study the efficiency among three of them. According to the results and discussion, the modified pole-and-knife method performed an excellent outcome as compared with the rest. This chapter will only discuss the results that will help this development project. The time taken to cut the fronds and bunches using the modified pole-and-knife method is significantly lesser than the others, meaning this method indeed reduce the force exerted and the energy of the harvester, considerably ease the harvesting process. This is a valuable finding that has meet the objective of this development project. But of course, this is also due to the improved design of the harvesting pole, which makes it easier to raise the sickle to the tree crown and then significantly reduce the time taken to cut off the fronds and bunches.

Speaking about the improved pole design of this method, the pole was divided into three sections made from different length. The main feature of this design is that the pole can easily assembly and disassembly to adapt different tree height. Due to its adjustable characteristic, this harvesting pole able to harvest trees on different plots conveniently (Adetan et al., 2007). Another advantage of this useful feature is that this kind of design can make the transportation of the harvesting pole become easier. The three sections can disassembly and tie together instead of just carrying a long and heavy pole. Figure 2.3 shows the sketch design of the modified harvesting pole.

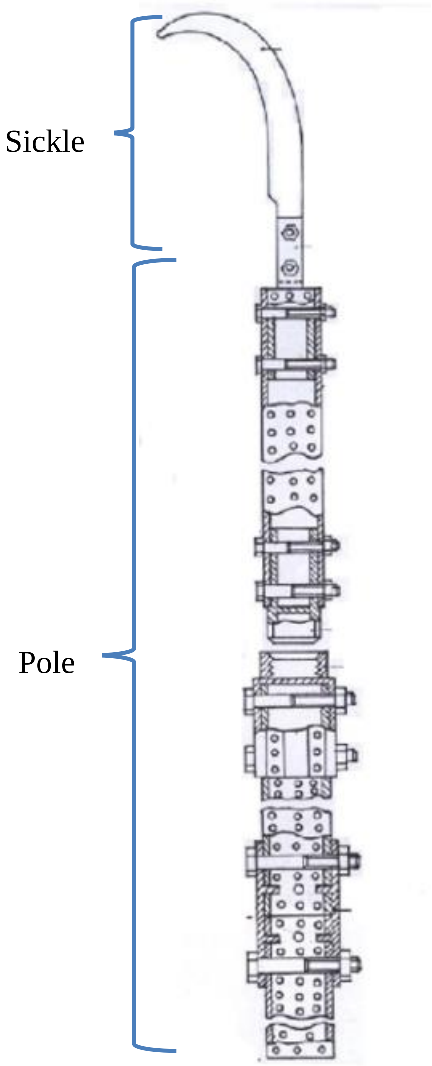


Figure 2.3: Sketch of the pole of modified pole-and-knife method (Adetan et al., 2007)

Throughout this literature, there are two main takeaways that will help with this development project. Firstly, the characteristic that easy to carry should be considered in the design criteria of this pole-and-knife springs system. Otherwise, if the development pole-and-knife springs system indeed could reduce the energy of harvester during the harvesting process but the portability of this development being neglected, that would be outweigh the benefits. Secondly, the variable length of the pole makes it able to harvest both tall and short trees, thus increase its flexibility to harvest the trees on different plots. This design criteria are strongly required in this development project, because while helping the harvesters reduce their energy, the flexibility of the harvesting tool should also need to be guaranteed. Last but not least, this article also mentioned a critical point which is the bending of the long harvesting pole could increase the difficulty of the harvesting process and it is being solved.

In short, these excellent characteristics that learnt from this literature need to be considered to the design criteria in order to achieve the objectives.

2.3.2 Palm Harvester Telescoping Pole

This section will analyze and evaluate an invention carried out by Thomas Baker, et al. (2015). Besides that, will summarize the major findings and implications, further absorb the advantages of this invention turn it into own strengths.

From Thomas Baker, et al. (2015), it was concluded that the traditional harvesting way was inconsistent, inefficient and dangerous. Besides, it also emphasized that in current oil palm industry, there is a need to have an efficient and safe way to meet the worldwide palm oil demand and at the same time to keep the harvesters in a safe manner. Therefore, the project team in this research came out with a design of telescoping harvesting pole with wheels, pulley system, and motor embedded. Figure 2.4 shows an overall sketch of the design of the telescoping pole from the project team.

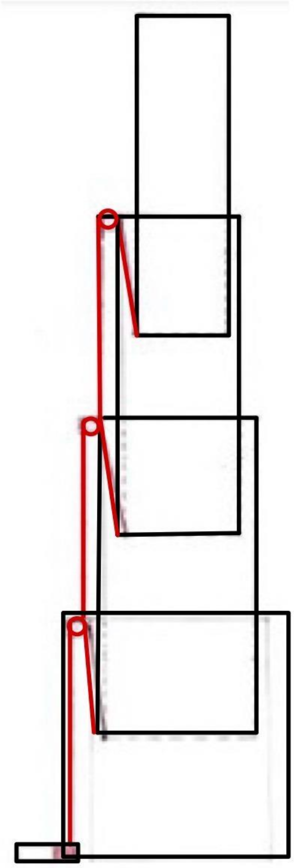


Figure 2.4: Sketch of telescoping pole with pulley system (Thomas Baker et al., 2015)

For this design, the telescoping pole with variable height can solve the issue of the different tree heights and increase its flexibility. This is what this project needs to follow suit. Besides that, the role of the wheels is that ease the transportation of the whole harvesting pole from tree to tree and further increases its mobility. However, the implementation of wheels is not suitable for this developing project because this implementation may increase the complexity of the whole design of the pole-and-knife springs system. This development project should only pay more attention to the modification of the pole. Next is the pulley system. The pulley system of this telescoping pole is used to control the up and down motion of the telescoping pole. However, Thomas Baker, et al. (2015) had proposed to add sheathing or alignment sheave to the system. The major purpose for the adding was to act as a guide for the cabling to prevent misalignment of the cable on the pulley, make it always maintain at the vertical alignment throughout the whole operation. Also, this addition can prevent anything from obstructing the pathway.

In a short summary, the project team wanted to deliver some outstanding features that will reduce the risk of the harvester, minimize manpower, diminish the ergonomic risk and improve the efficiency. The most valuable lesson from this literature was that the feature that prevent the misalignment of the cabling and the knowledge or feature of the telescoping pole with variable length. The addition of this feature may increase the stability of the final product. The other features such as wheels or motor indeed have their own purpose but somehow may also have limitations. For instance, the soil of oil palm tree plantation is soft and the wheels may not operate well. Although the wheels have some special features or it had well engineered, make it can roll on the soft soil, but the plantation also have a lot of potholes and the ground of the plantation could become very slippery after a rainy day. Meaning that is very depends on the topography of the plot. These factors could affect the performance of the wheels. Secondly, the implementation of the wheels may increase the cost of the system and may increase the level of the troublesome because of the need of maintenance.

2.3.3 EC-CUT Hammer cutter

EC-CUT hammer cutter is a new development that was developed by TenAsia, a Malaysia-based agricultural equipment manufacturer. It is designed to be used for harvesting oil palm fruit and is marketed as an effective and efficient solution to the challenges faced by manual harvesting.

This hammer cutter designed by TenAsia is different from the ordinary pole and knife cutter which it consists of moving sickle with hammering effect. Figure 2.5 shows the motion of the EC-CUT hammer cutter.

Figure 2.5: Motion of the hammering effect (Anon., 2015)

According to TenAsia, this type of cutter is suitable for new and unskilled workers, make it easier for them to harvest oil palm fruits. Besides that, it can also solved the problem of the sickle being stuck problem. In fact, in the actual scenario, the sickle may having chance to get stuck. This may be due to the improper angle of the sickle during cutting the frond, the dullness of the sickle, inappropriate techniques used by the harvester and the condition of the frond. However, with the momentum provided by the hammering effect, the stucking issue can rarely happen, because the motion of the sickle does have the displacement and can provide sufficient momentum to overcome the stuck problem.

2.3.4 Motorized Cutter (Cantas)

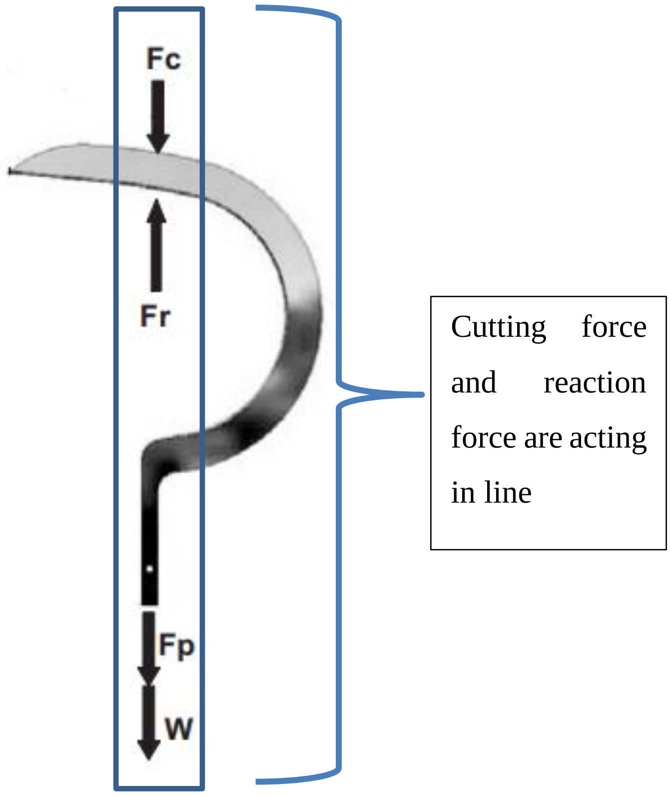
Recent years, Malaysian Palm Oil Board (MPOB) had developed a motorized cutter popularly known as Cantas. Generally speaking, Cantas is a hand-held cutter powered by a gasoline engine. A research article published by Razak Jelani, et al. (2008) had investigated the functionality of Cantas in different aspect namely time and motion study, cost effectiveness, commercialization, and its market potential. Although the design concept of Cantas is different from this development project, but the central theme for both is almost the same which is help on converse the harvesters energy and reduce their fatigue in order to prolonging the working hours. In the end, increase the productivity. Besides, this section will review this investigation and analyze what are the values that are worth to learn.

According to the research, Cantas has the design requirement that can:

(I) Reducing manpower in the harvesting operation
(II) Lowering production cost
(III) Increasing worker productivity, and
(IV) Reducing worker’s effort during the harvesting operation

Also, Razak Jelani, et al. (2008) commented that an excellent oil palm fruit cutter should have following characteristics: namely, easy handling by harvester, efficient in harvesting, comfort in handling and have good ergonomic design. The all above points or characteristics should be follow suit by this development project in order to come out with an excellent harvesting tool.

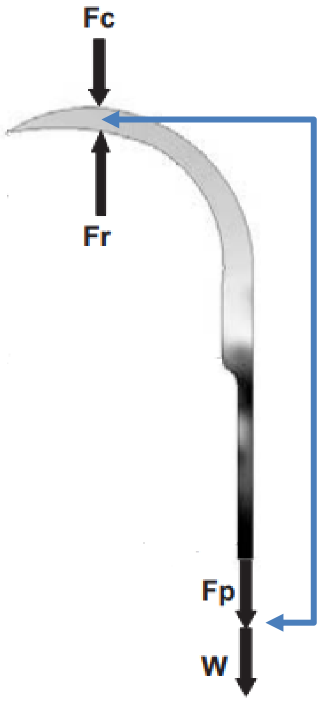
In the perspective of designation, the sickle embedded in motorized cutter is different from the conventional cutter. The sickle of motorized cutter is designed to a C-shape profile. The reason is the structure of this C-shaped profile can minimize the vibration to the harvester and thus increasing the cutting efficiency. Using the C-sickle, the cutting force exerted by the harvester will act in line with the reaction force created by the tree frond, in the result giving the maximum cutting force. Figure 2.6 provides clearer illustration to the flow of force on the C-sickle.



Cutting force and reaction force are acting in line

Figure 2.6: Forces acting on C-sickle (Razak Jelani et al., 2008)

However, when the situation come to the conventional sickle, the vibration generated due to the unbalance forces cannot be neglected. This is because the profile of the conventional sickle is J-shaped. Figure 2.7 provides clearer illustration to the flow of force on the J- shaped sickle. From the free body diagram of the J-shaped sickle, it is shown that the cutting force and reaction force are not acting inline.



Cutting force and reaction force does not acting in line.

Figure 2.7: Forces acting on conventional sickle (Razak Jelani et al., 2008)

Therefore, with the implementation of C-sickle, the unnecessary moment caused by the unbalanced force and then the occurrence of the vibration can be neglected. Besides, the pole of Cantas is telescopic. This makes the length of Cantas can adjustable. The other components of Cantas include petrol engine, gear set, connecting rod head casing and cover.

Furthermore, Razak Jelani, et al. (2008) also investigated and compared the performance between Cantas and the conventional pole-and-knife method. According to the result summary, Cantas has better performance, it can harvest more fresh fruit bunch per day and require less manpower. In short, using Cantas requires less manual labour because the engine drives the cutting action, which boosts productivity. From the economic perspective, it is found that using Cantas can save a lot of costs such as labour cost. Although Cantas was accepted by the industry because of its productivity, however, the acceptance of this machinery by workers should be more encouraging. This is because the implementation of automation should need to take good care and frequent maintenance. These require the effort of the workers. Furthermore, as the Cantas is powered by an engine to facilitate automation, it is inevitable that certain vibrations may arise while handling it. This vibrational force may cause the harvesters feel discomfort and eventually may cause injury to them in a long run. The another limitation was this cutter can only harvest oil palm trees up to 4.5m (Aramide and Adeyemi, 2015), yet the oil palm tree may keep growing for over 5 decades and its height can reach over 10m.

2.3.5 Robotic arm

In this century, the invention of robotic arm is no longer novelty. Engineers are adept at identifying and implementing innovative ways to effectively utilize robotic arms for variety of tasks, including the crucial process of crop harvesting. Indeed, the implementation of robotic arm technology has been investigated as a potential solution to improve the efficiency of harvesting oil palm fruits. The use of robotic arm technology for harvesting has the potential to reduce labor costs and increase productivity. Furthermore, the implementation of this technology can help alleviate the shortage of labor experienced in the oil palm industry. Figure 2.8 shows one of the examples that use robotic arm for harvesting oil palm fruits.

Figure 2.8: Harvester manipulator with robotic arm proposed by Razali et al., 2020)

Several studies have been conducted to evaluate the feasibility of implementing robotic arm technology for oil palm fruit harvesting. They had evaluated the performance of a robotic arm for harvesting oil palm fruits. The robotic arm was equipped with sensors to detect the position and size of the fruit bunches. The results of the study showed that the robotic arm was able to harvest oil palm fruits with a success rate of over 90%, with a mean time of 28 seconds per bunch.

However, despite the potential benefits of robotic arm technology for oil palm fruit harvesting, there are several challenges that must be addressed. One of the main challenges is the complexity of the oil palm tree structure, which makes it difficult for the robotic arm to access the fruit bunches. In addition, the uneven terrain of the oil palm plantation also presents a challenge for the implementation of robotic arm technology.

Moreover, the implementation of robotic arm technology for oil palm fruit harvesting requires a significant investment in terms of capital and maintenance costs. This may be a major barrier for small-scale oil palm growers, who may not have the financial resources to invest in this technology.

In a small summary, the implementation of robotic arm technology for oil palm fruit harvesting has the potential to improve the efficiency of the harvesting process and reduce labor costs. However, there are several challenges that must be addressed, such as the complexity of the oil palm tree structure and the uneven terrain of the plantation. Therefore, further research is needed to overcome these challenges and evaluate the feasibility of implementing this technology in the oil palm industry.

2.3.6 Tree Pruner / Pole Pruner

The tree pruner is the tree branches trimmer that utilized the combination of the pulley and string to cut off tree branches. Although the trimming process is different from the harvesting process, but the knowledge behind that implementation of pulley and spring is very beneficial to learn and study.

Figure 2.9 shows the conventional tree trimming system feature on the market.

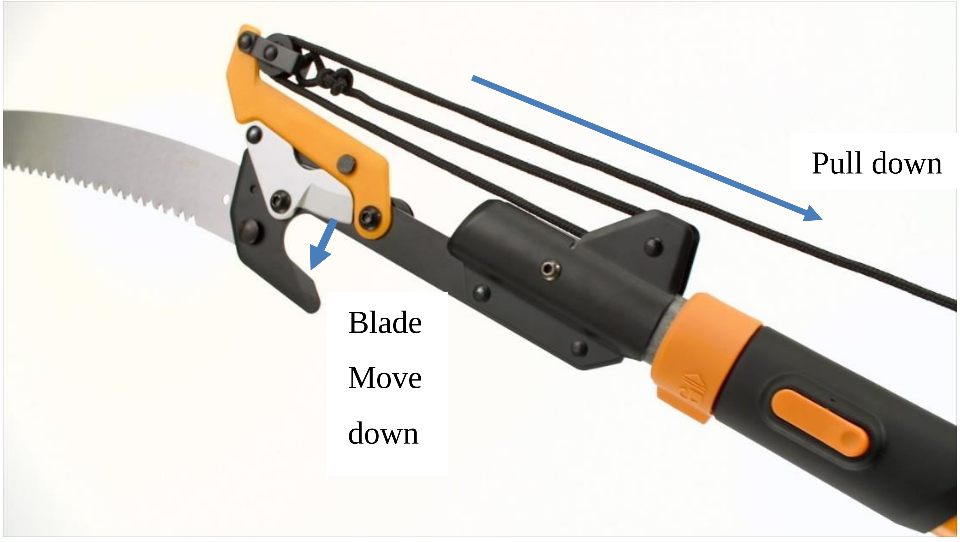


Figure 2.9: Pole Pruner (Fiskars Americas, 2017)

The cutting mechanism of the pole pruner required user to tug on the rope, and the pulley collaborate with the spring will start to operate. In the result, the blade will be moving down and make a cut. At the same time, the spring will being stretched. When the user releases pressure, the spring releases the stored energy, helping to complete the cutting action with less effort. This reduces the strain on the user's muscles and joints, making the tool easier and more comfortable to use.

2.4 Spring Mechanism

(Razak Jelani et al., 1999) had made a statement that a cutting tool could be powered by spring. The work also stated that spring powered tool may be an effective method to cut the oil palm fronds and fruits bunches. Indeed, the implementation of springs in harvesting tools is a relatively recent development in the field of agriculture. The purpose of the springs is to provide additional force and aid to the user during the harvesting process. This can increase efficiency and reduce physical strain on the worker. This statement can be validated because a compressed spring can store energy and it can release huge amount of energy, thus move at a very high speed once it is released (Site Editor, 2022). This ability of spring is beneficial for cutting fronds and bunches. Therefore, in current harvesting pole-and-knife method, the implementation of spring to that can become and efficient tool for cutting even without any hydraulic or automation motor embedded which are heavy and costly (Razak Jelani et al., 1999).

Apart from the ability of storing energy, spring also has the characteristic of high durability. Furthermore, it is easy to design and cheaper to produce. However, spring also has its limitations which spring will lose its elasticity and stability from day to day. Buckling phenomena could take place when the axial load of the spring is increased. Although it has its limitations, its benefits make it worth implementing.

Overall, the implementation of springs in harvesting tools can provide significant benefits to the user, including increased efficiency and reduce physical strain experienced by the harvesters. There are also several products embedding springs use to harvest crops, there all have potential to improve the efficiency and safety of the harvesting process. Further research and development in this area could lead to even more effective and innovative spring implementations in harvesting tools.

2.5 Summary

This section summarizes the major findings of the literature review and their implications for a development project on oil palm fruit harvesting. The review found that the ordinary harvesting method in Malaysia is not efficient and requires a lot of energy from workers. Therefore, advanced harvesting tools have been invented to increase efficiency and reduce the amount of energy required. Examples of these tools include the modified pole-and-knife method, palm harvester telescoping pole, EC-CUT hammer cutter, Cantas, and robotic arm.

However, these advanced methods have not become popular due to certain limitations. Therefore, the development project should aim to design a tool that increases efficiency while reducing worker fatigue and is easy to operate. The tool should also have an adjustable length to accommodate different tree heights, an efficient cutting mechanism, such as implementation of springs to increase efficiency further. By considering these factors, the development project can design a harvesting tool that is efficient, effective, and reduces the burden on workers.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

In this chapter, the research methodology for developing the pole-and-knife springs system for oil palm harvesting will be outlined, with the aim of reducing the energy consumption of harvesters, reduce fatigue and mitigating the waist pain they experience. The chapter will also detail the approach taken to carry out the project, including the tools and software utilized for designing the system. Additionally, the methodology used to evaluate the performance of the pole-and-knife springs system will be described. Any limitations or challenges faced during the project will also be discussed.

3.2 Methodological Approach

The methodology of a research project is crucial in determining its success. For this particular project, the methodology was focused on the utilization of knowledge and the implementation of a mechanical spring system onto the ordinary pole-and-knife method used to harvest oil palm fruits. On top of that, aiming to reduce the harvester’s effort by at least 30%, thus, increase the harvesting efficiency.

The first step in the methodology was to define the problem statement, aims, and objectives. This was followed by several research actions to gather information and knowledge about the harvesting tools used in the oil palm industry currently, which allowed the project could identify the strengths and weaknesses of existing tools and develop a design that would address these issues.

Throughout the project, a set of milestones were identified to ensure that the team stayed on track and successfully completed the project goals. The first phase was the define phase, which involved defining the objective of the project, the project scope, gathering requirements, and proposing an approach. Once the goals and objectives were identified, the project moved into the conceptual design stage. The conceptual design of this pole-and-knife spring system was drawn using SolidWorks. Several characteristics were identified which including:

(I) Portable
(II) Easy to carry
(III) Easy to use
(IV) Must not be too heavy
(V) Cost-effective

The conceptual design was then analyzed to prepare the list of parts and materials needed in the project. Next, a plan of action was developed to fabricate and assemble the pole-and-knife cutter prototype. The next phase was the testing phase, which involved testing the mechanism, simulating it, and observing its functionality. During this phase, a hanging scale was used to measure and record the force exerted. This can allow the evaluation of the performance of the pole-and-knife springs system and identify any issues that needed to be addressed.

Based on the evaluation results, necessary recommendations and reflections were made to improve the pole-and-knife springs system and achieve a better outcome. This feedback was critical to the success of the project, as it allowed this project to continually improve the design and functionality of the pole-and-knife springs system.

In conclusion, a carefully planned and executed methodology is vital to the success of any research project. In this case, this project utilized the knowledge to create a mechanical spring system that improved upon the current pole-and-knife method used to harvest oil palm fruits. The team set milestones to stay on track, designed and analyzed the system, tested it for functionality, and evaluated its performance. The result was a system that reduced the harvester's effort by at least 20%, increased efficiency, and was portable, easy to use, lightweight, and cost-effective.

3.3 Conceptual design

Figures 3.1 and 3.2 show the sketch of the conceptual design and the detail view using AutoCAD respectively. Furthermore, the isometric CAD model view of the pole-and-knife cutter is presented in Figure 3.3, allowing for a comprehensive understanding of its intricate components. The design comprises a sickle, sickle holder, aluminum pole, compression springs, spring supporting plate, and wire rope, as revealed by the figures. The wire rope is connected the sickle holder and the spring supporting plate as shown in Figure 3.4. The conceptual design for the pole-and-knife cutter features the following general dimensions: a total length of approximately 2.8 meters, a pole diameter of 38 millimeters, and a spring dimension that is yet to be determined. Additionally, the spring supporting plate will need to conform to the size of the spring selected for the design.

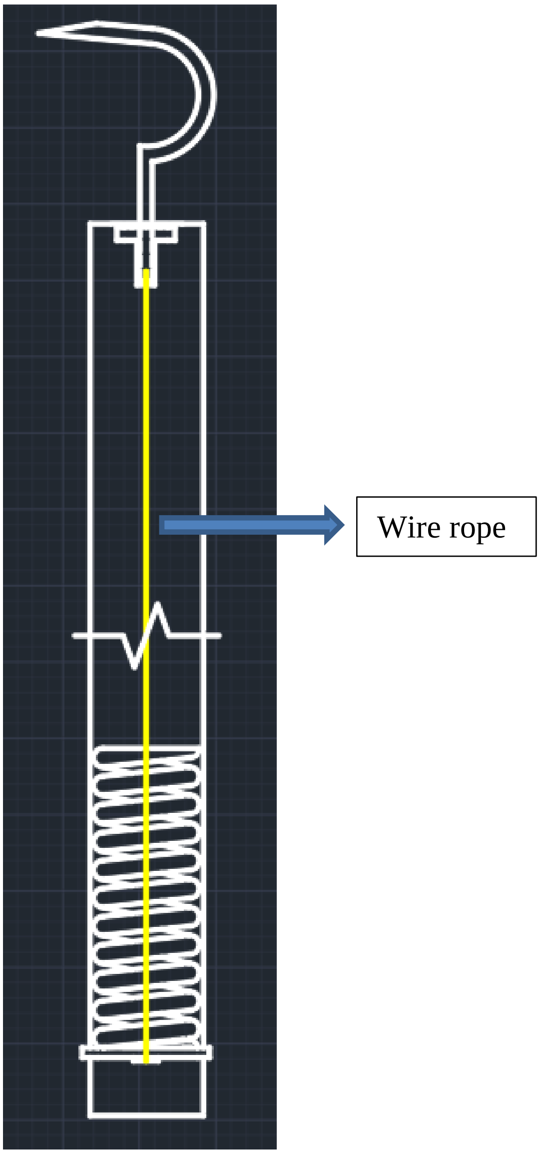


Figure 3.1: Sketch of conceptual design using AutoCAD

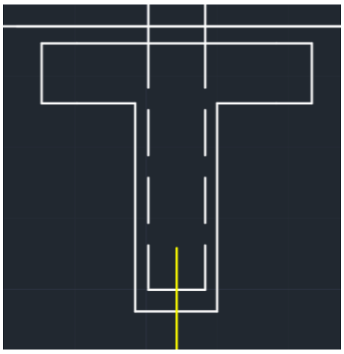


Figure 3.2: Detail view of Figure 3.1

Figure 3.3: Isometric View of pole-and-knife cutter

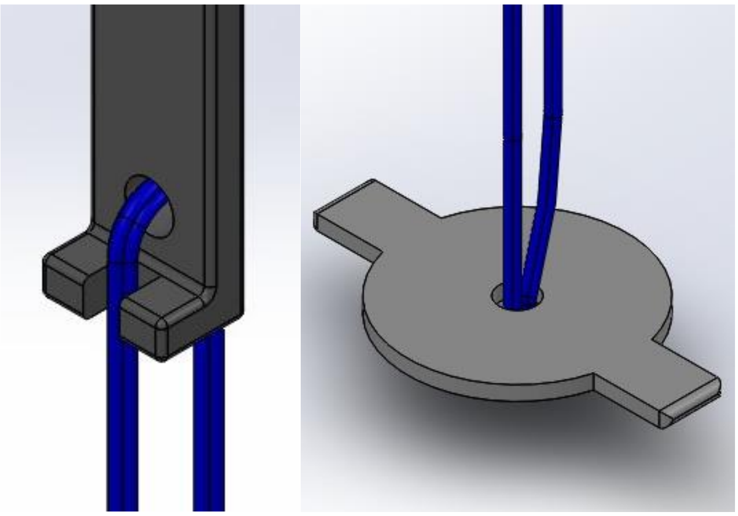
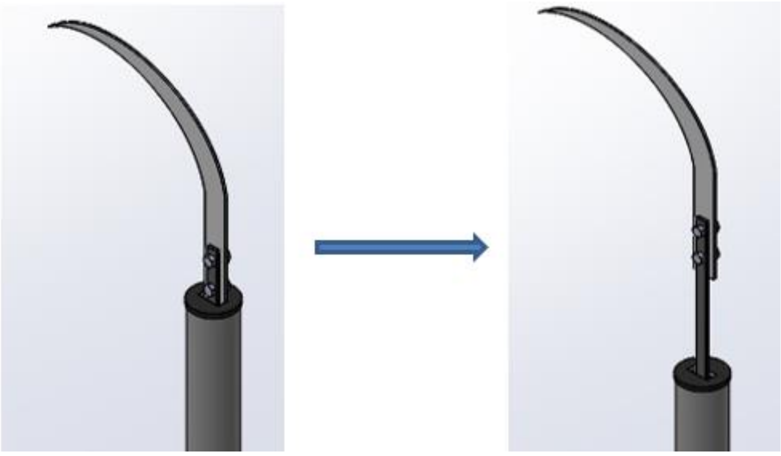


Figure 3.4: Sickle holder and spring supporting plate connected with wire rope

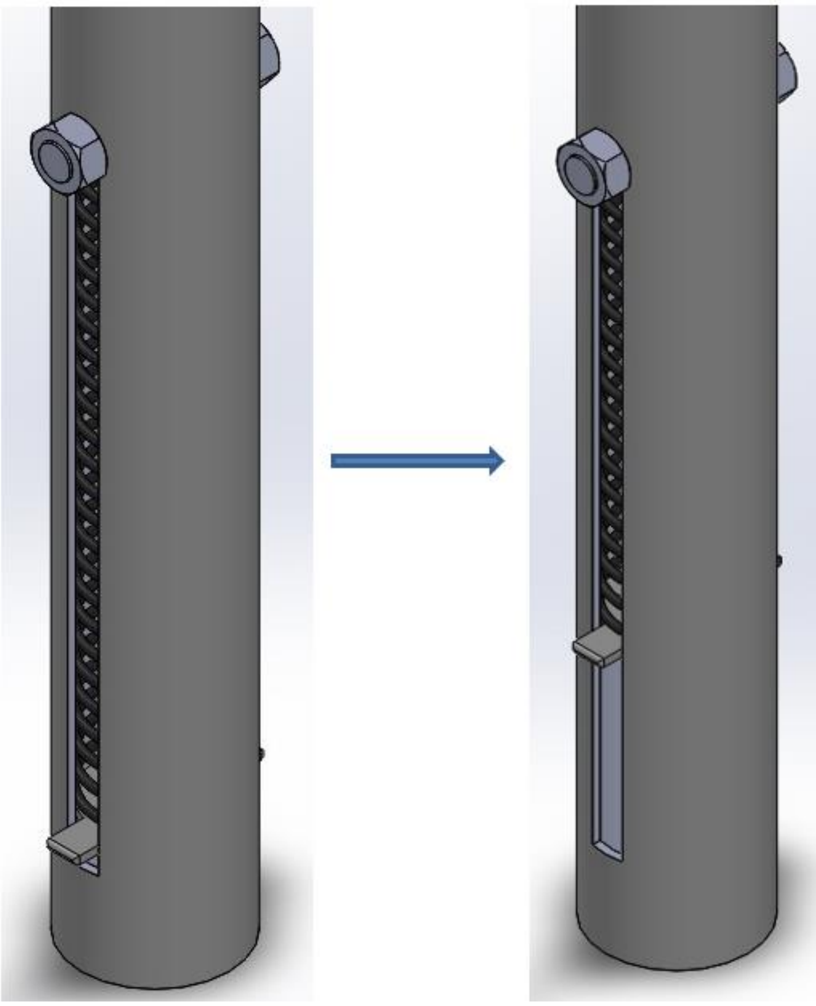
To operate this pole-and-knife cutter, harvester must first attach the sickle onto the targeted frond. It is noteworthy that the sickle of this cutter design can move both upwards and downwards, facilitating a hammering action. Next, the harvester must grasp the pole firmly and apply a pulling force. From the relative motion point of view, the pole is being pulled downward, while the sickle is behave in upward direction. As the wire rope is attached to both the sickle holder and the plate, the plate moves upward in tandem with the sickle. In the result, the compression springs are being compressed at this moment as the plate goes upward.

Once the harvester lets go of the pole, the compression springs release their stored energy and return to their original position. This action is repeated multiple times until the oil palm frond is successfully severed. The movements of the sickle and compression springs before and after the cutting action are further illustrated in Figures 3.5 and 3.6, respectively, providing clarity to the mechanism of the cutting action.



(a) (b)

Figure 3.5: Before (a) and after (b) form of the sickle



(a) (b)

Figure 3.6: Before (a) and after (b) form of the compression spring

3.4 Pole material Selection

Pole material selection is a critical aspect of oil palm harvesting, as it can directly impact the efficiency and safety of the harvesting process. The material used for the pole should be strong enough, while also being lightweight enough to be manoeuvrable and easy to handle. Additionally, the material should be durable enough to withstand the harsh conditions of the oil palm environment.

Some of the materials that can be used for oil palm harvesting poles include aluminum, fibreglass, carbon fibre or bamboo. The mechanical properties and some comments of each material are summarized as Table 3.1:

Table 3.1: Comparison of each suitable pole material

Material	Mechanical Properties	Comments
Aluminum	• Tensile strength: 90-690 MPa • Young's Modulus: 69 GPa • Density: 2.7 g/cm^3	• Light-weight, corrosion resistance, easy to manufacture, good strength to weight ratio, affordable. • Soft material.
Fibreglass	• Tensile strength: 62-124 MPa • Young's Modulus: 52-87 GPa • Density: 1.5-2.0 g/cm^3	• Strong, durable, and able to withstand exposure to environmental factors. • Brittle, limited fatigue resistance
Carbon fibre	• Tensile strength: 3-7 GPa • Young's Modulus: 200-500 GPa • Density: 1.75-2 g/cm^3	• Lightweight and extremely high strength-to-weight ratio, resistant to corrosion and fatigue. • Expensive, may not be suitable for all budgets.
Bamboo	• Tensile strength: 100-250 MPa • Young's Modulus: 8-30 GPa • Density: 0.6-1.2 g/cm^3	• Natural and renewable material that is lightweight and flexible, environmental friendly and biodegradable. • Brittle and susceptibility to moisture.

In this project, aluminum pole is selected due to its superior mechanical properties. The material's lightness and sturdiness make it an easy-to-handle option, which is particularly valuable in the context of the harvesting process. Furthermore, aluminum poles offer an affordable alternative when compared to other materials with similar mechanical features. While other materials were also considered, although carbon fibre has higher tensile strength and Young's modulus than aluminum, it is expensive and may not be suitable for all budgets. Fiberglass has good strength but is brittle and has limited fatigue resistance. Bamboo, on the other hand, is a renewable and natural material but is prone to moisture and is brittle. Overall, considering the project's requirements, aluminum is the most suitable material due to its excellent mechanical properties and affordability.

Ultimately, the choice of pole material will depend on a variety of factors, including the specific needs and the budget available. However, it is important to consider the durability, strength, and weight of the material, as well as its ability to withstand exposure to the elements.

3.5 Spring Selection

Spring is a great mechanical tool that will use in various application. Choosing the right spring for a particular application is crucial to ensuring its proper functioning and avoiding failure. Therefore, the process of spring selection should be done with careful consideration of the design requirements and specifications.

The selection of a spring involves several factors, such as the load requirements, space constraints, and environmental conditions. The first step in selecting a spring is to determine the load requirements. The load requirements can be calculated by analyzing the application and determining the amount of force that needs to be applied. This force can be constant or variable, and the spring should be chosen accordingly to ensure that it can handle the load without failure. Next is to consider the space constraints. The space which available for the spring in the application should be taken into account while selecting a spring. The spring should fit the space without compromising the performance of the application. Another critical factor in spring selection is the environmental conditions as certain conditions can affect the performance and lifespan of the spring. However, the environmental factor is not dominant in this case since in this project, the springs is design to place inside the aluminum pole. The most dominant factor is the space constraint.

There are several types of springs available in the market, such as compression springs, tension springs, torsion springs, and flat springs. In this design project, compression spring was selected as this type of spring require linear force which suit with the harvesting action using the pole-and-knife cutter.

3.5.1 Spring Parameters

The careful selection of components is crucial in any engineering project, and the dimensions of the pole-and-knife cutter are no exception. In this case, the dimension of the pole was meticulously chosen to be 35×38×2700 mm, representing the inner diameter, outer diameter, and length, respectively. Given that the springs were to be installed inside the pole, space constraints were the dominant factor in the selection process. Thus, the outer diameter of the spring had to be carefully considered, and the decision was made to select a spring with an outer diameter of 32 mm to fit within the available space.

In determining the optimal parameters for the springs to be utilized in the pole-and-knife cutter, the length of the spring also a crucial factor to be considered. As the harvester relies heavily on the displacement generated by the spring system to provide enough momentum for the knife to cut off the fronds, the spring length was carefully selected to ensure maximum efficiency. Thus, the total displacement of the sickle and the springs movement should reach 100 mm to 150 mm.

Lastly, the selection of the appropriate wire thickness is a critical decision, as it directly affects the functionality of the system. The wire thickness is directly proportional to the stiffness of the spring, meaning the thicker the wire, the stiffer the spring will be. Hence, a careful evaluation of the wire thickness options was necessary to ensure the optimal performance of the system. To determine the most suitable wire thickness for the pole-and-knife cutter, a series of wire thickness options were considered, including 1.5mm, 2 mm, 2.5 mm, and 3 mm. Each wire thickness was installed into the pole-and-knife cutter and subjected to a series of field tests to determine their functionality.

3.5.2 Sample calculation

The force required to cut off mature oil palm fronds using a sickle ranged from 80 N to 200 N (Jelani et al., 1999). Thus, the spring rate can be calculated accordingly.

Hooke’s Law: $k = \frac{F}{x}$, let the spring travel $x = 120\ mm$,

$$k_1 = \frac{80}{120}$$
$$k_1 = 0.667\ N/mm$$
$$k_2 = \frac{200}{120}$$
$$k_2 = 1.667\ N/mm$$

The spring rate selected should be in the range of 0.667 N/mm to 1.667 N/mm. With this range is said to be suitable to be use. To calculate the spring rate, a formula incorporating the slip modulus, wire thickness, outer diameter, and number of active coils has been employed:

$$k = \frac{G \times d^4}{8 \times D^3 \times N}$$

Where,
k = spring rate, N/mm
G = slip modulus, MPa
d = wire thickness, mm
D = Outer diameter, mm
N = number of active coils

Next, is to calculate the minimum untensioned length of the compression spring. To do so, the length of the fully compressed spring (L_c) must first be calculated.

$$L_c = [d \times (N + 2)] \times 1.0064$$

However, it is important to note that fully compressing a spring until its turns lie on top of each other can significantly reduce its lifespan and cause unnecessary stress on the steel. To avoid this, the maximum compressed length parameter (L_n) is used:

$$L_n = L_c \times 1.15$$

Finally, the minimum untensioned length can be calculated. The minimum untensioned length is then the minimum design length that must be adhered to for this spring.

$$Min\ untensioned\ length = \ L_n + spring\ travel$$

$$k = \frac{79000 \times 2.5^4}{8 \times 32 \times 17}$$
$$k = 0.6925\ N/mm$$

$$L_c = [2.5 \times (15 + 2)] \times 1.0064$$
$$L_c = 47.8\ mm$$

$$L_n = 42.77 \times 1.15$$
$$L_n = 54.97\ mm$$

$$Min\ untensioned\ length = \ 54.97 + 120$$
$$Min\ untensioned\ length = 174.97\ mm$$

As a result of the calculations, it has been determined that the compression spring can be used with an untensioned length of 174.97 mm or greater. It should be noted that altering the length of the compression spring does not have an impact on its spring rate. These calculations were performed utilizing Microsoft Excel and are presented in the Table 3.2 for various parameters.

Table 3.2: Sample calculation using Microsoft Excel

Compression spring calculation						
	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
G	79000	79000	79000	79000	79000	79000
d	1.5	2	2	2.5	3	3
D	32	32	32	32	32	32
N	14	7	15	17	15	25
k	0.1090	0.6888	0.3215	0.6925	1.6273	0.9764
Design control factor						
x	120	120	120	120	120	120
L_c	24.15	18.12	34.22	47.80	51.33	81.52
L_n	27.78	20.83	39.35	54.97	59.03	93.75
Minimum untensioned length	147.78	140.83	159.35	174.97	179.03	213.75

Table 3.2 provides a valuable insight into the selection of suitable springs for the pole-and-knife cutter, based on their spring rates. As per the results, options 2, 4, 5, and 6 exhibit suitable spring rates that can be considered for installation in the cutter. However, it is imperative to validate these configurations by cross-checking them with the catalog provided by the supplier to ensure their compatibility and reliability. It is essential to note that selecting the appropriate spring configuration plays a crucial role in the overall effectiveness and efficiency of the cutter. Therefore, further testing and analysis should be conducted to determine the optimal spring configuration that can provide maximum performance and safety.

3.6 Flow Chart

The schematic representation of the Final Year Project can be found in Figure 3.7. This detailed flowchart provides an overview of the entire project from start to finish, encapsulating its key stages and summarizing the complex process in a concise manner. By following the flowchart, it becomes evident that the project was systematically executed with a well-defined methodology. This allowed for greater efficiency, accuracy, and success in achieving the project's objectives.

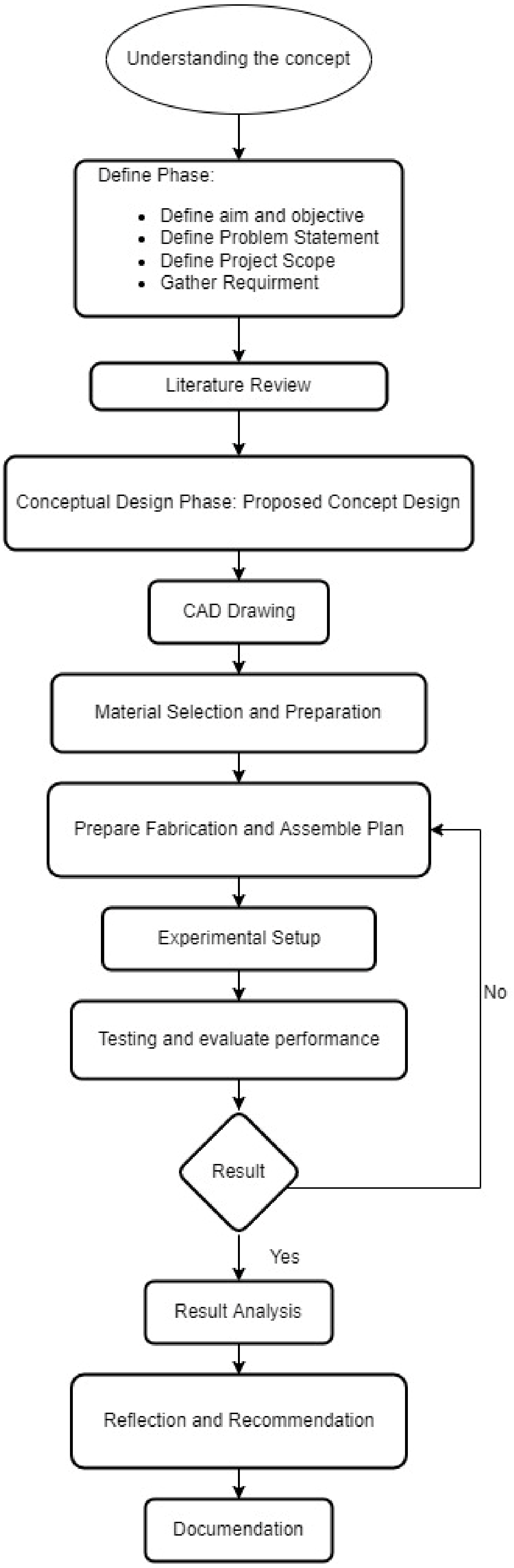


Figure 3.7: Flowchart for FYP

3.7 Methodological Limitation

In the journey towards developing the research methodology and work plan, limitations are to be expected. One such limitation is in the testing phase where the proposed method involves the use of a digital hanging scale to measure the force exerted by the user. The aim is to determine if the force applied is less than the force required to harvest oil palm fronds using the conventional harvesting method. While this testing procedure may prove that the force exerted by the worker is reduced, it does not necessarily prove an improvement in harvesting efficiency. To fully evaluate the performance of the harvesting tool, a field test is required, as indicated by previous research done by Jelani et al., (2008). This field test would not only examine the force exerted but also record the time to harvest a fresh fruit bunch and the number of fresh fruit bunches harvested within a specific time period. However, a limitation to conducting this field test is the absence of oil palm plantations nearby, which presents a significant challenge.

Regarding the testing phase limitation, one possible solution is collaborate with a local plantation owner or agricultural research institution that has access to oil palm plantations for conducting the field test. By collaborating with these entities, it would be possible to conduct field tests in a more suitable environment and obtain valuable feedback from experienced laborers. This approach would offer a wider range of observations and could provide crucial insights into the effectiveness and efficiency of the pole-and-knife springs system cutter design.

Additionally, another foreseeable limitation is that the pole-and-knife cutter design may not have a telescoping feature, making it difficult to harvest from higher or older oil palm trees. As such, this tool may not be suitable for all harvesting situations. Nonetheless, despite these limitations, the development of this tool presents an exciting opportunity for improving oil palm harvesting efficiency.

3.8 Summary

In a nutshell, there are several milestones that should be targeted during the development phase such as the material selection, springs parameter determination, experimental setup, testing and evaluation scope. During the experimental setup, which involves assembling the different components of the pole-and-knife springs system according to the conceptual design and CAD model. This requires attention to detail and precise measurements to ensure that the pole-and-knife cutter functions effectively and safely during testing.

On top of that, the evaluated results should be satisfactory and meet the objective of reducing the harvester's effort and increasing the harvesting efficiency. It is important to note that if the results are not satisfactory, adjustments and modifications to the pole-and-knife cutter may be required to improve its performance. Therefore, a continuous improvement approach should be implemented to achieve the desired outcome.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The present chapter details the findings of a study that examined the performance of the pole-and-knife springs system cutter for oil palm harvesting. The design and construction of the cutter is described, along with the force required to cut off oil palm fronds using this tool. The study also compares the efficiency and effectiveness of the cutter to traditional harvesting methods, providing valuable insights into the potential benefits of implementing this newly developed tool idea. The implications of the study's findings are significant for the oil palm industry, which has been grappling with the need to improve productivity and sustainability. By demonstrating the advantages of the pole-and-knife springs system cutter, this study offers a promising solution that could help to address these challenges. Moreover, the potential for further development of this technology is highlighted, providing a roadmap for continued progress in this area. Overall, this study represents an important contribution to the ongoing efforts to enhance the efficiency and sustainability of the oil palm industry.

4.2 Prototype configuration

The fabrication of the prototype was meticulously executed, with a steadfast adherence to the CAD model designed through SolidWorks. The resulting prototype is comprised of several key components, including a moving sickle that incorporates a hammering effect, a 2.7-meter-long aluminum pole, wire rope, two compression springs, and a spring supporting plate, as previously detailed in the conceptual design section. Each of these components was selected and crafted to ensure optimal functionality of the final product.

The two compression springs are installed in series configuration inside the pole-and-knife cutter. This arrangement was chosen due it can provide more linear response than a single spring, ensuring that the displacement generated is maximized, leading to a more efficient cutting process. The results of the field tests were analyzed and evaluated, and it was determined that the combination spring option 4 and 5 was the most appropriate choice for the pole-and-knife cutter. These springs provided the optimal level of stiffness, ensuring that the system was effective in cutting the oil palm frond while also maintaining a reasonable level of flexibility to ensure the smooth harvesting process. The spring parameters chosen are as follows: 2.5×32×220 mm and 3×32×180 mm, denoting wire thickness, outer diameter, and spring length, respectively. These dimensions correspond to spring rates of 0.687 N/mm and 1.899 N/mm. To provide a clearer representation, the dimensions of each spring are presented in Table 4.1.

Table 4.1: Springs selected

No	Wire Thickness (mm)	Outer diameter (mm)	Length (mm)	Spring rate (N/mm)
1	2.5	32	220	0.687
2	3	32	180	1.899

The spring rate value of the selected springs are based on the catalog. By connecting two springs in series, the resulting system is equivalent to a single spring with a total spring constant of k_{total}.

$$\frac{1}{k_{total}} = \frac{1}{k_1} + \frac{1}{k_2}$$

$$k_{total} = 0.5045\ N/mm$$

To provide a better visual presentation, the prototype of the pole-and-knife springs system is shown in Figure 4.1, whereas Figures 4.2 and 4.3 show the upper part and bottom part of the prototype. With a weight of approximately 2.24 kg, measured using a digital hanging scale, this prototype is a relatively lightweight and efficient tool that may significantly reduce the harvester's effort.

The prototype operates based on the principles outlined in the conceptual design section. Firstly, the user must hang the sickle on the targeted frond before applying a pulling force. As the user applies the pulling force, the pole moves downward, causing the sickle to move in an upward direction in a relative motion. Simultaneously, the springs move upward along with the sickle and become compressed. Upon releasing the force, the springs release their stored energy and return to their original position. This process is repeated until the oil palm frond is severed.

Figure 4.1: Prototype of pole-and-knife springs system cutter

Figure 4.2: Upper part of the prototype

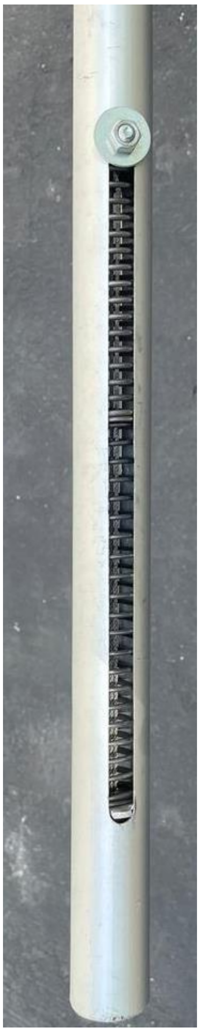


Figure 4.3: Bottom part of the prototype

4.2.1 Self conducted field test

To evaluate the performance of the pole-and-knife springs system cutter prototype, a series of tests were conducted using a digital hanging scale to measure and record the force required to cut off a single oil palm frond. The testing procedure involved simulating the pulling action performed by a user during the harvesting process. The resulting data was compiled and presented in a tabulated format, allowing for the calculation of an average force value. This data was then compared with the force required when using a conventional cutter, enabling a thorough evaluation of the prototype's effectiveness. Table 4.2 presents the recorded static force exerted when simulating the pulling action using a digital hanging balance in 12 trials. The results show that the force required ranged from 5.07 kg to 7.01 kg, with an average force of 6.2 kg or 60.83 N.

Table 4.2: Force measured using digital hanging balance

No	Amount of force (kg)	Amount of force (N)
1	5.07	49.74
2	5.82	57.09
3	5.45	53.46
4	5.73	56.21
5	6.39	62.69
6	6.34	62.20
7	6.73	66.02
8	5.49	53.86
9	6.91	67.79
10	7.01	68.77
11	6.88	67.49
12	6.59	64.65
Average	6.20	60.83

In addition to measuring the force, the prototype was also tested for its ability to effectively and efficiently cut off the oil palm tree fronds. The time required to cut off a single frond was recorded and tabulated, allowing for the calculation of an average time value. This data was gathered to provide a comprehensive evaluation of the prototype's performance and to assess its viability as a potential tool for use in the oil palm industry. Table 4.3 presents the time taken to cut off a single oil palm frond using the prototype. The results ranged from 4 seconds to 13 seconds, with an average of 7.6 seconds. Based on the average time recorded, the prototype can be said that was able to cut off a single oil palm frond efficiently and in a relatively short amount of time.

Through these tests, valuable insights were gained into the efficiency and effectiveness of the cutter and its potential for improving the harvesting process.

Table 4.3: Time taken to cut off an oil palm frond

No	Time taken to cut off a single oil palm frond (s)
1	8
2	10
3	7
4	7
5	5
6	7
7	9
8	6
9	13
10	4
Average	7.6

4.3 Field Evaluation

The prototype was used to conduct field test to examine its functionality and feasibility, and at the same time, examine its effectiveness to harvest the oil palm tree. The place for testing the prototype is located nearby Universiti Tunku Abdul Rahman. Through the testing, valuable insights were gained into the efficiency and effectiveness of this concept and its potential for improving the harvesting process. Furthermore, any recommendation on future improvement also can gain from the field testing.

From the force measuring test, it can be seen that the force requirement is lower than the conventional harvesting method which reported by the Journal of Oil Palm Research. It reported that the force required to cut off the oil palm frond requires a force of ranged from 80 N to 200 N. (Razak Jelani et al., 1999) Although the average force exerted is lesser, the reliability of the results can be improved by increasing the number of tests, leading to more rational and reasonable results. Furthermore, the force required to cut off a single oil palm frond is subject to various factors, including the frond's age and size, the sharpness of the sickle, and the strength and technique of the harvester. Therefore, a field test is necessary to gain more valuable insight. The field test will also provide a more accurate and reliable force requirement for cutting off a single oil palm frond, which can be used to evaluate the effectiveness of the proposed prototype.

Besides, based on the average time recorded, the prototype can be said that was able to cut off a single oil palm frond efficiently and in a relatively short amount of time. This is comparable with using the motorized cutter to cut off a frond which also taken 6-10 s to harvest a frond. (Jelani et al., 2018) However, it is important to note that the time taken to cut off a frond also depends on various factors, such as the frond condition, sickle condition, and most dominantly, the strength and technique employed by the harvester, with skilled harvesters typically achieving better results. Not only that, to obtain more accurate and rational results, it is necessary to increase the number of trial and average the results to reduce the effect of any outliers. Furthermore, field testing at the oil palm plantation with the assistance of skilled workers is crucial to validate the performance of the developed prototype in real-world conditions, ensuring that the prototype's effectiveness is consistent across various situation.

During the field test, the sharp edge of the sickle may encounter resistance from the tough and fibrous parts of the frond. If the angle or force of the sickle is not optimal, the sickle may get stuck in the frond or even break. Additionally, if the sickle is not properly sharpened, it may not be able to cut through the frond cleanly, further increasing the chances of getting stuck. Finally, if the harvester is not using the proper technique, such as not applying enough force or using the wrong angle, the sickle may have a higher chance of getting stuck in the frond. Figure 4.4 illustrates the situation of the sickle getting stuck in the frond. However, it is worth to noting that with this prototype design, which features the sickle along with the hammering effect and the support of the springs, the chances of getting stuck may be reduced. Moreover, the prototype may reduce the energy required to cut the frond without the need to remove the stuck sickle, allowing the user to continue the cutting process. On top of that, reduce the fatigue experienced by the harvester as they do not need to waste their time and energy to remove the stuck sickle. It can improve the harvesting efficient in the long run.

Figure 4.4: Sickle gets stuck in the frond

In a short conclusion, the underlying principle driving the prototype design is centered around maximizing productivity and efficiency in the process of harvesting oil palm fruits. The primary objective is to devise a solution that optimizes the overall output and streamlines the harvesting operations, ensuring a more efficient and effective approach to obtaining the oil palm fruits. By prioritizing productivity enhancements, the design aims to minimize any potential wastage or delays, ultimately resulting in higher yields and improved operational efficiency throughout the harvesting process. Furthermore, user experience played a crucial role in the prototype's development. Therefore, ergonomic considerations were taken into account, ensuring that the operators can carry out their tasks comfortably and with reduced fatigue.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This project intends to contribute to the improvement of oil palm fruit harvesting methods to develop an efficient pole-and-knife springs system cutter by balancing the applied force against the maximum load output. This newly designed harvesting tool consists of a sickle with hammering effect, aluminum pole, wire rope, and the aid of compression springs. Careful consideration was given to the selection of compression springs used in the prototype by analyzing its application and computationally designed. The chosen springs have the spring rate of 0.687 N/mm and 1.899 N/mm where there were connected in series to provide a smoother harvesting process while maximizing displacement and generating enough momentum to ease the harvesting process, reduce the physical strain experienced by the harvester.

The developed prototype of this pole-and-knife springs system cutter was brought to conduct field testing. The amount of force examined using the prototype was found with an average 60.83 N which can said is lesser than the conventional tool. The average time taken to cut off an oil palm frond is 7.6 seconds, which is comparable to the time taken by using motorized cutter to do the similar task.

Beside that, this prototype also have the benefit of lightweight, weighing only 2.2 kg, making it easy for harvesters to carry around the plantation without putting too much strain on their bodies. In the nutshell, the combination of a well-designed harvesting tool and the optimal springs will be the key factor in successfully mechanizing the oil palm fruit harvesting process.

5.2 Recommendations for future work

Based on the results of this study, it is evident that there is still a big room for improvement. One such improvement could be the utilization of stronger materials for the pole to enhance its mechanical properties, considering the high-intensity daily work it undertakes. For instance, aluminum alloys have excellent mechanical properties and can be up to thirty times stronger than pure aluminum, making them a viable option. Furthermore, they typically have a superior weight-to-strength ratio compared to steel. Another option is the use of carbon fibre, a highly robust material with an incredibly high tensile strength and lightweight nature. However, it should be noted that carbon fibre can be relatively costly. Besides that, the concept of telescoping pole can be apply in the future research direction. The telescoping pole can eliminate the limitation that can only harvest short oil palm tree. In addition, the concept of a telescoping pole could be explored in future research. This type of pole would eliminate the height limitation, enabling the tool to harvest taller oil palm trees. However, the displacement offer by the spring would need to be carefully considered to optimize its effectiveness.

Additionally, further field testing and validation of the prototype in real-world conditions is necessary to ascertain its effectiveness and feasibility for commercial use. It is recommended to conduct the experiments in an actual oil palm plantation where various factors such as weather, terrain, and different frond conditions can affect the performance of the prototype. It is also essential to involve skilled workers in the field testing as they can provide valuable feedback and insight into the prototype's effectiveness and feasibility.

Last but not least, the reliability of the data is impacted by the frequency of the testing and sample size. Therefore, it is recommended to perform multiple rounds of field test to ensure that the results are consistent and reliable. The data collected from the field testing can be used to validate and refine the prototype design, ensuring that it is efficient, effective, and safe to use in actual oil palm plantation settings.

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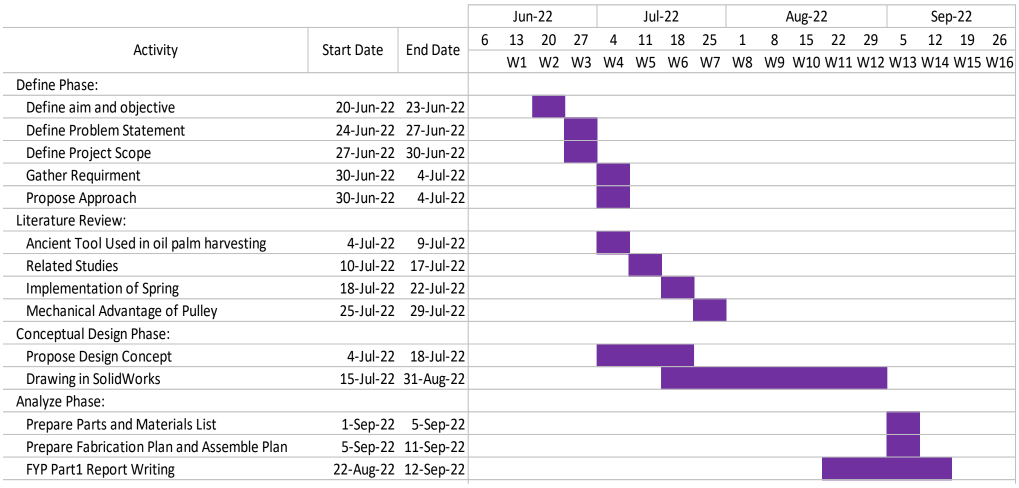
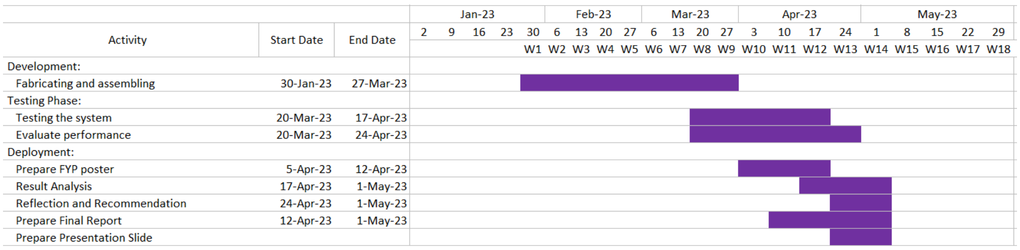
APPENDICES



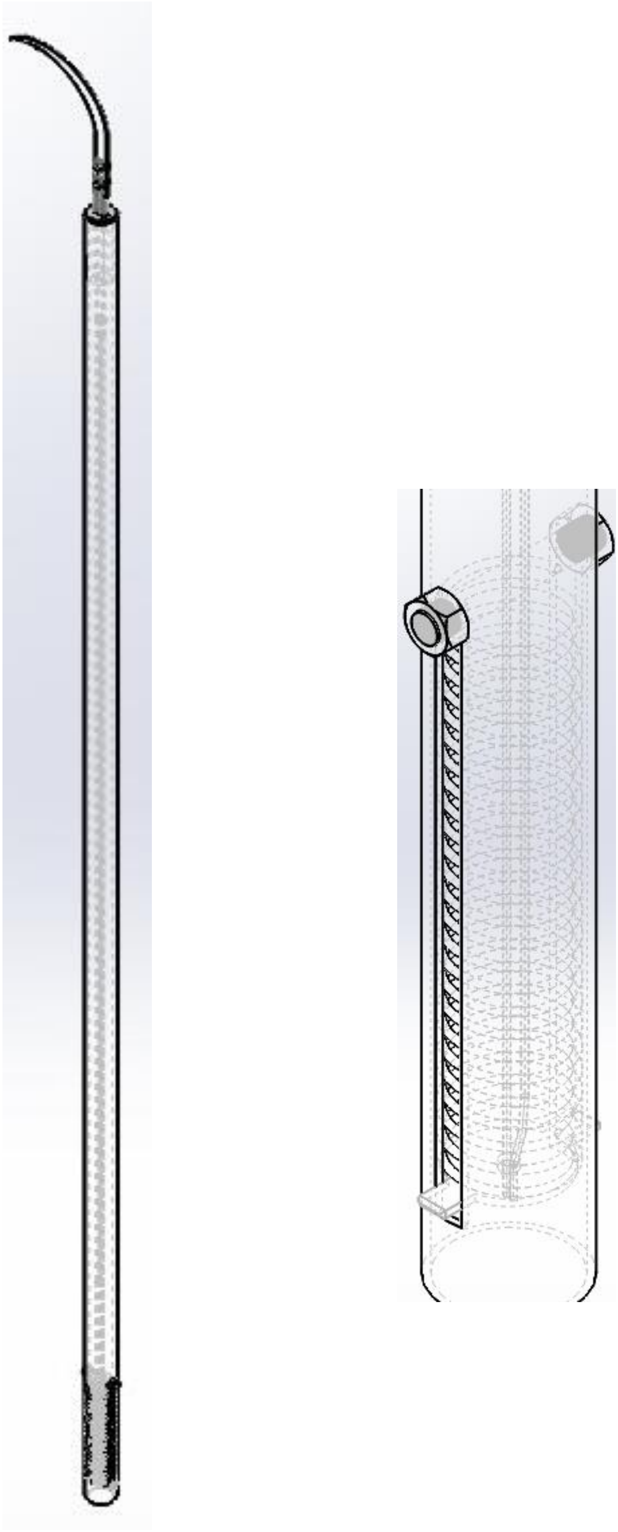
			Jun-22				Jul-22				Aug-22					Sep-22			
Activity	Start Date	End Date	6	13	20	27	4	11	18	25	1	8	15	22	29	5	12	19	26
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16
Define Phase:																			
Define aim and objective	20-Jun-22	23-Jun-22			■														
Define Problem Statement	24-Jun-22	27-Jun-22				■													
Define Project Scope	27-Jun-22	30-Jun-22				■													
Gather Requirment	30-Jun-22	4-Jul-22					■												
Propose Approach	30-Jun-22	4-Jul-22					■												
Literature Review:																			
Ancient Tool Used in oil palm harvesting	4-Jul-22	9-Jul-22					■												
Related Studies	10-Jul-22	17-Jul-22						■											
Implementation of Spring	18-Jul-22	22-Jul-22							■										
Mechanical Advantage of Pulley	25-Jul-22	29-Jul-22								■									
Conceptual Design Phase:																			
Propose Design Concept	4-Jul-22	18-Jul-22					■	■	■										
Drawing in SolidWorks	15-Jul-22	31-Aug-22							■	■	■	■	■	■	■				
Analyze Phase:																			
Prepare Parts and Materials List	1-Sep-22	5-Sep-22														■			
Prepare Fabrication Plan and Assemble Plan	5-Sep-22	11-Sep-22														■			
FYP Part1 Report Writing	22-Aug-22	12-Sep-22											■	■	■	■			

Appendix 1: Gantt Chart for FYP1

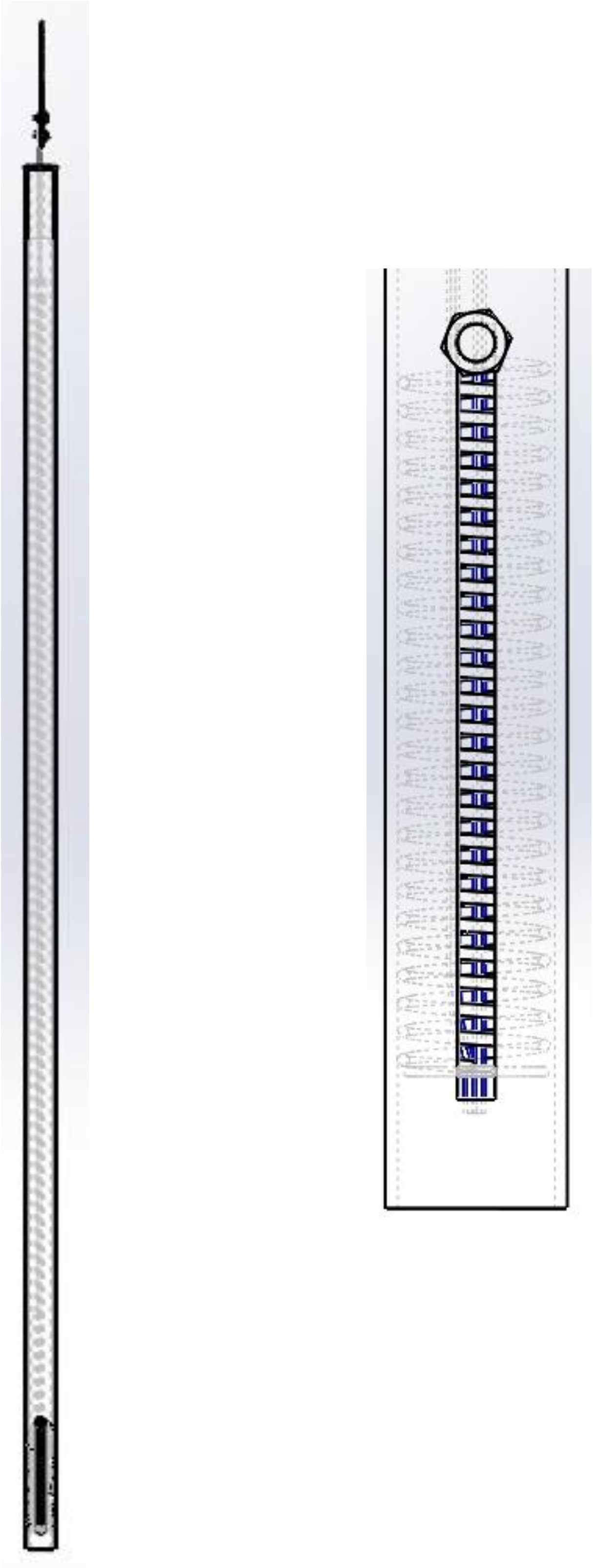


			Jan-23					Feb-23				Mar-23				Apr-23				May-23				
Activity	Start Date	End Date	2	9	16	23	30	6	13	20	27	6	13	20	27	3	10	17	24	1	8	15	22	29
							W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18
Development:																								
Fabricating and assembling	30-Jan-23	27-Mar-23					■	■	■	■	■	■	■	■	■									
Testing Phase:																								
Testing the system	20-Mar-23	17-Apr-23												■	■	■	■	■						
Evaluate performance	20-Mar-23	24-Apr-23												■	■	■	■	■	■					
Deployment:																								
Prepare FYP poster	5-Apr-23	12-Apr-23														■	■	■						
Result Analysis	17-Apr-23	1-May-23																■	■	■				
Reflection and Recommendation	24-Apr-23	1-May-23																	■	■				
Prepare Final Report	12-Apr-23	1-May-23															■	■	■	■				
Prepare Presentation Slide																			■	■				

Appendix 2: Gantt Chart for FYP2



Appendix 3: Isometric view with hidden lines

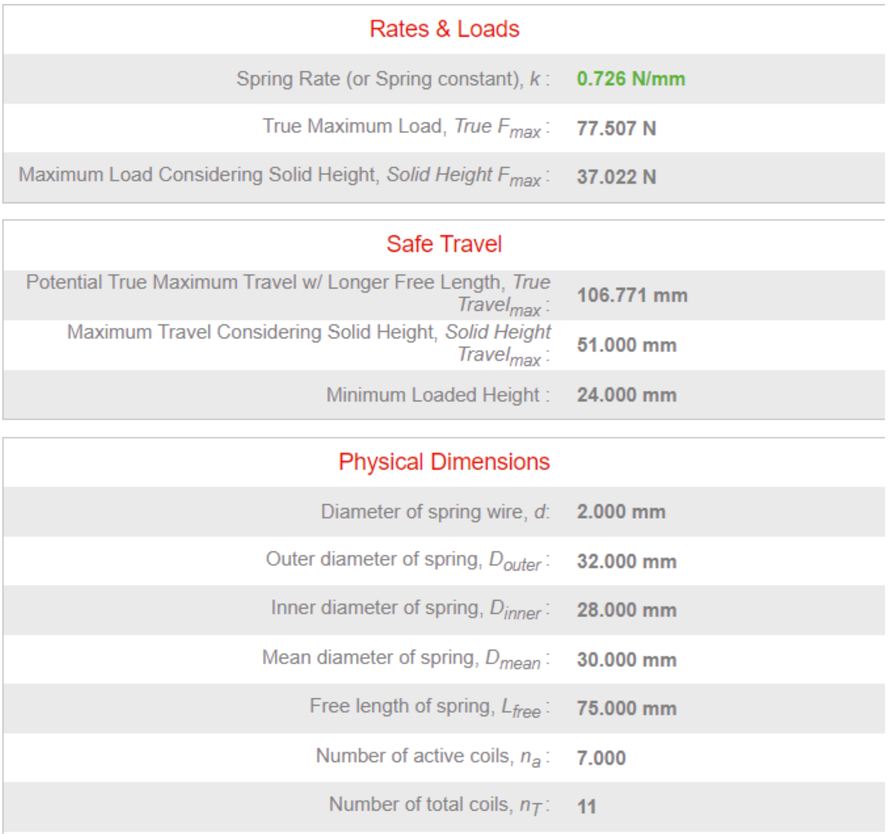


Appendix 4: Side view with hidden lines

More force (stiffer)	Less force (softer)
Smaller outer diameter	Larger outer diameter
Less coils	More coils
Thicker wire	Thinner wire
More Travel	Less travel

Appendix 5: The force chart of the compression spring

Appendix 6: Weight of prototype measured using digital hanging scale

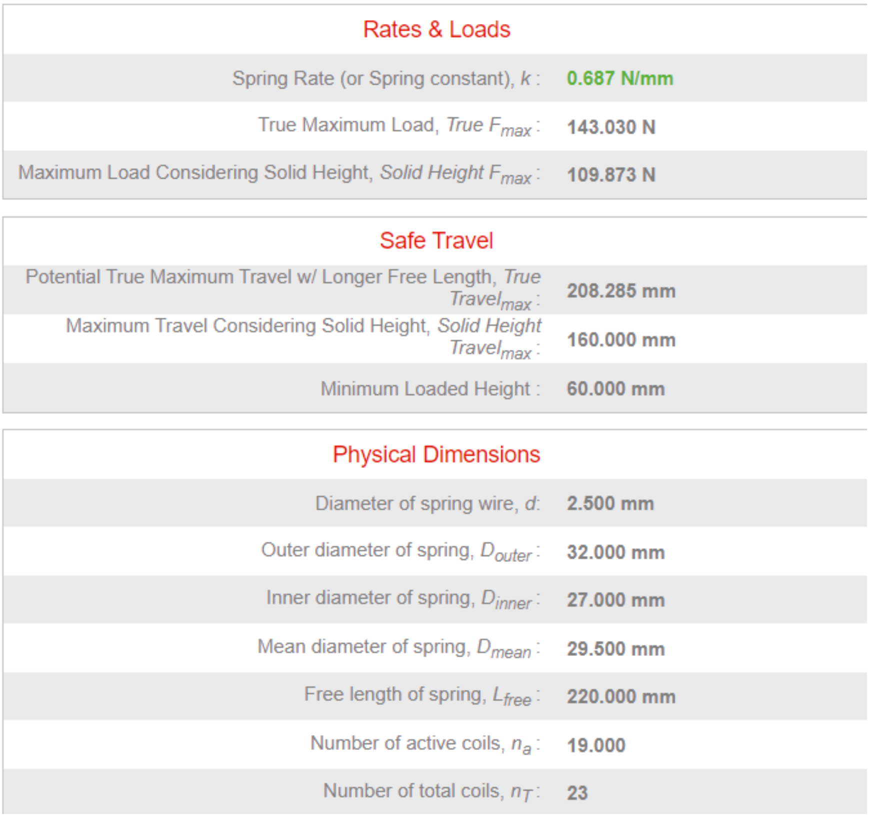


Rates & Loads	
Spring Rate (or Spring constant), *k* :	0.726 N/mm
True Maximum Load, True F_{max} :	77.507 N
Maximum Load Considering Solid Height, Solid Height F_{max} :	37.022 N

Safe Travel	
Potential True Maximum Travel w/ Longer Free Length, True $Travel_{max}$:	106.771 mm
Maximum Travel Considering Solid Height, Solid Height $Travel_{max}$:	51.000 mm
Minimum Loaded Height :	24.000 mm

Physical Dimensions	
Diameter of spring wire, *d*:	2.000 mm
Outer diameter of spring, D_{outer} :	32.000 mm
Inner diameter of spring, D_{inner} :	28.000 mm
Mean diameter of spring, D_{mean} :	30.000 mm
Free length of spring, L_{free} :	75.000 mm
Number of active coils, n_a :	7.000
Number of total coils, n_T :	11

Appendix 7: Spring Specification (option 2)



Rates & Loads	
Spring Rate (or Spring constant), *k* :	0.687 N/mm
True Maximum Load, True F_{max} :	143.030 N
Maximum Load Considering Solid Height, Solid Height F_{max} :	109.873 N

Safe Travel	
Potential True Maximum Travel w/ Longer Free Length, True $Travel_{max}$:	208.285 mm
Maximum Travel Considering Solid Height, Solid Height $Travel_{max}$:	160.000 mm
Minimum Loaded Height :	60.000 mm

Physical Dimensions	
Diameter of spring wire, *d*:	2.500 mm
Outer diameter of spring, D_{outer} :	32.000 mm
Inner diameter of spring, D_{inner} :	27.000 mm
Mean diameter of spring, D_{mean} :	29.500 mm
Free length of spring, L_{free} :	220.000 mm
Number of active coils, n_a :	19.000
Number of total coils, n_T :	23

Appendix 8: Spring Specification (option 4)

Rates & Loads

Spring Rate (or Spring constant), k :	1.899 N/mm
True Maximum Load, True F_{max} :	233.835 N
Maximum Load Considering Solid Height, Solid Height F_{max} :	227.830 N

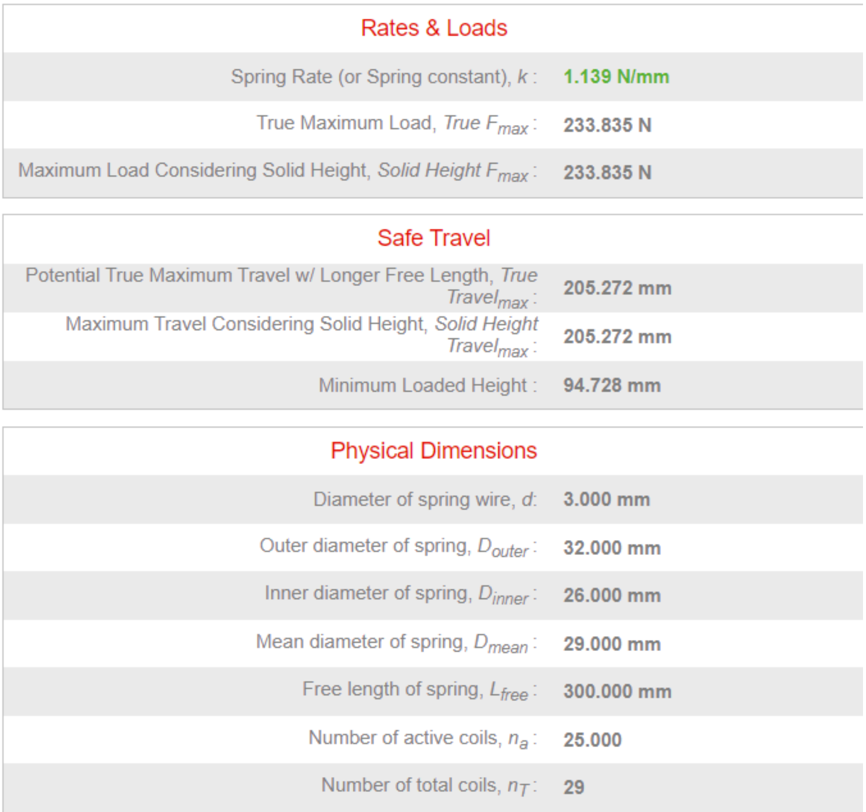
Safe Travel

Potential True Maximum Travel w/ Longer Free Length, True $Travel_{max}$:	123.163 mm
Maximum Travel Considering Solid Height, Solid Height $Travel_{max}$:	120.000 mm
Minimum Loaded Height :	60.000 mm

Physical Dimensions

Diameter of spring wire, d:	3.000 mm
Outer diameter of spring, D_{outer} :	32.000 mm
Inner diameter of spring, D_{inner} :	26.000 mm
Mean diameter of spring, D_{mean} :	29.000 mm
Free length of spring, L_{free} :	180.000 mm
Number of active coils, n_a :	15.000
Number of total coils, n_T :	19

Appendix 9: Spring Specification (option 5)



Rates & Loads

Spring Rate (or Spring constant), k :	1.139 N/mm
True Maximum Load, True F_{max} :	233.835 N
Maximum Load Considering Solid Height, Solid Height F_{max} :	233.835 N

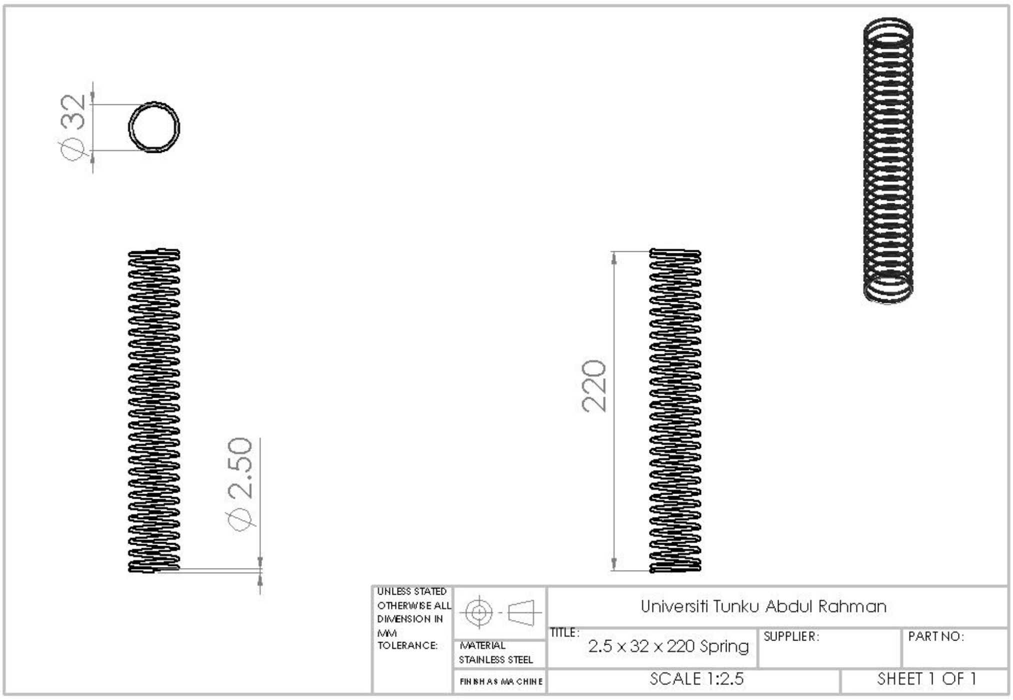
Safe Travel

Potential True Maximum Travel w/ Longer Free Length, True $Travel_{max}$:	205.272 mm
Maximum Travel Considering Solid Height, Solid Height $Travel_{max}$:	205.272 mm
Minimum Loaded Height :	94.728 mm

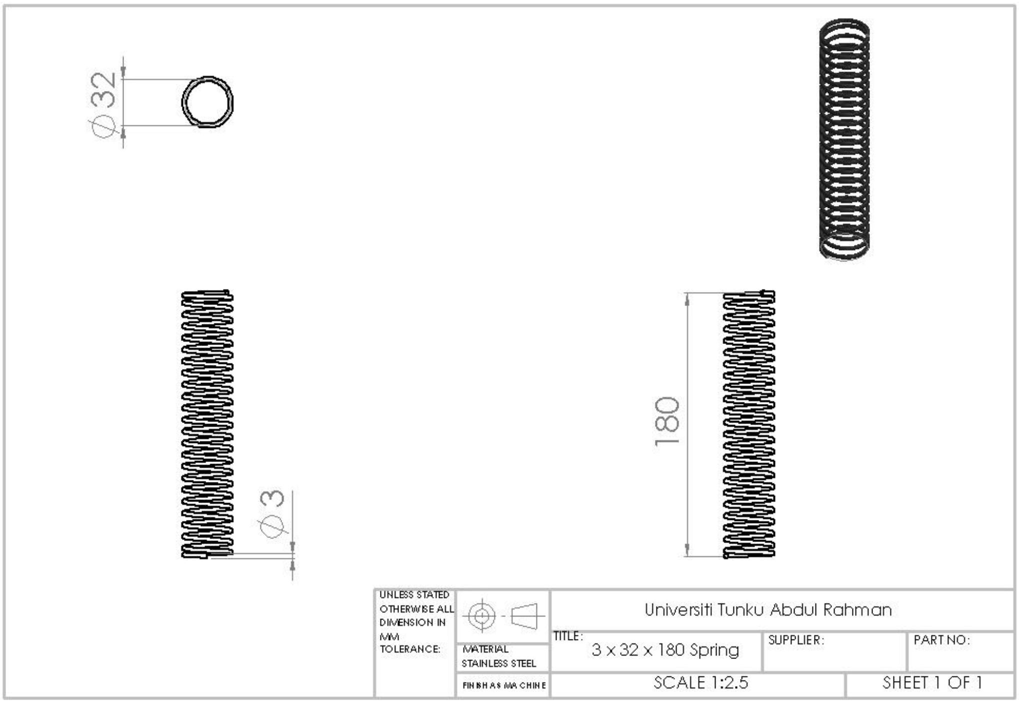
Physical Dimensions

Diameter of spring wire, d:	3.000 mm
Outer diameter of spring, D_{outer} :	32.000 mm
Inner diameter of spring, D_{inner} :	26.000 mm
Mean diameter of spring, D_{mean} :	29.000 mm
Free length of spring, L_{free} :	300.000 mm
Number of active coils, n_a :	25.000
Number of total coils, n_T :	29

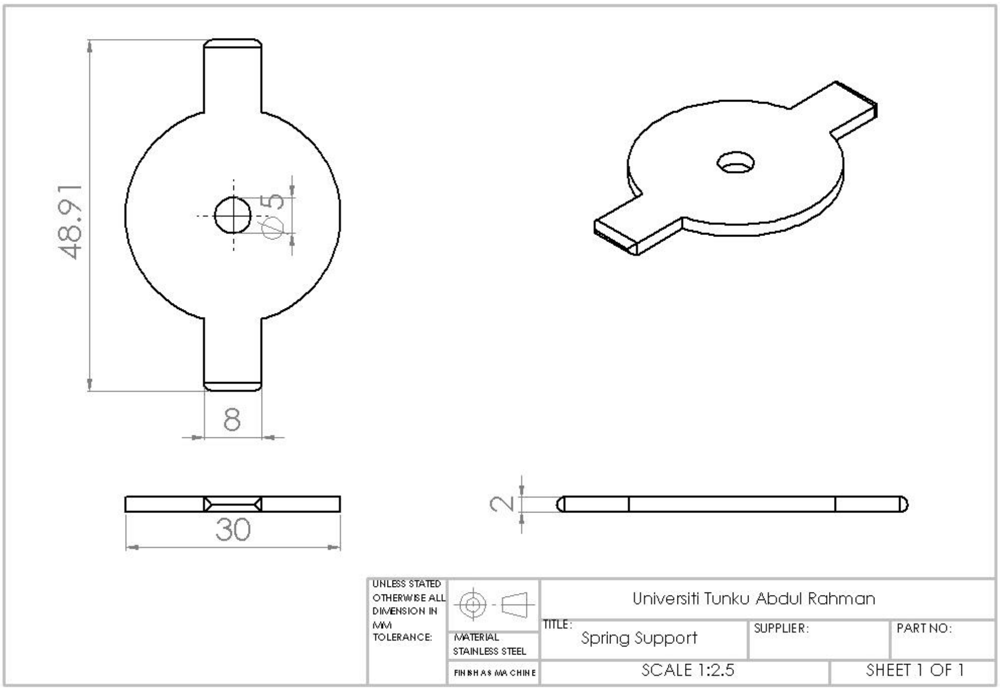
Appendix 10: Spring Specification (option 6)



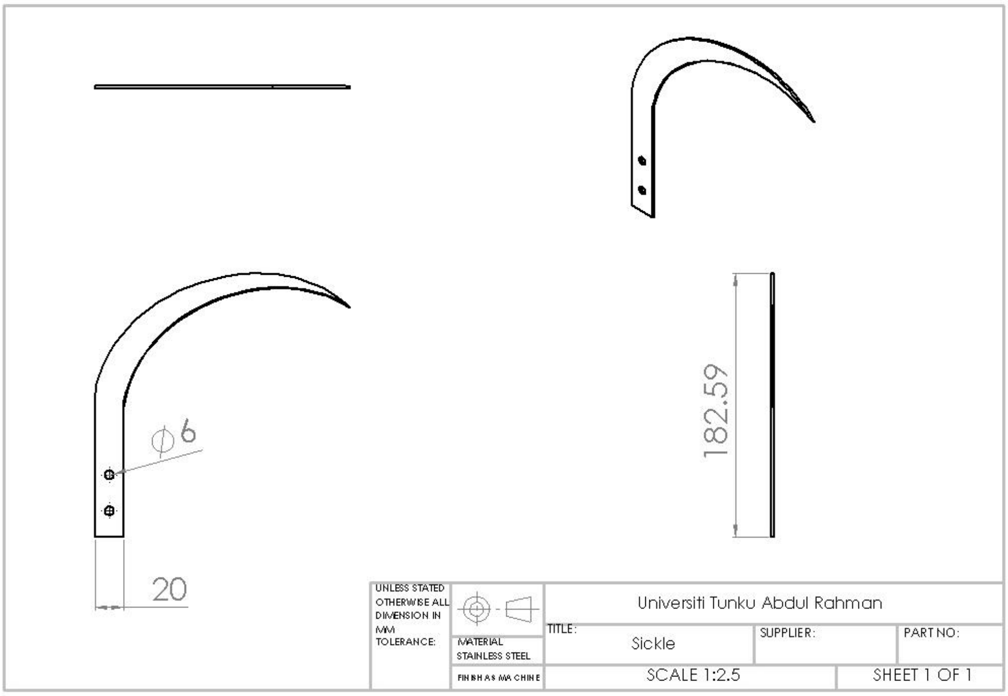
Appendix 11: 2.5 × 32 × 220 Spring



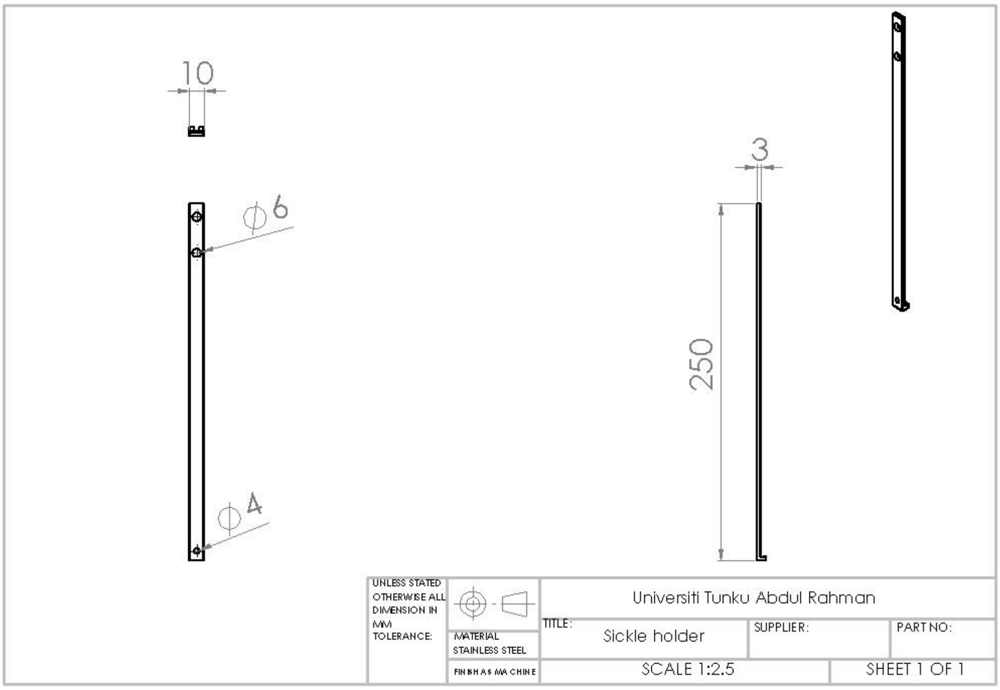
Appendix 12: 3 × 32 × 180 Spring



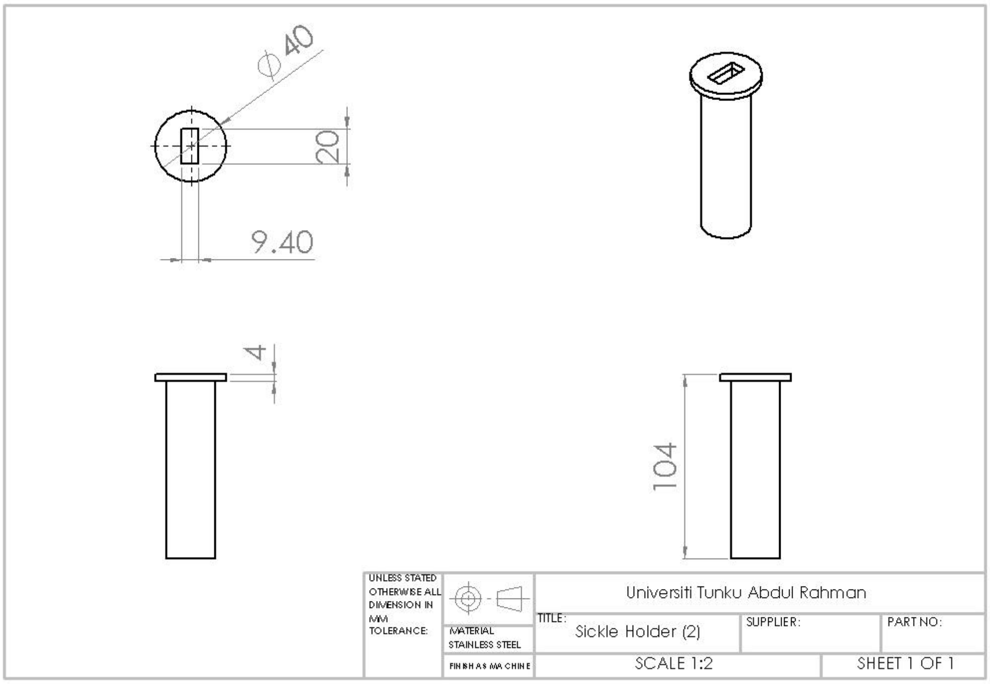
Appendix 13: Spring support plate



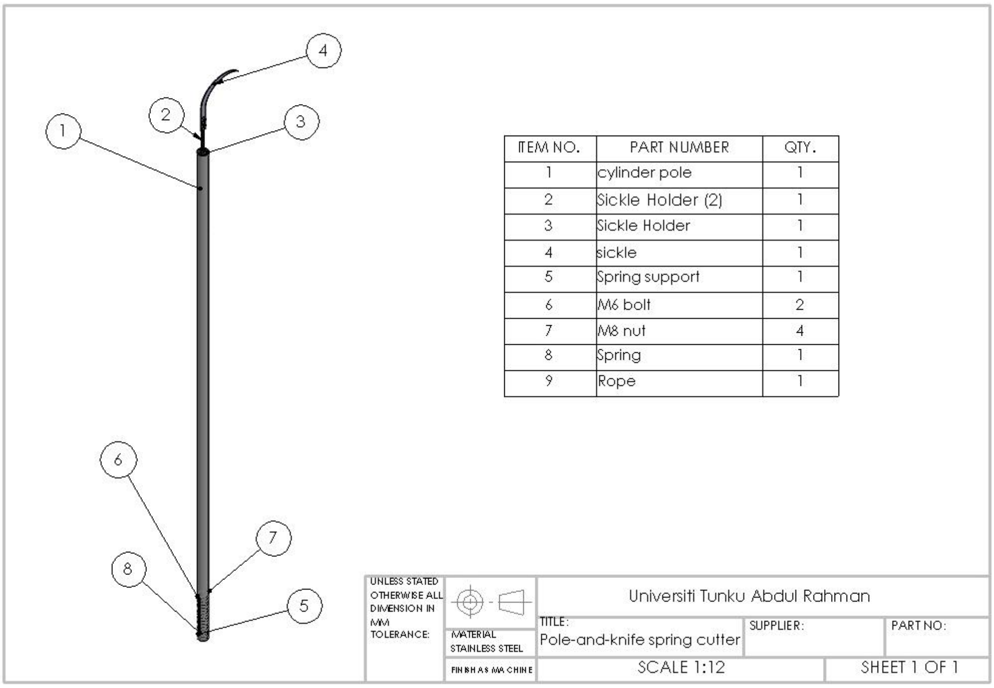
Appendix 14: Sickle



Appendix 15: Sickle Holder



Appendix 16: Sickle Holder (2)



ITEM NO.	PART NUMBER	QTY.
1	cylinder pole	1
2	Sickle Holder (2)	1
3	Sickle Holder	1
4	sickle	1
5	Spring support	1
6	M6 bolt	2
7	M8 nut	4
8	Spring	1
9	Rope	1

Appendix 17: Pole-and-knife springs cutter