



KAUNAS UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING AND DESIGN

Praveen Karuppanpillai Somasundaram

BRUSHWOOD CUTTER MODERNIZATION

Master's Degree Final Project

Supervisor
Assoc. Prof. Jolanta Baskutiene

KAUNAS, 2017

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Reviewer

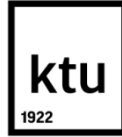
Dr. Arūnas Žvironas

Project made by

Praveen Karuppanpillai Somasundaram

KAUNAS, 2017

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KAUNAS UNIVERSITY OF TECHNOLOGY

Faculty of Mechanical Engineering and Design

(Faculty)

Praveen Karuppanpillai Somasundaram

(Student's name, surname)

Mechatronics Engineering (621H73001)

(Title of study programme)

BRUSHWOOD CUTTER MODERNIZATION

DECLARATION OF ACADEMIC HONESTY

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08

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Approved:

Head of
Production Engineering
Department

(Signature, date)

Doc. Kazimieras Juzėnas

(Name, Surname)

**MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme MECHATRONICS**

1. Title of the Project

Brushwood Cutter Modernization

Approved by the Dean Order No. V25-11-8, 21 April 2017

2. Aim of the project

To develop the modernization solution for the brushwood cutter angular trajectory control and stabilization under desired response time.

3. Structure of the project

Summary, Introduction, Literature review (Existing types of cutter, previous researches in controlling the cutter, cutter parts, problems identification in controlling, Proposed system), Mechanical and Hydraulic modelling in cutter, Controlling the cutter using PI control, Responses from the PI for various inputs using Simulink and stabilization of cutter using AMESIM, conclusion.

4. Requirements and conditions

- Controlling the angular movement of the cutter to 35°.
- Improving the stabilization of the cutter movement by varying damper parameters from 30mm cylinder diameter and 2.5mm orifice diameter to 32mm and 1.5mm to improve the response time

5. This task assignment is an integral part of the final project

6. Project submission deadline: 2017 May 08th.

Student

Praveen Karuppanapillai Somasundaram

(Name, Surname of the Student)

(Signature, date)

Supervisor

Assoc.prof. Jolanta Baskutiene

(Position, Name, Surname)

(Signature, date)

Praveen Karuppanpillai Somasundaram BRUSHWOODCUTTER MODERNIZATION. *Master's Final Project* / supervisor Assoc.prof. Jolanta Baskutiene; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Research field and area: Manufacturing and production engineering, Technological sciences

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SUMMARY

Presented project considers the modernization of the brushwood cutter. Main tasks are related to improvement of the angular trajectory and stabilization control of the cutter. The analysis of existing cutters model is presented. The control model of the brushwood cutter is developed by using Simulink and AMESIM. The hydraulic and mechanical parts of the cutter are modelled in Simulink for angular trajectory control. Advanced simulation software is used to improve the stabilization of the cutter at a desired response time. The dampers are introduced to achieve the stabilization of a cutter. The analysis is made under different values of the particular parameters and response time is taken into account. The results of simulation are discussed. The conclusions of the project are given.

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SANTRAUKA

Pateiktame projekte nagrinėjamas miško genėjimui skirto įrankio modernizavimas. Pagrindiniai uždaviniai yra susiję su genėjimo įrankio kampinės trajektorijos ir įrankio stabilizavimo valdymu. Pateikta egzistuojančių genėjimo įrankių analizė. Sudarytas genėjimo įrankio valdymo modelis. Genėjimo įrankio valdymo modeliavimas atliktas naudojant SIMULINK ir AMESIM programinę įrangą. Sudaryti hidraulinės ir mechaninės genėjimo įrankio dalių Simulink modeliai ir atlikti kampinės trajektorijos valdymo tyrimai. Šiuolaikinė modeliavimo programinė įranga panaudota įrankio stabilizavimo tyrimui siekiant pagerinti atsako trukmę. Genėjimo įrankio stabilizavimui pasiūlyta naudoti slopintuvus. Analizė atlikta esant skirtingoms aktualių parametų reikšmėms ir atsižvelgiant į atsako trukmę. Aptarti modeliavimo rezultatai. Pateiktos projekto išvados.

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Regards

Praveen karuppannpillai Somasundaram

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INTRODUCTION

The forestry machine manufacturers are giving keen interest to improve efficiency and empowered robustness control of forestry machines to create a user-friendly environment to users. Moreover, in order to do that and also to increase work profit, it heavily depends on working condition of forestry machines. Due to this consequence, modern control terminology is implemented in forestry machines to improve the system features. So that it is useful to reduce interaction between humans and machine. Still, it needs some improvement at the end effector control part of the system to move it in a particular trajectory path with the desired responses. In such cases, in this thesis work the controlling module is developed to the trajectory angular path control of the brushwood cutter model and also by increasing the stabilizing of the cutter by changing the parameters of dampers in the real time to achieve a quick response from the end effector part of the model.

In order to implement that, the hydraulic segment, and a detailed overview of trajectory movement, degrees of freedom, hydraulic fluid properties and controlling segment of PID controller are concerned from various literary sources. From those studies, linear controlling of system and modeling parameters are done by using MATLAB Simulink multibody and in AMESIM are get to known and it is more useful to implement the controlling in the machine's environment. The linear modules are done according to an exact trajectory which previously used in the system. Then the brushwood cutter simulation model is done by using Simscape multibody and SimHydraulics for the trajectory angular control and AMESIM is used to make the system stable by changing properties of the damper and it is tested in the real-time to achieve the quick response without oscillation. These are some control terminologies that used to enhance the system to get efficient work from the cutter and to make the system more effective and user-friendly.

Aim: to develop the modernization solution for the brushwood cutter angular trajectory control and stabilization under desired response time.

TASKS

- To review the existing forestry cutters and their control methods.
- To develop the model for the cutter trajectory angle control using Simulink and AMESIM software.
- To develop the modernization solution for the forestry cutter control.
- To carry out the Real-time simulation testing of the angular trajectory control, stabilization of the cutter taking into account the response time.

1. REVIEW OF CUTTERS

1.1 Overview of the forestry cutter model

In today's world, forestry is playing a vital role in constructional and manufacturing fields like pulp industries, constructional works etc., in order to grow the trees with a proper size, is important to use it in the various field. To do that, and to maintain the growth, forestry space must be cleaned and the trees should be cut in the proper shape. By doing these kinds of the process by a human it took a large amount of time and it is not an economical way in the case of a lot of large scale forestry products harvesters. so instead of using the human power; nowadays the machinery is used to do that works for cutting the trees, shaping the trees, removing the unwanted scraps from the tree to get proper size of the tree. In that machine, some of them are semi-automatic and manually operated. By converting them into completely automatic and controlling them using Proportional Integrative Derivative (PID) controller to get the proper direction and trajectory control, and stabilize the entire machine movement by using the controller to make ensure the user-friendly environment to the driver [2].



Figure 1.1 Forestry Cutter [21]

From the Figure 1.1, it is semi-automatic brushwood cutter model and which contains the support arm, an actuator, and cutter with the support covers. It contains the blades with diameter of 60 cm with sharpening edges. These are controlled by the ergonomic joysticks to make the movement as per the user requirement. Due to control by using the ergonomic joysticks there is some communication problem should occur in between the hydraulics and mechanical parts of the system that leads to some technical error while in the operating condition. So, in this chapter, the review is of the different types of the cutter modules existed and the different methods of controlling features exist and parts of the cutter are taken into the survey to propose the changes in the model.

1.2 Types of Brushcutter

In this chapter, the clear overview and distinct types of the cutter which are in usage now and their advantages and disadvantages are explained in the following sub-chapters.

1.2.1 Manual Brush Cutter

This Brush cutter is completely manual. This is the mechanical brushwood cutter which is used now for removing the scraps in the garden and in some forestry, uses also. It is used only for the limited uses and it contains the blades with the certain diameters. it is very compact and less in weight.

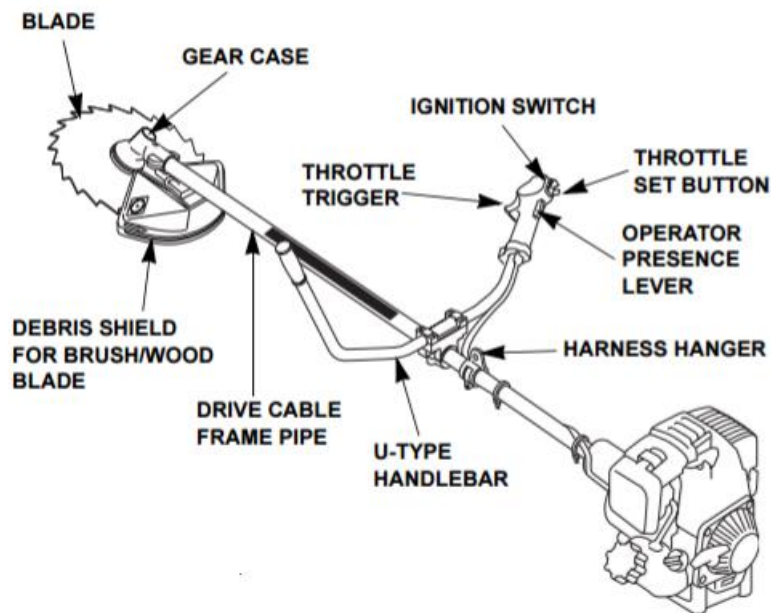


Figure 1.2 Manual Brush cutter [23]

This brushwood cutter contains the debris shield, blade cover, blades at the post end are shown in Figure 1.2. This is completely manual and it is easy to handle and carry. The trimmers are protected by using cover to reduce the damages to the machine and to the user. It contains the throttle set button by using that the adjustment can be done to a certain level to increase or reduce the number of revolution per minute according to the usage. The brushes are quite strong and it get varied depends on the types of weed going to cut [13]. Normally for the tree scraps, the brushes are of the diameter of 9 inches. The u-type handlebar is used to hold the device and the positioning is done by the user. The throttle trigger is used in this model to enhance the operation by triggering. It contains the engine part which runs the motor and due to the shaft movement, the cutter gets moved. The operator presence lever is used to control the throttle operation bumping while the operator doesn't touch with the control handle in order to prevent from unwanted damages [12].

Advantages:

- Easy to carry and so compact
- No professional skill is required

Disadvantages:

- Time consumption is high
- Too hard to remove the tree scraps in the forest.

1.2.2 Forestry Manual controlled cutter

The forestry machine blades are quite bigger in size and larger in diameter and it can be controlled in the different methods like manually controlled, auto controlled and semi auto controlling. In the Figure 1.3 which is shown below is the cutter model which is used for the forestry tree cutting purposes and it is controlled completely manually by using levers. It also has too much weight. Hence it required more pull load to do the work.

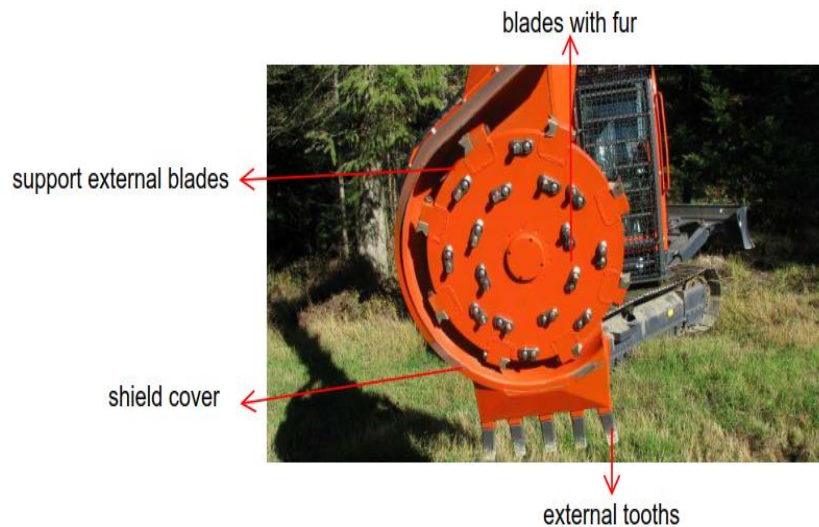


Figure 1.3 Manually controlled cutter example [22]

The cutter contains the shield cover which is used to cover the external part of the cutter to prevent the damages from the scraps and the blades are completely made of light steel with the sharpening edges. In this cutter, contains some blades with fur, these are useful to cut and short down the small trees. The controlling of the cutter is completely manual and it could control by using the levers in which either pneumatic or hydraulic drive is used to make the movement of the cutter. The line trajectory of the cutter is not exactly positioned because of too much weight in the cutter model. Due to the external weight of the cutter, the position is not proper and also it needs much load from the machine to move from one part to another part. Moreover, while in the operating condition response time is too high when compared to the other cutters due to the manual control terminology [21].

Advantages:

- Able to cut the large trees and scraps.
- More stable in performance.

Disadvantages

- A professional driver is required to drive the component.
- Performance is low because of heavy load.
- Completely manually operated.

1.2.3 Forestry Flat brush cutter

In this cutter model, it contains the rigid deck cover, drives of the cutter and at the back end of the cover, it contains the chain frames and which is useful to protect the scraps from the tree to hit on the machine. From the Figure which is shown below is a semi-auto control brush cutter to clear the small trees and scraps.

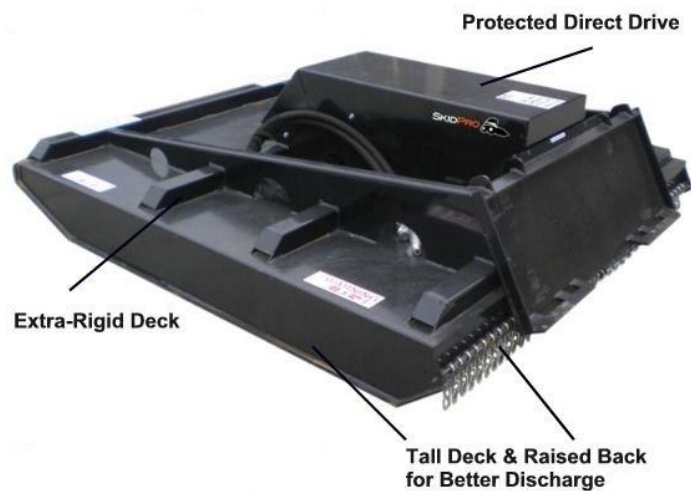


Figure 1.4 Flat forestry Brush cutter [24]

These cutters are controlled by using an ergonomic joystick. It contains the valves and the cylinder in the protected direct drives and the extra rigid deck is used to lift the cutter to a certain height. The cutter contains the hydraulic part which is used to tilt the cutter body to a certain level and it contains the motor for running the cutting blades and most importantly due to an enormous size and the heavy weight of the cutter it can lift up to a certain height. This cutter is not suitable for the uneven surface because of less flexible and compactable size of the cutter [14]. This cutter can able to remove more than two or three trees at the time because of its width and with more number of blades inside the cutter. The extra rigid deck is useful to prevent the damages from the cutter and also it is useful to hold the support for the trees. These flat cutters are widely in used in flat surface forest nowadays. Due to the heavy load of this cutter, the body of the machine weight also increased because

of its directly proportional to the end effector. These types of cutter covered the large distance with their width and the cutting speed is high when compared to the other cutter which is existed now. Due to the semi-manual control of this cutter it hard to lift and it took a lot of response time during the operation. The communication between the cutter and the driver is not so much compactable while using [24].

Advantages:

- Having more efficiency that other existing cutters
- Highly economical
- Used for the multipurpose in both forests and on the farm.

Disadvantages:

- It took more time to respond compared to other cutters
- Heavyweight and not compact in size
- It cannot able to use on uneven surfaces.

1.2.4 Consistent Brush cutter

This is a type of brush cutter which is used in nowadays for cutting the trees and to sizing the trees by giving the certain range of height to the system. These cutters are now widely in developing state and it is completely controlled by auto-controlling terminology with ergonomic joysticks. This cutter contains the gears which are used to hold the tree and also it is used to remove the branches from the trees while sizing the trees into several parts. This cutter is more economical than the other type of cutter and very less in weight.

It can able to hold the small trees and the medium size trees which less than 45 cm diameter. it is concerned as the biggest drawback of the cutter and it also took more response time while the user giving input to the system. The cutter also contains the knife which is used to slice the tree into more numbers. This cutter having more oscillation while under the working condition and because of that the sizing of the trees is get varied and cutter cannot able to tilt more than the certain angle and due to this it can be mostly used in the similar sizing trees. The most important part of the cutter is the actuator angle, it is initially at the certain angle and it can be able to make the movement to a certain extent of time because of this the response is taking too much time when compared to another cutter. Due to this auto-controlling, the cutter can easily find the diameter of the trees by the sensor and it will cut automatically by giving the length [22].



Figure 1.5 Sizing cutter [22]

This cutter having more compact size and it is easy to lift and used in the desired direction and it can tilt to a certain extent. Hence it is more useful to cut the trees at the desired level of high accuracy. The performance of the cutter is more due to this compactness. It is widely used in the pulp forestry and rubber trees. It can be easily liftable so it is used even in the uneven surfaces also.

Advantages:

- More compactable in size and weight.
- High-performance index.
- Easily sizing the trees according to user needs.
- Highly economical for the forestry harvesters.

Disadvantages

- Certain diameter trees only able to cut.
- It can move only particular angular extent.

Hence from the overview of the different cutters and their properties, the most of them are more economical but without compact size. They are mostly controlled by the semi- auto controlling terminology. These cutters are moved only to the certain extent with taking more response time. Some cutters are only is used for the small size trees only and also with certain limitations. So, from the above cutter, it clearly clarified that it needs some improvement in the controlled terminology of the forestry machine to make the movement in certain angles with a stabilizing state.

1.3.2 Rugged electro-hydraulic PID controlling

In 2013, the research journal is published by the University of Kolkata in which the rugged type of electrohydraulic PID method is implemented. It is the system which preferred for the core application with the low bandwidth, and flow non-linearity in the proportional valves and with nonlinear friction with industry grade cylinders along with the machines. This research paper which gives more importance to the servo control of the model is in the form of feedforward control and it contains the design which compensating the nonlinearities of the machine arm movements [4]. In that research work, the feedback of the system is the piston displacement and it also acts in the form of unmodeled effects. The algorithms of the controller are made by real code genetic platform and to get the real-time response, the Sine signal and step signal are used in order to achieve modern servo system to control the machine.

The proportional valves are considered for controlling the movement of the system by regulating the low-frequency tracking controls and by comparing the servo valve the proportional valve contains much clearance and dead bands. The system with the proportional valve is easier to handle. So, that the implementation of the rugged method of controlling to the piston by controlling the flow through the orifice of the proportional valve by using PID controller to get appropriate results.

1.3.3 Dynamics identification and controlling of machine

By enhancing the dynamics and kinematics part of the forestry machine, it is easy to get the precision in the working condition. According to that in the year of 2016 from the Norwegian University, the research is taking place regarding the identification and control of the electro-hydraulic crane. From the research by improving frictional force, dead zone and vibrations due to hydraulics are considered and algorithm for forestry machine is defined in a linear way to compensate the non-linearity to track the exact reference trajectory and end effector of the system [3]. The control design is with the inner loop to compensate the vibration in the hydraulic system to perform the function in the more linear way. From this, the kinematics of the forestry machine elements are taken as the reference for the thesis work.

In the research work each part of the joints contains the angular position sensor and it sends the feedback to the model which should be attached to the PID controller and it will control the proportional valves and the angular movement of the each joint and sends their feedback to the system and it responds according to that the controller design is implemented in the model to get the damping and oscillations results and the by implementing dynamics way of approaching only it should act at

a constant pressure and some sensor are also used to give the experimental results such as for pressure, force etc.[4].

1.3.4 Trajectory planning and control of machine

In the forestry logging process, the machine arm is an important part and its control in various terminology but the most important part of them is trajectory planning and controlling. As for that concern by making the forestry robotic arm with automation to make the operator to work easier. By concerning that and creating the trajectory planning algorithm and motion control methods, by designing the feedback controller to track the references based on the sensor measurements and then by controlling the model in the both open and close loop method to make the time efficient to control the trajectory of the logged tasks by carry out the various performance in the predictive control and fuzzy control in a discrete way of controlling and handling the joysticks in an ergonomic way to move the trajectory plane movement in the perfect manner[4,5].

1.3.5 Performance of control for hydraulic machines

The performance of the controller while in the dangerous and unfavorable soil conditions are considered and the reaction of the controller depends upon the condition which are consider as a research in the year of 2008 the electronic control system is introduced and adapted the hydraulic transmission by controlling them by modulating the forward speed of a trailer to the tractor to force the hooked components in the system and it is controlled by using the PID controller and by that time the power from the system which exceeding the normal pressure of the system which required to access the machine part of the forestry machine [3]. By giving the feedforward control to the system it will perform and it will access the four-wheel axle of the system. Also, the arm of the system is to lift the vehicle up from the dangerous areas and their performance of the system is analyzed by using the mechatronic simulation software called AMESIM to get the performance and the reaction of the model [4].

1.3.6 Traction control system in agricultural machine

In the traction control system is one of the most important parts of the forestry industry. It is used to keep the machine in an exact position and to control by designing the controller to control the traction of the system and the by adjusting the condition of the system to various soil conditions. By improving the properties of the hydraulic parts of the system and by using the fine-tuning method the traction of the machines can be easily reduced and it is easy to implement the system to improve the efficiency of the machine to make the machine electrically and hydraulically with infinitely variable transmission by the drive feedback to the module [7,8]. So, by giving the traction module as the input to the system it will react according to the conditions of the situation of the machine performance the controller will automatically switching the mode to empower the efficiency of the machine [9].

1.4 The Brushwood cutter

The brushwood cutter is designed for professional uses for small harvesters. It is used for the young wood forest. Because of portable dimensions, it can work even in complicated surfaces also with exact trajectory control position. From this kind of machines, it is easy to improve proper growth of plants by removing unwanted scraps in the forest. So, due to this, brushwood cutters are important to obtain the fast rate of growth and satisfactory results.

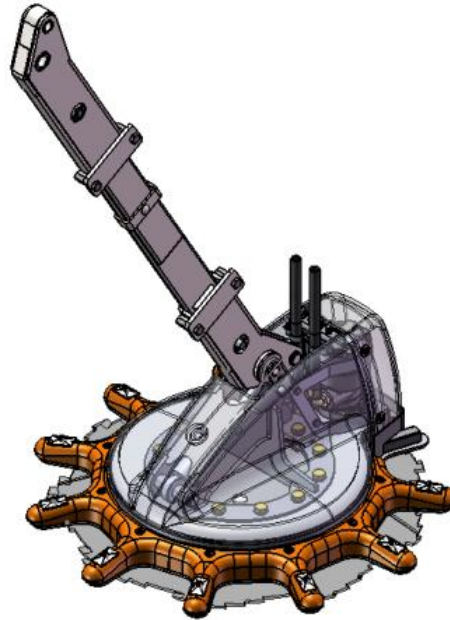


Figure 1.7 Usewood Forest Master [20]

The brushwood cutter which shown in the Figure1.7 is controlled by ergonomic joystick and communication between them is given by CAN network based system and due that system communicates each other while under the multi-operating condition without delaying the response. The brushwood cutter which contains blades and actuator part and these are connected by using revolute joint and hydraulic fluid is passed to the system by using 35mm hoses. This liquid flow is controlled by using directional valves and depending upon the flow of liquid to move the cutter from zero-degree position [19]. The brushwood cutter has connected arm of cranes and it also with respective to movement of the arm. With the use of this brushwood cutter, harvesters are removing strips from the forest and let trees to grown up to their desired level of growth. So, this brushwood cutter is 80% more efficient when compared hand brushwood cutter which operated manually. So, it is widely used by small and large-scale harvester like in pulp and papers tree producers [20].

1.4.1 Brushwood cutter model with parts

The Brushwood cutter contains arm and cutter part. In which rear end of the arm is connected to the main arm by using revolute joint and the front end of the arm is connected to the cutter by using tilt actuator which is tilted at an angle of 15° and the Figure 2.8 is from the SolidWorks model.

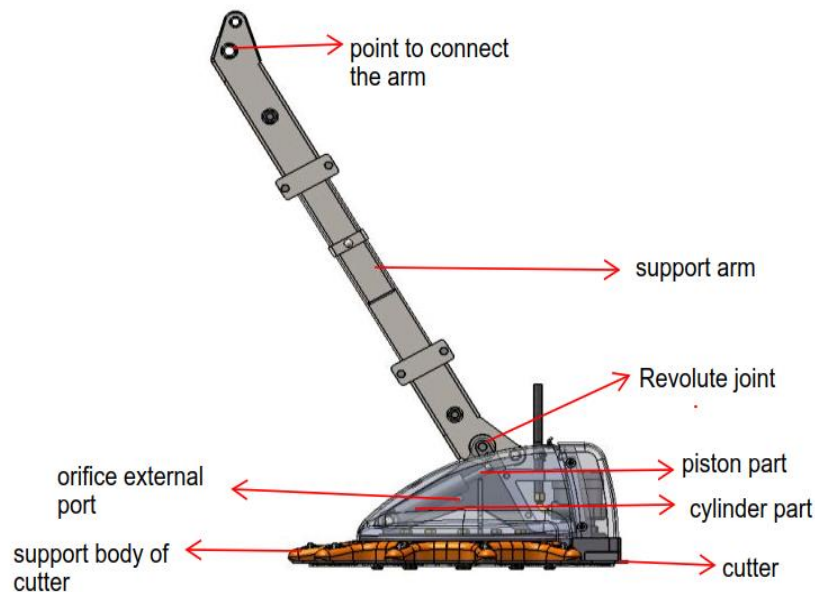


Figure 1.8 Brushwood cutter model [20]

In Figure 2.2, the different parts of brushwood cutter are shown, in which hydraulic source is given to actuator so that it helpful to tilt cutter to a certain extent to cover a wide area. In robotics arm, its act as end-effector part so according to movement of arms cutter arm movement get varies and mostly cutter movement is depending on revolute joint movement [12]. Hence from this by controlling hydraulic source given to tilt actuator and it can control movement and get feedback from the system by a revolute joint which is connected to the cutter. By giving input to PID controller to control the movement of arms and cutter with the desired rate of output with more accurate results.

The brushwood cutter which having one degree of freedom with respect to z-axis as gravity source. The arm is initially with an inclined angle of 31° and with movement is respect to the x-axis. The cutter is also having one degree of freedom and it also with respect to z-axis and movement of the cutter is along x and y-axis. The tilt actuator is fixed with the angle of 25° and its movement is along the z-axis and its connected with prismatic joint with friction coefficients like damping friction, static friction, breakaway friction. Due to this friction, the cutter is initially at stable condition without any oscillations. The main purpose of adding friction in the system is to arrest vibration to get expected output without any errors [7].

1.4.2 Brushwood cutter parts description

The main parts of the brushwood cutter and their properties are explained below.

Support arm

The support arm consists of a heavy rod which is used to interconnect the cutter to the main link. It plays the vital role to keep the cutter in a particular angle. It is completely made of steel and in the support arm one end is connected with the arm of the main link and the other end is connected with the cutter model by using the revolute joint. This joint helps to move the cutter freely while giving the power to the system. The Figure 1.9 which is shown below is the arm part of the brushwood cutter model.

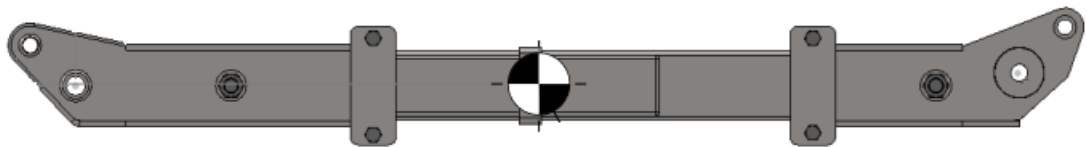


Figure 1.9 Support arm

This the arm which is used in the brushwood cutter model. The main purpose of this is to give the support to the cutter and to keep the cutter in the particular angle.

Revolute joint

The main function of the revolute joint is to connect the cutter and the support arm and also it will give the free movement to the cutter by arresting the movement of the support arm. In future, the sensor is going to place in this part to detect the angle of tilt in the cutter.

Motor

The main function of the motor is to give the power to the cutting blades and it will rotate at a certain number of revolution per times. The control of the motor is directly connected to the main control of the system.

Cutting blades

The cutting blades having the diameter of 18 inches and it is used to cut the tree with the sharp edges. The cutter is varied for the different types of model. In this model, the 45cm to 60 cm cutting blades are used.

Actuator

The actuator is the important part in the system which is used to move the cutter as per the requirement of the user.

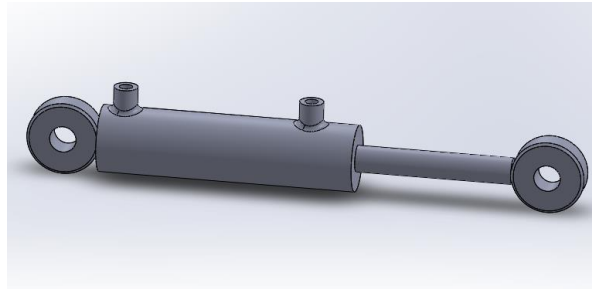


Figure 1.10 Actuator of the cutter model

It is initially fixed at the certain angle in the system. In which the whole control movement is controlled by using this part by sending the hydraulic fluid to the system. It also acts a passive damper in order to arrest the vibration to make the system stable.

1.5 Problem in the Brushwood cutter model

The various problems detected of the brushwood cutter model in hydraulic and control part are discussed in the following section.

1.5.1 Problem detected in the system

Normally in forestry machines, there are several performances took place at the working condition and even sometimes at the same time so many parts of machines should have to work on. Under this condition, the skilled and experienced driver should take charge, if the machine is without having automatic control. Hence by concerning this circumstances and consequences, according to user needs by integrating the machine with automatic control to make a user-friendly environment. Due to this, one can control machine in the desired trajectory and at desired angle too and its help us to improvise unwanted disturbance like vibration, oscillation etc. Hence control system is included and skill of the driver is not important to obtain satisfactory results. So, anyone can do work like professional one can do [12].

While introducing automated operation in the vehicle are evolved and now it gets developed day by day with so much of smart technology. In forestry machine, joysticks play a key role, which is used to control the movement of the arm by sending an electrical signal to control the flow of the hydraulic system [15]. Due to this movement of arm get varied and the proportional valve is used to the desired rate of flow of fluid inside hydraulic actuator and it controls all operation of the entire machine.

By using a joystick in the desired direction with maximum deflective angle and altitude; the driver skill plays a significant role to obtain an efficient result. Instead of that by using an intelligent control system to make an alternative to joysticks while in some operation like cutting and lifting is very easier to enhance operation with the desired angular movement under the stable condition. It is useful to make the user-friendly environment in an ergonomic way to forestry machine driver [17].

1.5.2 Problem in controlling system

The major problem that occurs in controlling the hydraulic system is to control the pressure of fluid and valve passage openings. In order to that from Figure 1.11 is the controlling module of the brushwood cutter flow level requirement is high mean it needs a lot of variation in pressure. Due to this, movement occurs in actuating part of system and cutter makes a movement. It is controlled by sensing loading area of the discharge of the valve in the system. The pressure flow and valve maximum opening areas and flow discharge coefficient and leakage area are specified to the system according to operating condition and its varies depends on movement [5].

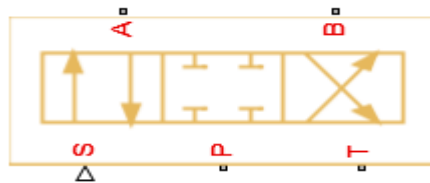


Figure 1.11 Controlling valve [12]

The 4/3 directional spool valve is used to control the flow of fluid and it is responsible for a constant fluid power source to the system. So, this spool valve is controlled by PID controller by giving the desired angle as input and to achieve the desired angle as output by tuning PID controller in forestry machine. The pressure relief valve is used to maintain the desired level of pressure in the system and transmission fluid is used as a hydraulic source [7]. The cylinder which is used in the structure is a double acting cylinder and its acts in a positive or negative direction according to the requirement of the user. PID controller which is used to control this system is by using the parallel form to get finely tuned output from the controller. The fluid is pumped from the fixed displacement pump and it passes to pressure relief valve after that it directly hit spool valve and according to input given to spool valve directional valve is open and actuator starts moving. While during this operation vibration occurs due high-pressure hits system by that time damping system is used to arrest vibration in the cylinder and makes movement smoother and easier with less number of bugs in the system [6]. Hence it concluded that in the system major part in this thesis work, it needs to control is the pressure of fluid and valve openings of the system and also enhances features of friction system to make the movement in the desired angle and by changing the damper parameter to adjust the flow by making the system stable to get good results without any overshoot or undershoot in the system.

1.6 Proposed System

From this master thesis work, by developing a simple controller, which control the movement of brushwood cutter to have a forestry machine in a linear trajectory plane with desired angular direction. From this trajectory control, the control movement in the desired direction with more accurate level without any interacting with humans. Due to this way of the approaching system, it creates a user-friendly environment to drivers and machines can work with high efficiency too. So, they can gain a profit in a significant gross level in Figures over years.

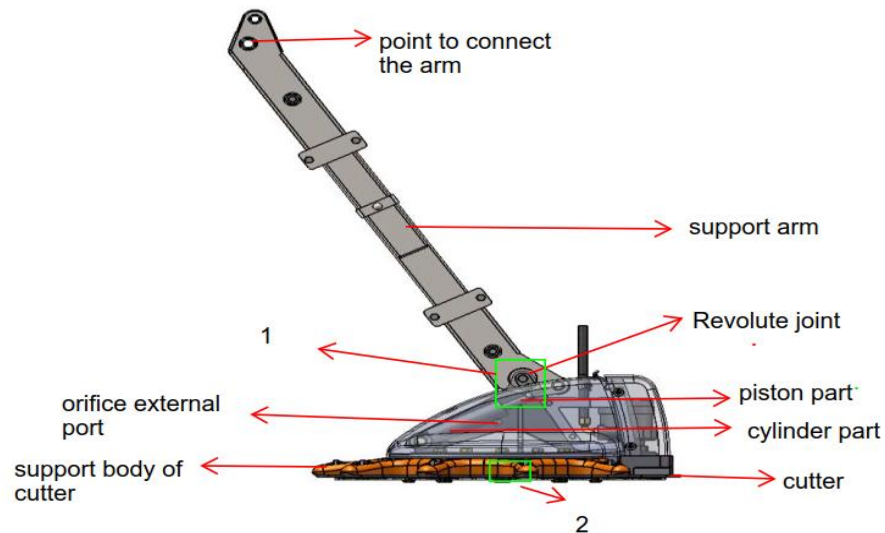


Figure 1.12 Proposed model changes to control

The green spotted one are the parts of the system in which going to add the sensor to the system in order to detect the cutter at which angle it is and how much it want to tilt. In this part, the transform sensor and the graphical user interface (GUI) are used to get the response of the system and the feedback of the controlling is working based on this output from the transformation angle from the transformed sensor. Depending on that the cutter movement will take place under a stabilized condition.

In this thesis work, to control the cutter in the desired level of the angle from 35° to 45° and to make the system more stable while working to get the quick response. The controller is designed to control the movement of the cutter and to get a significant response of the system. So the design of the controller which works more linearly to the system which is used to control. Hence, the Proportional Integral controller is used. So, by using this controller in this thesis work, it helpful to work in real time before implementing in the machine directly. For this, the Simulink and an AMESIM are used to develop a model to get required trajectory movement in the cutter and to analyses performance of the system.

2. MECHANICAL AND HYDRAULICAL SYSTEM

2.1 Mechanical system

In this part all the mechanical system which is used in the research work is discussed in the following section.

2.1.1 Design of mechanical system

The preliminary design of the mechanical system contains three parts that are simple in design for the simulation process in Simulink for controlling angular movement, and the model with the whole arm part of the system including cutter in AMESIM is for the stabilizing the movement of the cutter to get the quick response. Then the solid works model of the brushwood cutter is designed for the future implementation while used in the real- machines.

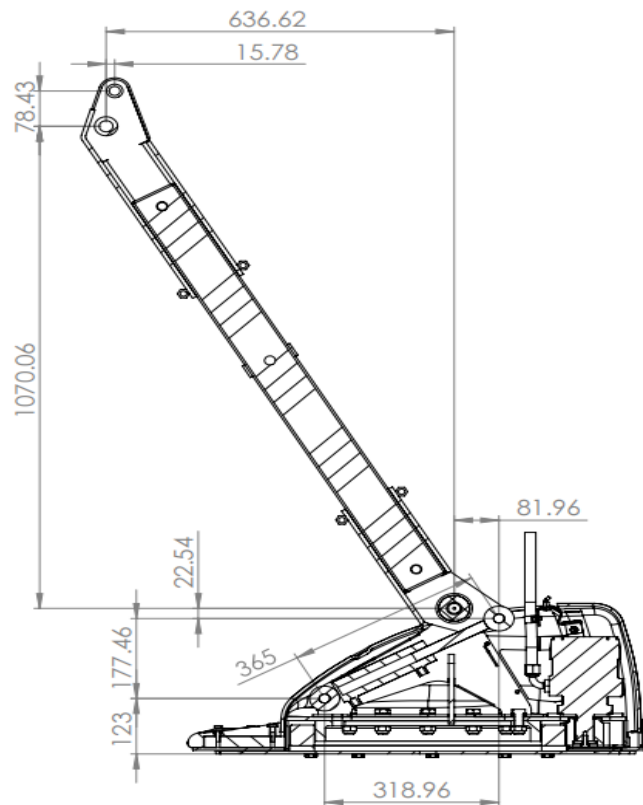


Figure 2.1 Parameters of Brushwood cutter

From the Figure 2.1, by using this parameter the simple structure of the mechanical system is designed in the AMESIM mechatronic simulation software for the controlling purpose. The images of the mechanical part of the system are shown in the upcoming Figures 2.2 and 2.3. From this mechanical system, each model is designed and connected by using the pivot joint and the revolute joint depending upon the movement of the system. The kinematics and the hydraulic parameters and their calculation of the mechanical system are made with their parameters provided by the manufacturers.

2.1.2 Mechanical model by using AMESIM

The mechanical model made from the AMESIM mechatronics simulation software is shown below.

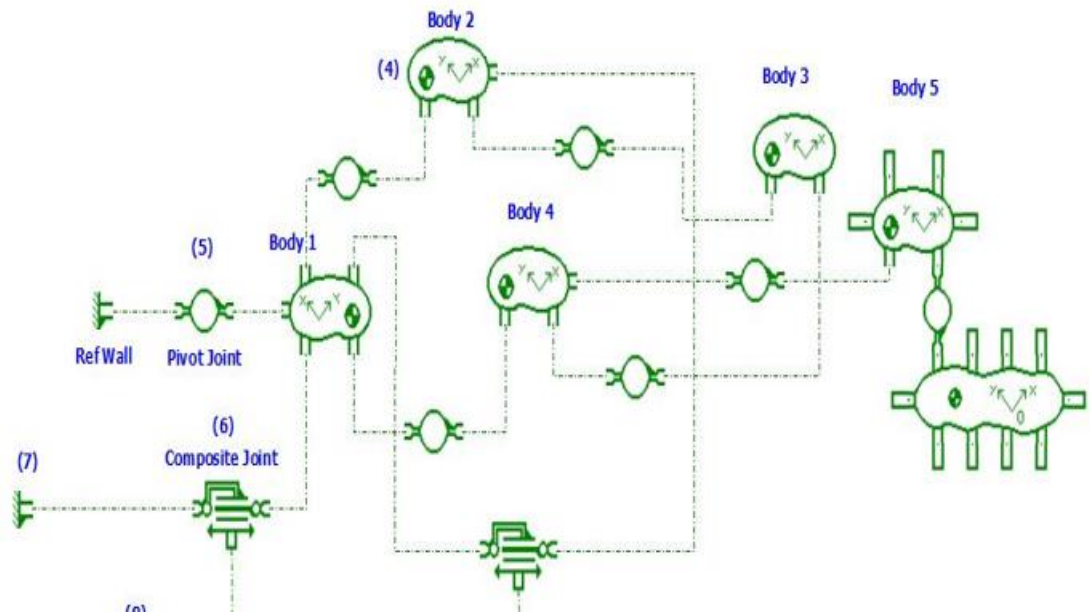


Figure 2.2 Mechanical body of AMESIM model

From the Figure 2.2, each part of the body is connected with the pivot joint and the power is supplied to the model from the hydraulic part of the system. So, the controlling of the cutter model is done by using hydraulic models of the system. The simple model which designed from the AMESIM is shown below in Figure 2.3. This is going to use for the improving the stabilization of the cutter by changing some damping parameters in the cutter and the real-time results are taken in the form of graphs with a real-time movement in the model.

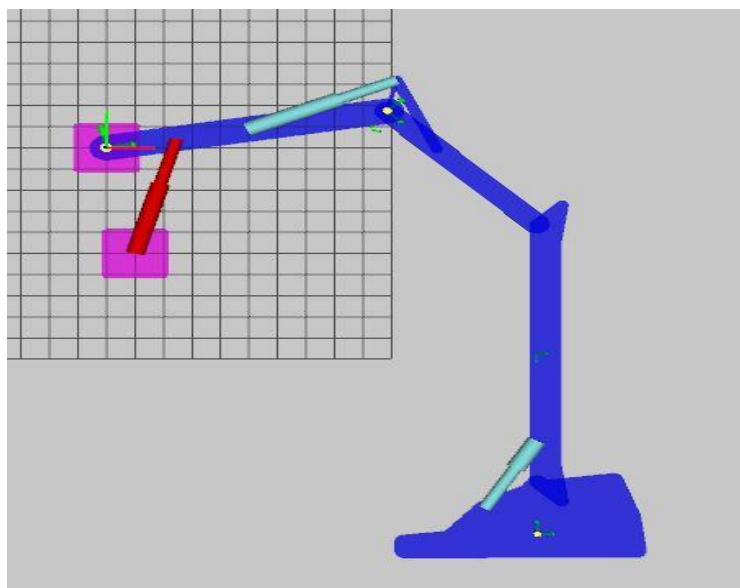


Figure 2.3 Simple model from AMESIM for real-time

2.1.3 Mechanical model using Simulink

The mechanical parts of the brushwood cutter are made by using Simscape Multibody and each part of the body is connected with the revolute joints and the pivot joint. The Simscape Multibody part of the cutter model is shown in Figure 2.4.

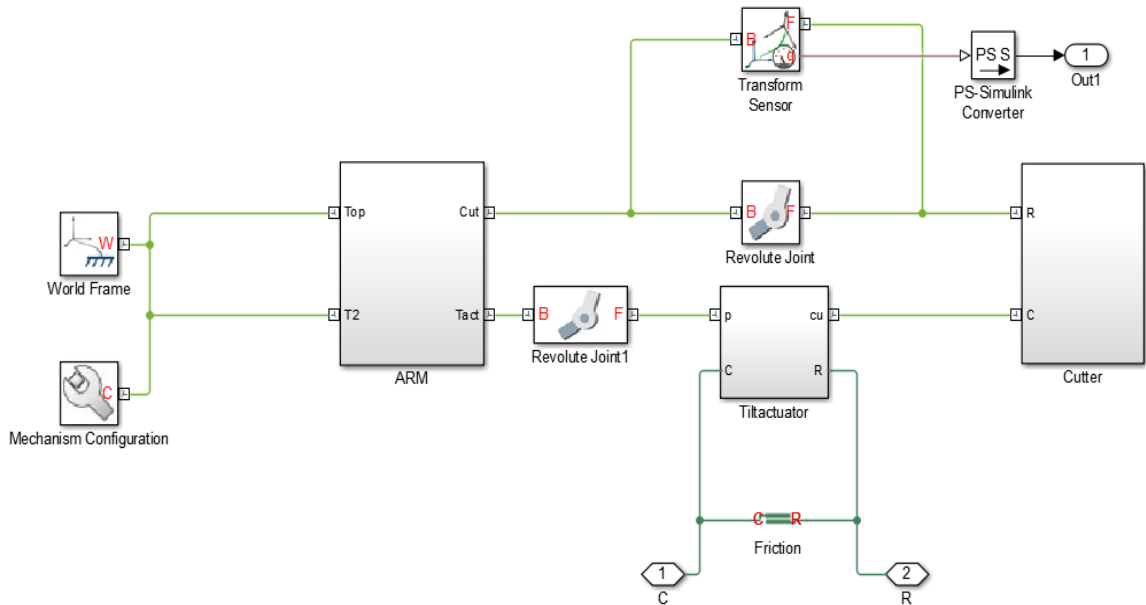


Figure 2.4 Mechanical body design using Simulink

From the Figure 2.4, all the part of the body is designed according to the parameters of the brushwood cutter. That are created by using the rigid transform and the solid body elements and each of them is connected by using revolute joints and the pivot joint. The simple structure which is used for controlling the angle by using the Simulink is shown below.

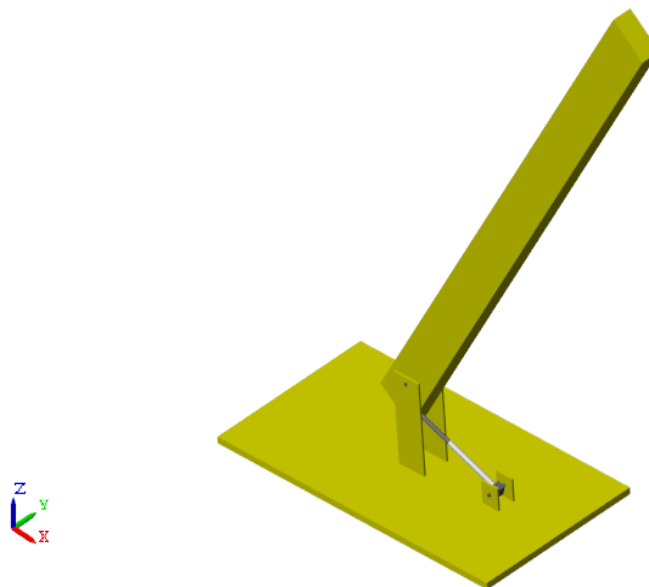


Figure 2.5 Simple cutter model using Simulink

The Figure2.5 which is shown above is the model used for controlling the angular trajectory motion in the Simulink and the results are taken in the form of a graph with the real-time movement of this cutter.

2.1.4 Mechanical model for the real-time implementation.

Once the controlling part of the system is done by using the Simulink multibody and by the AMESIM. For the further implementation of the real machine and to check the movement of the cutter before implementing, the solid work model is used to check the movement and the response of the system. For that the solid works model is designed and that are replaced in the arm and to cutter part of the Simulink to see the realistic movement of the cutter.

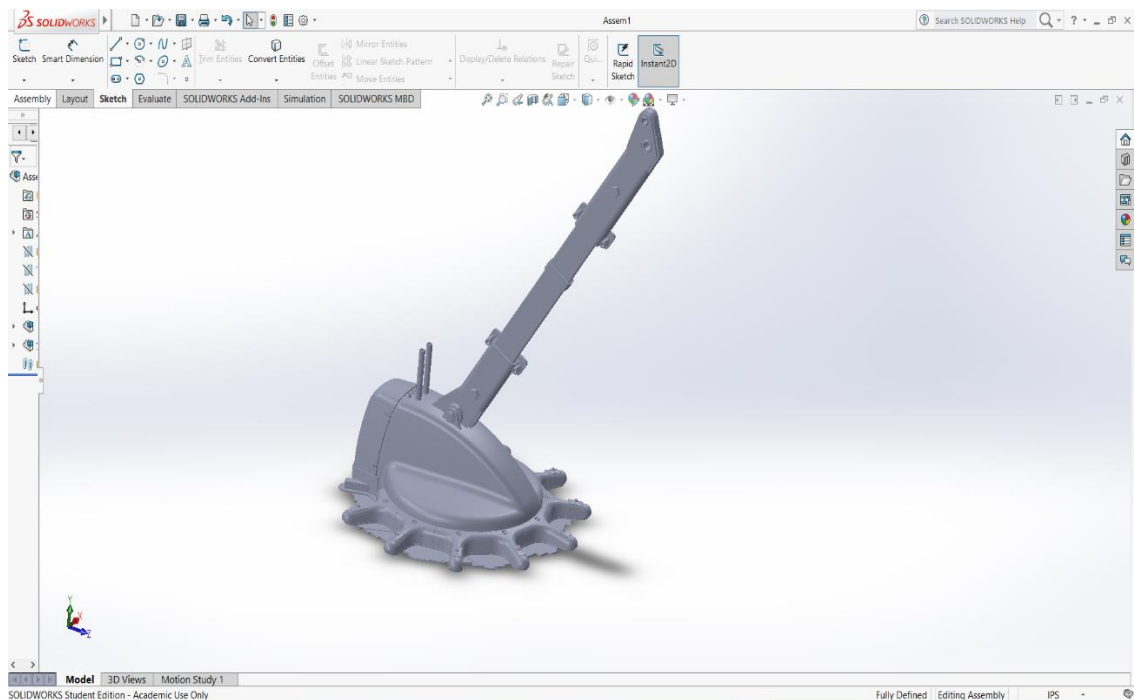


Figure 2.6 The Brushwood cutter model

This model contains the arm part and cutter part in which they are connected by using the revolute joint. Similarly, in the Simulink model, each and every part is connected by using the revolute joint. Hence by importing this SolidWorks arm and the cutter model to the Simulink body the real-time movement of the cutter can be able to see with their controlling performances.

The part of the cutter body contains the hydraulic actuator which acts a passive damper and by varying the size of the passive damper while controlling the system. It makes the system stable and with a quick response time. Hence the actuator part contains the external orifice. The transform sensor is placed in the revolute joint of the arm to detect the angular movement of the cutter body. From that, the feedback of the system is given to the controller to make the movement in the desired angle.

2.2 Hydraulic system for the model

In order to control the movement of the machine, each part of the body in the system is connected with other parts of the system, for example, hydraulic part is connected with PI controller and the whole hydraulic system is connected to double acting cylinder. The double acting cylinder connects to mechanical part of the system via the actuator. It relates to end of movement of brushwood cutter.

Hence these blocks are designed in Simulink by using Simscape Multibody and SimHydraulics under state space equation of system. From this, the first cylinder moves and make the joint moves and as follows till the end of brushwood cutter where first joint q is at the fixed condition and without any movement in the z-axis.

The hydraulics part of the system to control brushwood cutter movement and it contains constant pressure source, pressure relief valve and all are connected with directional valve and it also contains hydraulic actuator of the system. These are controlled by connecting with PI controller by giving reference input to the system and which relates displacement in directional valve and displacement of the body is occurred with different joint angles and with fixed axis position.

2.2.1 Directional valve in Simulink

The directional valve which is used in forestry machine is same for all hydraulic system. They are mainly model by discharge areas and displacement. This directional valve which contains input from the hydraulic fluid part and also from PI controller and output is connected to the system. The system is either mechanical or electrical etc., depends on the requirement of use and it could frame system in form of transfer function. For system which designed for a thesis in Simscape Multibody, a transfer function of the system is in mathematical expression [14].

$$k_v = \frac{1}{\frac{1}{w_n^2}s^2 + \frac{2\xi}{w_n}s + 1} \quad (2.1)$$

Where $w_n = 2 * \pi * 50$ rad/s and $\xi = 0.9$ and along with this is an input signal is given as u . and it flows to orifice of system which contains flow discharge coefficient of $C_d = 0.7$ and maximum opening area $V_m = 0.05$, Reynolds number \Re of 12, leakage area = $1e-12$ and pressure $P = 190$ bar.

The Hydraulic model which is designed for the brushwood cutter in Simulink in order to control the angular motion is shown in Figure 2.7.

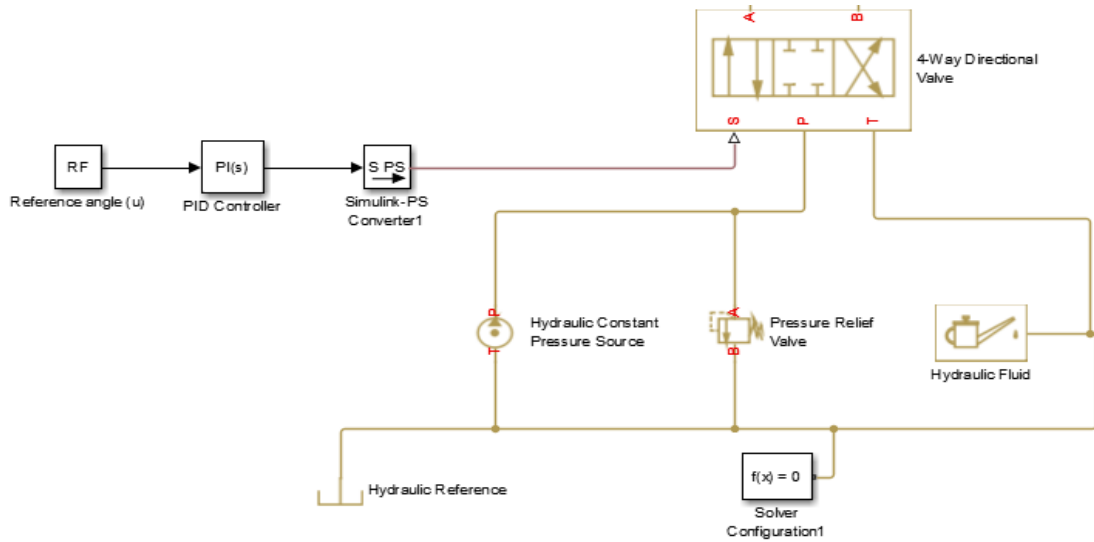


Figure 2.7 Model of Directional valve in sim-hydraulics

The parameters of the hydraulic pressure relief valve and the constant pressure source are shown in the form of Matlab scripts with the comments in Appendix. And the output model of the valve with the input along with the mask model which designed for forestry machine is shown below in Figure2.8.

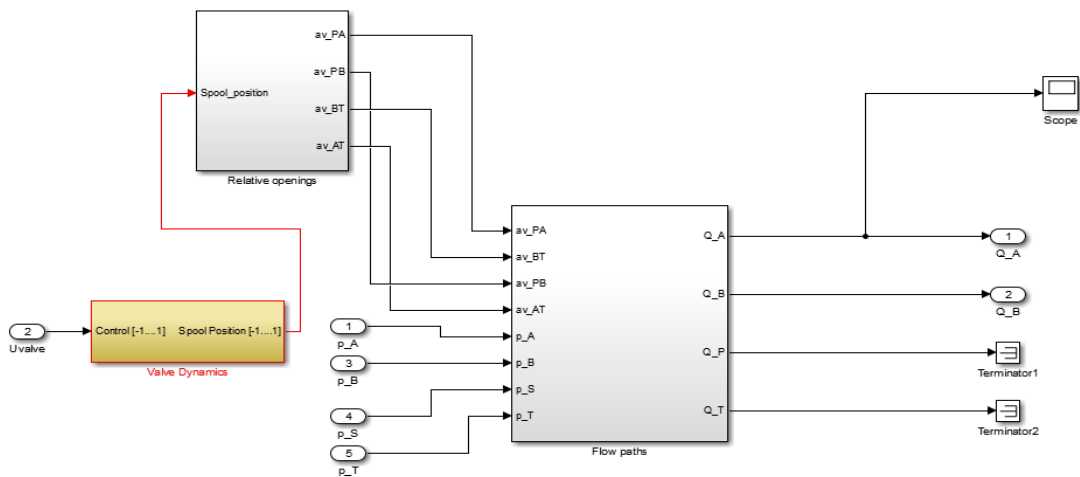


Figure 2.8 Model for Directional valve in Simulink

The valve which contains valve dynamics and spool positions and flow paths where depending upon the movement of system flow of fluid is passed away through the orifice of a cylinder with the output port of Q_A and Q_B . Depending upon the flow from the spool valve the movement of the cutter should occur. Hence the discharge of the hydraulic valve equations is described and the values are determined in the hydraulic calculation parts.

2.2.2 Actuator in Simulink

The actuator is modeled by using Simscape Multibody for the cutter. The expression in the hydraulic cylinder is used to model a continuity equation of piston rod and stroke length of the actuator. The parameters of the actuator of brushwood cutter are shown in the following table 3.2.

Table 2.1 Parameters of hydraulic actuator in brushwood cutter

Description	80x40-420 C720
Diameter of Rod d_o in (mm)	80
Diameter of piston d_p (mm)	40
Stroke length l_c (mm)	420
Dead volume V_{10} (mm ³)	50
Dead volume V_{20} (mm ³)	50
Friction coefficient B_p (N/(m/s))	120

By applying Newton's second law to calculate the force in actuator by applying pressure to the cylinder at a rate of 190 bars. The below equation which is going to illustrate the behavior of the actuator while applying maximum pressure with only affecting of damping coefficients is as follows [12]. The model which is designed in a Simscape Multibody is shown in the following Figure 2.9.

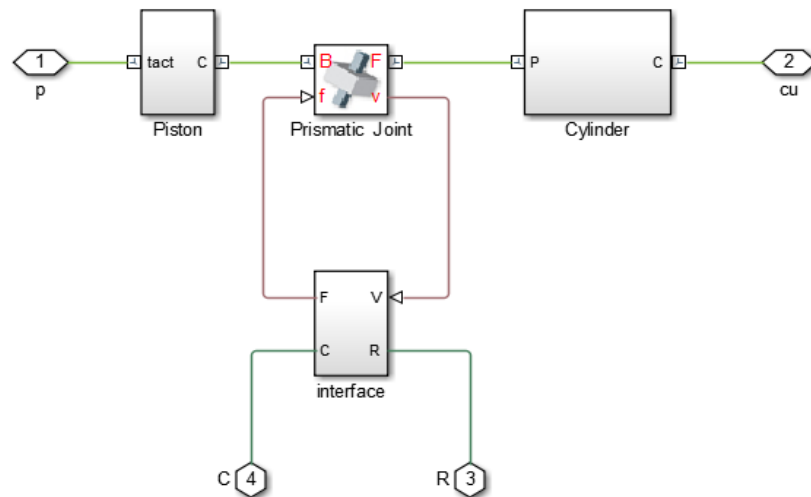


Figure 2.9 Simulink mechanical model

The actuator which contains, a cylinder and the piston part and it is attached by a prismatic joint Where shown in above Figure 2.9. The prismatic joint which holds a piston and a cylinder to make a translational movement and it is controlled by using interface where inside a subsystem translational

sensor and ideal force sensor are used to use the desired amount of force at a rate of translational movement. The friction part is added to the system to arrest the vibration and oscillation in the x-axis. So that the cutter can able to move only in the y-axis.

2.2.3 Hydraulic model in AMESIM

The simple hydraulic model of brushwood cutter contains a directional valve, hydraulic cylinders, and pipes, hydraulic pressure source and tank. In a brushwood cutter forestry machine load sensing element is attached to an axial piston and also with the joints, so according to that fluid supplied to displace piston by supply required volume of fluid and by supply pressure at the desired range by limiting using a pressure relief valve. The electro proportional way of controlling the controller is used to vary a displacement of the pump in a certain angle of displacement. [16]

Normally it contains a pressure relief valve, pump and a cylinder which is actuating the arm of the cutter. Where pressure source is controlled and limited by using pressure relief valve. The maximum pressure that flows through the actuator is 190 bar to the maximum exceeding the limit of the usewood forestry brushwood cutter machine. In order to the model in this thesis work by negotiating the pressure relief valve and a pump by using a constant pressure source from a tank and directly feed into the valves and by controlling it by using input by signals like step signal or ramp signal or sinusoidal signal. These signals are controlled by using a PID controller by varying the proportional gain and integrative gain to respond a system quickly with a transient period of 0.2 and with a response time of 0.1. After by applying this controlling segment in the model hydraulic cylinder is getting controlled with the movement and the designed actuator model in cutter movement is also the controller. Hence simplified model of a hydraulic model is shown in upcoming Figure 2.10 which is used for this thesis work and by using that system is controlled in various segments and also a friction coefficient is also used to reduce the vibration of a system. The servo valve is used to control a flow throughout the system [17].

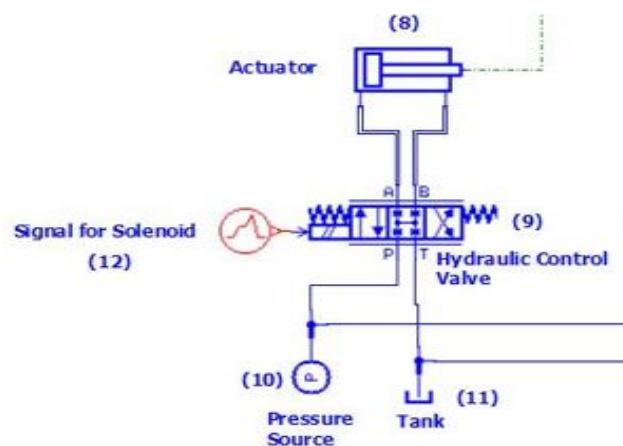


Figure 2.10 Hydraulic model in AMESIM

The hydraulic pipes are connected depending on the position of the actuator which is fixed and compressibility, friction hydraulic lines. Where compressibility of a fluid is defined here to determine the expansion of a pipe with a pressure act on a system module are considered and a bulk modulus of a system is also considered. The compressibility of a model is calculated from the thickness of a wall tube and it is considered in the AMESIM simulation model. So, the young's modulus of material is 57bar and thickness of the wall are 1.245mm [12]. The friction of the pipe is also considering by using the friction factor, Reynolds number, and roughness of a material. From the table 2.2, a pressure source and friction coefficient and relative roughness of material of the three cylinders are as follows.

Table 2.2 Hydraulic line parameters [17]

Description	Actuator 1	Actuator 2	Actuator 3
Length of pipe[mm]	0.5	2.5	6
Diameter of pipe[mm]	20	12	8

From the above parameters, the area of a valve and flow rates of a fluid through an orifice in the system to an equivalent area of a diameter of the double acting cylinder to satisfy pressure drop of the system and volumetric flow rate of the system. These are correlated with the equation and it is as follows [12].

$$q = Ac_M \sqrt{\frac{2\Delta p}{\rho}} \tan Z \left[\frac{2 d_s \sqrt{\frac{2\Delta p}{\rho}}}{v\lambda} \right] \quad (2.1)$$

ρ - hydraulic fluid density in kg/m³;

q - flow rate of fluid m³/s;

Δp - pressure of fluid (difference between pressure) in Pascal;

v - kinematic viscosity in m²/s;

λ - transition in between turbulent and linear flow of the system.

3. CALCULATION FOR MECHANICAL AND HYDRAULICS PARTS

3.1 Kinematics calculation

The arm of a robot or a machine is defined kinematically by describing four parameters of each link and these are derived by the Denavit-Hartenberg notation. The relation between one link and neighbor link gets from two of those parameters. The joints in the machine are revolute joints and there are three joint variables with fixed parameters they are represented as θ_j .

From this study, the main objective is to get precise movement from brushwood cutter in the desired trajectory. Hence, by considered link and movement of forestry machine are in 2D axis to make it simpler. From this, the z-axis considers as fixed angle and center of gravity of the body is acting in the Z-axis only. The parameter of each link is described here in the following table having no movement in the Z axis. The general form of them is shown in the table below.

Table 3.1 Parameters of the joints [4]

Link j	θ_j	d_j in (m)	a_j in (m)	α_j
1	q_2	0	0	0
2	q_3	0	L_2	0
3	q_4	0	L_3	0
4	0	0	L_4	0

By using this DH parameter, the length of arm and joint which is used to control are expressed in angles θ_j and offset link d , the length of the arm as a and twisting angle as α .

3.1.1 Inverse kinematics of manipulator to brushwood cutter

The inverse kinematics of the brushwood cutter which contains the two revolute joints and reference model is shown in Figure 3.4

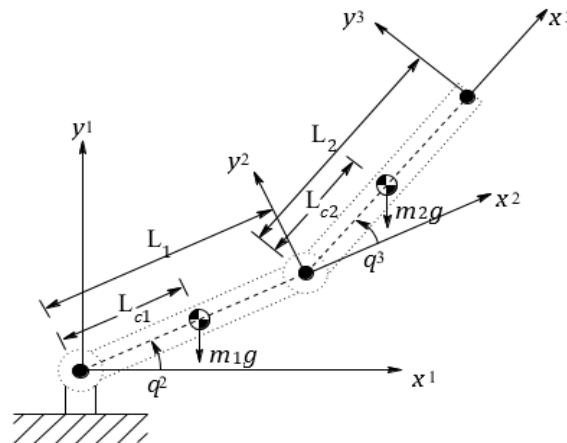


Figure 3.1 Arm to connect brushwood cutter [12]

In which “ q ” denotes joints in system and “ m ”, “ L ” are denoted as mass and length of the link which going to attached with brushwood cutter. This is important to find dynamics of the body of the machine and with help of Jacobian matrices of final joints where brushwood cutter is going to attach. By correlating with joint velocities, Jacobian matrices are used and the velocity of the arm is calculated by relation [11].

$$V = j(q)q' \quad (3.1)$$

The transformational matrices of each joint and link of the arm are to be defined and applying DH convention to find the transformation of body T_j .

$$T_j = \begin{bmatrix} \sin \theta & -\sin \theta \cos \alpha & \sin \theta \sin \alpha & a \cos \theta \\ \cos \theta & \cos \theta \cos \alpha & -\cos \theta \sin \alpha & a \sin \theta \\ 0 & \sin \alpha & \cos \alpha & d \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3.2)$$

The frames of each link are described by their link parameter and its multiplying with the transformation of single body and with N+1 frames [18].

$$T_n = T_{j1}T_{j2} \dots \dots T_{j(n+1)} \quad (3.3)$$

The link of the frame in which brushwood cutter is considered as q_3 . The transformation matrix of them in to fix trajectory by using Jacobian matrix expression is shown below.

$$T_{j2} = \begin{bmatrix} \cos(q2) & -\sin(q2) & 0 & L \cos(q2) \\ \sin(q2) & \cos(q2) & 0 & L \sin(q2) \\ 0 & \sin(q2) & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3.4)$$

$$T_{j3} = \begin{bmatrix} \cos(q2 + q3) & -\sin(q2 + q3) & 0 & L3 \cos(q2 + q3) + L2 \cos(q3) \\ \sin(q2 + q3) & \cos(q2 + q3) & 0 & L3 \sin(q2 + q3) + L2 \sin(q3) \\ 1 & \sin(q3) & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3.5)$$

$$T_{j4} = \begin{bmatrix} \cos(q2 + q3 + q4) & -\sin(q2 + q3 + q4) & 0 & L3 \cos(q2 + q3 + q4) + L2 \cos(q3) \\ \sin(q2 + q3 + q4) & \cos(q2 + q3 + q4) & 0 & L3 \sin(q2 + q3 + q4) + L2 \sin(q3) \\ 1 & \sin(q3 + q4) & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3.6)$$

Hence by applying the values of the parameter from the following table 3.2 and considering as the reference of table 3.1 then $T_{j(n+1)}$

Table 3.2 Parameters for transformation matrix

Link j	θ_j in degrees	d_j in (m)	L_j in (m)	α_j
1	$30^\circ(q1)$	0	3.560 (L_2)	0
2	$45^\circ(q2)$	0	1.725 (L_3)	0
3	$60^\circ(q3)$	0	0.650 (L_4)	0

Hence the total transformation of the system is considered and calculated from the above table and hence the $T_{j_{n+1}}$ is as follows.

$$T_{j_{n+1}} = \begin{bmatrix} -0.707 & -0.707 & 0 & -0.159 \\ 0.707 & -0.707 & 0 & 0.169 \\ 1 & 0.965 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3.7)$$

3.1.2 Geometric model of arm to precise the movement of brushwood cutter

In order to the precise exact position of brushwood cutter, it is important to make the movement of arm linearly in the desired trajectory of the Cartesian coordinate system. It is important to explain in detail description and connection between arms and link of brushwood cutter movement. Hence these relation is described by the relation of a geometric model using DH convention.

Initially, by considered from the system, the sewing part is fixed and triangular shaped is formed by L_2 , L_3 , L_4 and joining frame 1 and to frame 4. It can move both up and down directions. These are going to relate us to precise movement of brushwood cutter. So, by considering this triangular movement and by applying cosine law to solve the equations to find the coordinates of x and y-axis without any movement along the z-axis[16].

$$q = \left(\frac{L_2^2 + L_3^2 + L_4^2 - x^2 - y^2}{2 * L_2 L_3 L_4} \right) \pi \quad (3.8)$$

$$q = 11.5^\circ \text{ (angle of tilt normally by cutter)}$$

This expression is applied to a solid triangular movement and to declare working condition and it is checked by existed solution of brushwood cutter movement linearizing from the arm of forestry machine [16].

$$\sqrt{P(x_2^2 + y_2^2)} \leq L_2^2 + L_3^2 + L_4^2 \quad (3.9)$$

The movement along x and y-direction either upward or downwards of the arm are denoted based on term q_1 . Now the movement of the arm with respect to “q” as the base frame is q_2 and q_4 are as follows. If the frame is lower than zero level with respect to base frame q_1 . This means too that its elbow is in down condition. If it is higher than zero then q_2 is expressed in terms [13].

$$q_3 = \beta + \Psi \quad (3.10)$$

where β is the quadrant in the axis of x and y and φ is used in terms of the cosine law that implement in the model.

$$\Psi = \arccos\left(\frac{\sqrt{x^2+y^2}}{2L_3}\right) \quad (3.11)$$

the configuration of joint angle θ_j is

$$q_3 = \arctan\left(\frac{x}{y}\right) + \arccos\left(\frac{\sqrt{x^2+y^2}}{2L_3}\right) \quad (3.12)$$

$$q_3 = 61.2^\circ$$

3.2 Hydraulics calculation in Brushwood cutter

The hydraulic system is containing hydraulic fluid, hydraulic pump, hydraulic actuators, pressure relief valve, hydraulic valves. From this, the pump is to give constant flow to the system from hydraulic references. The proportional valves are used to control the movement of brushwood cutter and detailed description about that are explained below. Hence the torque given to the cutter is expressed in the formation of equations below

3.2.1 Hydraulic force and torque of the cutter model

The expression which derived above defines torques according to the inverse kinematics of system. From that torque of body is going to use in order to relate with hydraulic cylinder force. By this relation, hydraulic and mechanical torque are worked in principle given equation below [14].

$$T dq = F dx \quad (3.13)$$

$$T = F \frac{dx}{dq} \quad (3.14)$$

$$J(q) = \frac{dx}{dq} \quad (3.15)$$

Where

F - refers to force producing by cylinder;

J - change in displacement of cylinder;

q - angular position. (obtained from trigonometric mapping values).

3.2.2 Framing the relation of dc_3 (cylinder displacement)

To calculate piston displacement dc_3 by correlating with the angle of q_2 are by the trigonometrical way is shown below. The displacement of the cylinder is defined by the links of the cutter with respect to the first link joint hence the expression of dc_3 is

$$dC_3 = \sqrt{L_1^2 - 2 \cos \left[\beta_1 - \frac{\pi}{2} + \beta_2 - q_2 \right] L_1 L_3 + L_3^2} \quad (3.16)$$

3.2.3 Directional valve calculation

The main purpose of directional valve is to drive system by using fluids. The directional which is used in thesis work is three land-four-way valve. Where valve which contains three input S, P, T and two outputs are A and B.

The spool which contains orifice with variable areas and is controlled by displacement of the valve and flows through the orifice is defined by given general equation [9].

$$Q = C_d A \sqrt{\frac{2}{\rho} * \Delta P} \quad (3.17)$$

Where

C_d is the coefficient of discharge

Δp is, the pressure drops in the orifice

ρ is the density of fluid

A is the area of orifice

It is get varied depend on the geometrical form of a valve. In thesis work, the orifice is symmetrical like in normal directional valves and by considered orifice area as A and expression for the proportional valve is given by following equation (4.18). The linear area of the orifice with stroke and along with the width and sleeve of the valve is calculated and its expression is shown in the equation (4.19).

$$A_1 C = A_3(x_v) = A_2(-x_v) = A_4(x_v) = A(x_v) \quad (3.18)$$

Where

$$A = W(x_v) \quad (3.19)$$

$$W = \pi * d_p \quad (3.20)$$

From discharge of fluid in the directional valve, it flows through port Q_A and Q_B to double acting cylinder in order to make movement in brushwood cutter and the relation between the amount of discharge from the directional valve is related by using following general equations (3.23) with double acting cylinder respectively [24].

$$Q_A = C_d w x_v \sqrt{\frac{2}{\rho} |\Delta P_A|} \quad (3.21)$$

$$Q_B = C_d w x_v \sqrt{\frac{2}{\rho} |\Delta P_B|}, \quad (3.22)$$

$$Q_A = Q_B = 7.85 * 10^{-5} \text{ m}^2$$

3.2.4 Double acting Hydraulic cylinder

The displacement of the hydraulic cylinder is depending on the flow of fluid from the orifice of directional valve and flow through the orifice is controlled by using the PI controller in order to get the desired trajectory from the hydraulic cylinder. In the thesis work, the directional valve is symmetrical and hence according to that following equation (3.23) to find the amount of flow that will discharge and to find the displacement of the cylinder by the following equation[25].

$$\rho = \rho_i + \frac{\rho_i}{\beta_e} P, \quad (3.23)$$

By applying the continuity equation to the piston chamber and the relation is given below [25].

$$Q_A - C_{ip}(P_A - P_B) - C_{ep}P_A = \frac{dV_1}{dt} + \frac{V_1}{\beta_e} \frac{dP_A}{dt} \quad (3.24)$$

$$C_{ip}(P_A - P_B) - C_{ep}P_B - Q_B = \frac{dV_2}{dt} + \frac{V_2}{\beta_e} \frac{dP_B}{dt} \quad (3.25)$$

Where

V_1 - volume of the forward chamber;

V_2 - volume of return chamber;

C_{ip} - leakage coefficient in the Internal port;

C_{ep} - leakage coefficient in external port;

β_e - bulk modulus of the fluid that selected.

By considering a system without any leakage in the cylinder and without any leakage coefficient in internal and external ports then the following equation is obtained.

$$Q_A = \frac{dv_1}{dt} + \frac{v_1}{\beta_e} \frac{dP_A}{dt} \quad (3.26)$$

$$Q_B = \frac{dv_2}{dt} + \frac{v_2}{\beta_e} \frac{dP_B}{dt} \quad (3.27)$$

The volumes of the piston chamber as

$$V_1 = v_1' + A_1 x_p \quad (3.28)$$

$$V_2 = v_2' + A_2 x_p \quad (3.29)$$

where

A - area of the piston;

x_p -piston displacement;

v_1' , v_2' - a volume in the forward chamber and backward chamber.

and by using the volume that used previously; in chamber equations and by applying continuity equation of piston in following equations.

$$Q_A = A_1 \frac{dx_p}{dt} + \frac{v_1'}{\beta_e} \frac{dP_A}{dt} \quad (3.30)$$

$$-Q_B = -A_2 \frac{dx_p}{dt} + \frac{v_2'}{\beta_e} \frac{dP_B}{dt} \quad (3.31)$$

From above equation, the rate of flow at in and out of cylinder along with piston displacement is considered with desired pressure on both sides of the cylinder [8]. To simplify above equations, and to calculate area and diameter of piston and rod.

$$A_1 = A_2 = \frac{\pi(d_p^2 - d_r^2)}{4} \quad (3.32)$$

At initial volume, chambers are considering with dead volumes and at a free actuating length with stroke length l . Then by considering cylinder which is in Centre position too. By using following terms volume of a cylinder is expressed in the following equation.

$$v_1' = V_{10} + \left(L_x + \frac{L_c}{2}\right) A_1 \quad (3.33)$$

$$v_2' = v_{20} + \frac{L_c}{4} A_2 \quad (3.34)$$

4. CONTROLLING BRUSHWOOD CUTTER MOVEMENT

In this thesis work, the main objective is to control the movement of brushwood cutter in desired angular projection and stabilizing the movement of the cutter in the desired response time. To meet the objective, the model of the system is done by Simscape Multibody and SimHydraulics and AMESIM. Now by applying control theory to the model so that it is controlled in a desired trajectory at an axis movement in the expected range with a more stable response. To get an expected range of results, the system should be at state space and will be modeled with the linear analysis of the system. In order to get proper feedback from the system, the close loop method is used.

4.1 Proportional Integrative (PI) Control

By the transfer function of the system, the controller can be tuned to get the output in a closed loop control. The closed loop control system contains a basic structure as shown in Figure 4.1.

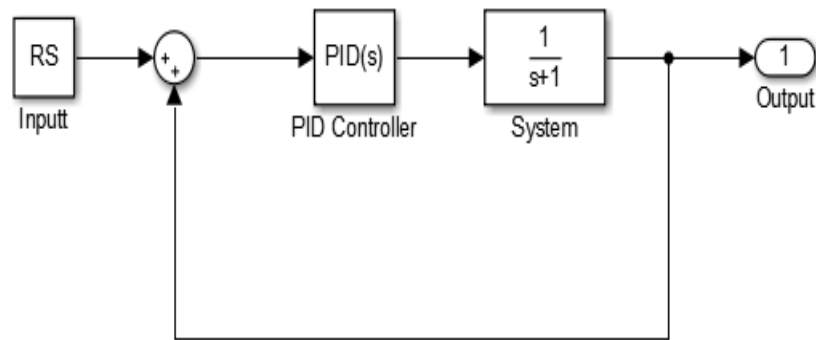


Figure 4.1 Basic unity feedback PID control system

From the Figure 4.1, RS refers the input to a system and it contains a PI controller and it passed plant and it will process a plant and output of a plant are send as a feedback error signal to a system. This how the basic PID controller working.

The PI controller which contains an auto-tuning and a manual tuning. In this thesis, a controller is manually tuned by using the Ziegler's- Nicholas method. By using the ZN table P and I value is manually tuned. [12]

The general equation of PID controller is shown below [26].

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt} \quad (4.1)$$

Where K_p and K_i values are taken from ZN- table as shown in Table 4.1 [26].

Table 4.1 Ziegler's Nicholas table [6]

<i>Controller</i>	K_p	K_i	K_d
P	$0.50K_u$	Nil	Nil
PI	$0.45K_u$	$1.2K_p/P_u$	Nil
PID	$0.60 K_u$	$2K_p/P_u$	$K_pP_u/8$

The Proportional Integral (PI) controller is used in this modeling brushwood cutter to control the movement of a cutter because it is easy to implement in real time application. The PI controller which is used in the model is in a closed loop. In P controller, it doesn't cancel the preliminary error in the output signal so only for this thesis work PI controller is suitable for the forestry machine. The integral term which contributes a much in term of proportional to magnitude and duration of the error. By using this controller, the error should be zero and performance will improve by increasing a gain in a system [17].

By considering sampling time $T_s = 0.2$ and by giving a various k_p and K_I are based on the transient behaviour of the system. By increasing response time of the system and the transient behavior stability of the system get improved and reduced an overshoot and track a path quickly without taking longer settling time. Due to this, PI controllers are widely used in the forestry machine application. By using a closed loop, it easy to reduce the error in a system by giving disturbances to model. The maximum transient period is 0.5 and with a response time of 0.5 sec is used. The proportional gain and an integrative gain used in a brushwood cutter model to control is

$$K_p = 3.1072$$

$$K_i = 0.1568$$

According to this thesis work instead of plant, it contains sim-hydraulics and simscape multibody parts and position of the system are sent as a feedback to the PI controller and a process is continued until to get the desired result. The complete model of brushwood cutter is shown in Figure 4.3.

From model, feedback from system is taken out from cutter and it is basically sensed by using transformation sensor and it convert by using Simulink converter to digital signal and it transferred to feedback loop by using radian to degree conversion because the system is giving

degree as input so that it is easy to analyse model at which angle error should be and how to minimize it and in order to reduce overshoot auto tuning is used in PI controller so that it tuned automatically with a fine response time and transient behavior of system.

4.2 Process flow chart of controlling module for Simulink

This process flow chart describes the various function that is carried out to design the control module of the cutter.

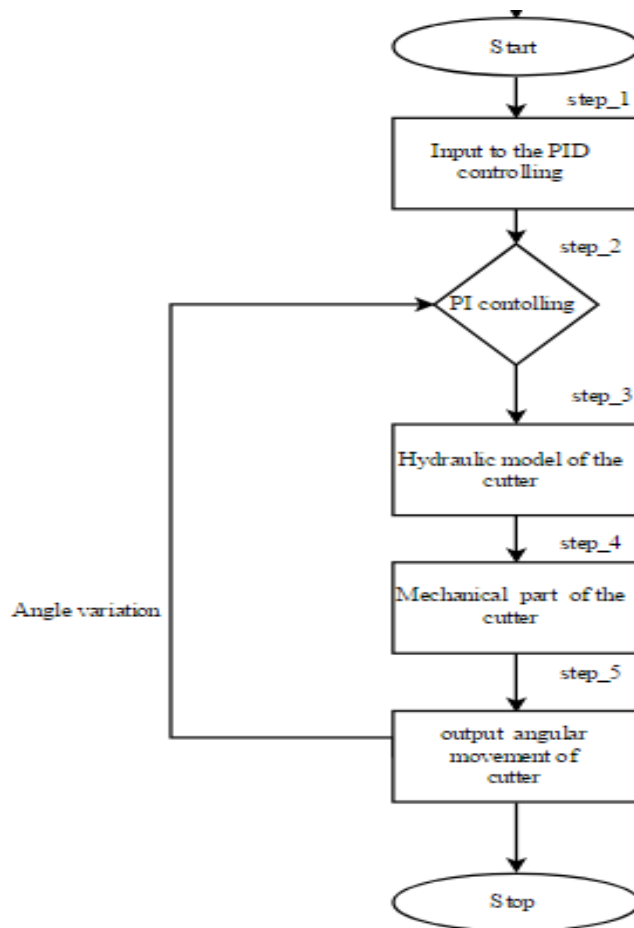


Figure 4.2 Process flowchart of Simulink model

This flow chart represents the step by step process of the brushwood cutter model controlling to get the desired trajectory angular output. Where the hydraulic model and the mechanical model of the cutter parts are explained in the previous chapters 3.1.2, 3.2.1 and 3.2.2. In that, the hydraulic model is used to control the movement of the Mechanical model. The Input signal to the hydraulic is given by using the Proportional Integral controller and the output of the mechanical model is sent as the feedback to the controller. Where the input and feedback signal of the controller is given in degrees. The step signal as the input given to the system. From this process, the angular movement of the cutter is controlled and moved it in a desired angular trajectory level. Furtherly the complete control model of the Brushwood cutter is shown in the following Figure.

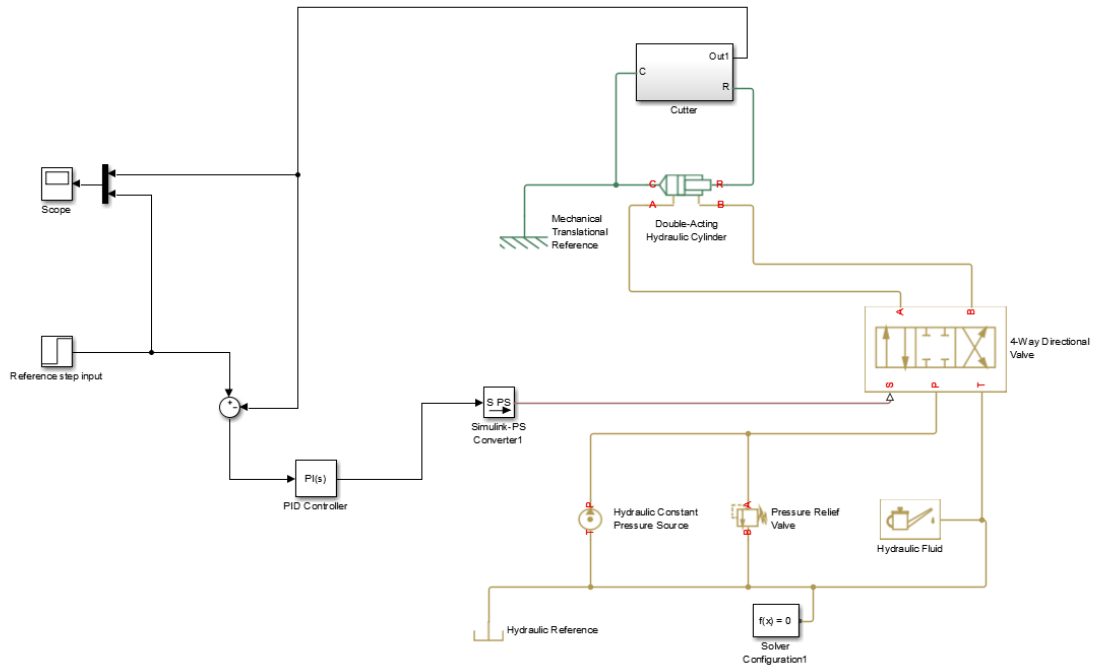


Figure 4.3 Complete model of Brushwood cutter

The Simscape multibody contains world frame where it is used to fix the axis without any movement. According to this thesis work, brushwood cutter doesn't have any movement in the z-axis and mechanism configuration which contains the gravity to act in which axis according to that model makes a movement. The arm part of the system contains the bar and with one degree of freedom and it can move only in the Y-axis and it is normally at a tilting angle of 31° from the y-axis. The revolute joints are used to connect arm and cutter in which where it acts as a linking element between links in the brushwood cutter. The rigid transforms are used to design simple model at a size of brushwood cutter and later by applying the control segment of the body, to get controlled by supply hydraulic power via tilt actuator. The transform sensor is used in the system which gives a feedback to the controller to determine at which point the cutter is in. According to that PI controller changes the valve to get desired results. The friction part of the system is added to arrest a vibration occurred by while moving. It contains the breakaway friction, Coulomb friction, viscous friction and transition coefficient of a system to reduce the vibration occurred in the system.

By designing the directional valve and the hydraulic actuator by using the SimHydraulics and Simscape Multibody. It has connected each other to apply the control in a steady space-state model to get the angle of movement of the brushwood cutter from a linear projection of an arm. The blocks are connected in a closed loop so that by applying the pressure and hydraulic fluid inside the directional valve, the mechanical part of the system get moved.

In this Simulink model of hydraulics part is designed in sim hydraulics and where it contains hydraulic references it refers brushwood cutter is working by using hydraulics energy and the

hydraulic constant pressure source is used to get constant pressure. According to thesis work, usewood forestry machine is working with a maximum pressure range of 190 bars. The pressure relief valve is used to relief pressure in certain conditions and it contains certain parameters like flow discharge coefficient, Reynolds number and leakage area [15]. These parameters are given according to the usewood forestry machine parameters. The hydraulic fluid part is also essential to show what type of fluid that in this thesis work. The fluid, which is commonly used for the transmission, is Transmission fluid ATF and the system's operating temperature is 60° , relative air trap is 0.05.

These parts relate to the directional valve and the valve which contains three ports in which one is forward and the return port and the third port is used to control the valve by using the PI controller to get a significant angular movement of brushwood cutter. The directional valve which contains two output ports A and B where that is connected to the double acting cylinder. By giving the maximum passage area of valve, maximum opening area of valve, flow discharge coefficient, Reynolds number and leakage area and initial opening condition of a system the flow through an orifice of a valve gets controlled so that double acting cylinder movement get arrest and moved at desired rate of flow inside the chamber to the cylinder.

The double acting cylinder relates to a model which is designed to a thesis work and it contains several parameters like a piston areas, stroke length, dead volumes, specific heat ratio and orientation of cylinder. It also contains a contact stiffness and constant damping properties of the system. So, this double acting cylinder is used to make movement in brushwood cutter at an angle. From the above, control model the movement of the cutter in the Figure2.4 is worked in the real time with the desired output from the system.

4.3 Control model of the AMESIM

The control model of the AMESIM is most similarly like the Simulink model. But in this part, the stabilization of the cutter by using damper is taken into account. So, the various process that is carried out for the AMESIM model is expressed in the form of the flow chart. Initially, for controlling the stabilization of the brushwood cutter with a quick response time the mechanical model is required and it is designed in the AMESIM and for actuating the arm the hydraulic model is required and the parameters are given as per the manufacturer's data. Then the controlling process is done by sending the signal to the damper part and by varying the parameters in the real-time in order to get the output.

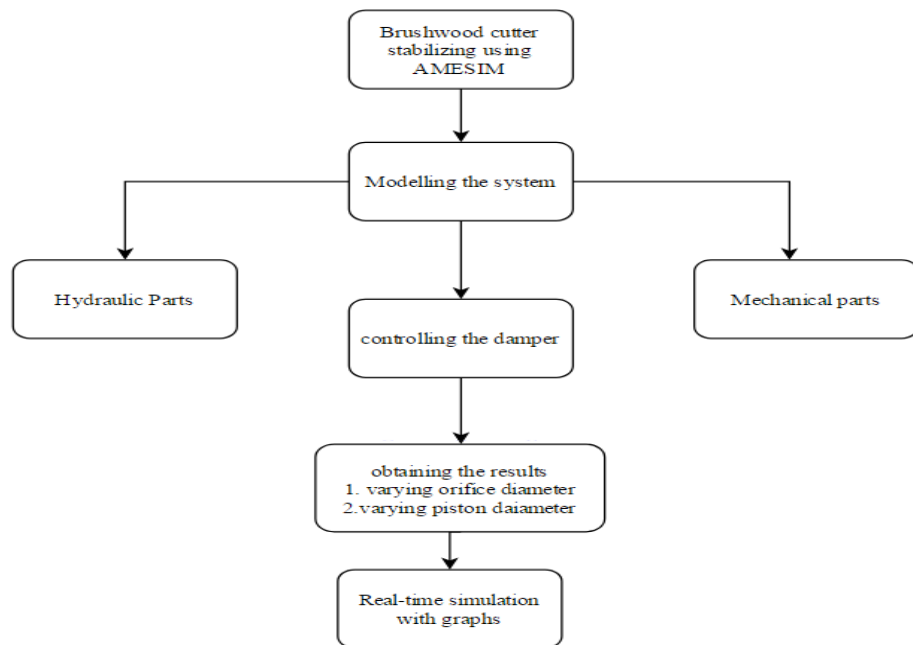


Figure 4.4 Flow chart for AMESIM model

By controlling the movement of the cutter, it is important to using controlling platform in AMESIM and where the complete model of forestry brushwood cutter machine are shown in Figure 4.5. It contains the 2-dimensional structure of brushwood cutter model as shown in the Figure2.3. In that the hydraulic cylinder is displaced by giving signals and it related to each trajectory of the system with an offset of each cylinder and the angle of the movement and this is useful to correlate the displacement of a cylinder in the arm and the angle of displacement in a cylinder which is used in a brushwood cutter. So, that system performance is analyzed and adjust the position of accuracy in the model [17].

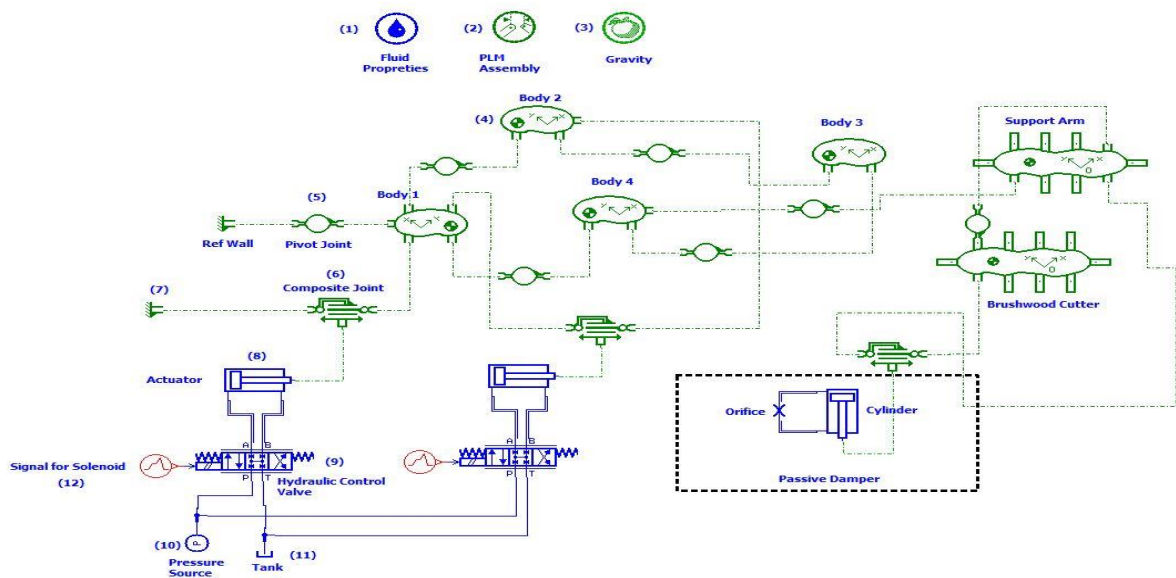


Figure 4.5 Complete model of brushwood cutter

From the Figure 4.5, it is clearly illustrated the process of the Brushwood cutter model which is done by using Mechatronic Simulation assistant AMESIM. Where initially the process is for the stabilizing the brushwood cutter model by giving damping, for that the mechanical model is designed like cutter part, arm part and actuator part at a fixed axis by using the body elements in AMESIM. The hydraulic parts like a directional valve, pressure source is designed. These are connected to each other by using pivot joints and the controlling is done by giving reference signal to the directional valve. This valve sends the fluid at desired rate to the orifice diameter of the damper and to the cylinder. So that by varying the orifice and diameter of the damper the response of the system can be obtained with a real-time simulation movement.

After designing and the mechanical model by using AMESIM the control process is carried out by sending the reference signal with the amplitude of sinusoidal waves and the hydraulic fluid is pumped out from the hydraulic source at the range of 190 bars to the directional valve. According to the reference signal the directional valve orifice are is opened and it actuated the double-acting cylinder which is attached along with the valve. This actuator is attached to the mechanical model of the system. That system will move according to the rate of flow of the fluid is passing to the hydraulic actuators. The passive damper is used to control the stabilization and to improve the response time of the system and it contains the orifice external tube in order to adjust the excess flow of the fluid to the system. By varying the diameter of the orifice tube which is attached along with the cylinder is used to control the stabilization of the cutter. Initially, by giving the diameter of 1.5 mm and the response of the system in seconds are taken out in the form of graphical representation. Similarly, by varying the diameter of 2mm,2.5mm,3mm and the time response also taken and considering the response of the system which took short time to achieve the response is considered. Now by keeping this orifice diameter constant and by varying the piston diameter to 30mm,32mm and 35mm and the response time of them are considered. And as a result, the system which achieves the very less time to get the stable condition are taken and the movement of that model is simulated in the AMESIM software.

5. RESULTS FOR BRUSHWOOD CUTTER CONTROLLING

5.1 Performance of cutter in Simulink

The PI controller is designed with a suitable parameter to the brushwood cutter model and by analyzing it in the close loop by giving reference signal to the system. From the model of Figure 5.2 which shown above in the output of a system is resulted in the form of graphical representation.

The simulation of real-time also represented in the system and by giving reference signal how the system gets respond at Cartesian coordinate and the angle is obtained. After displacement of hydraulic cylinder movement of cutter should take place and deflected the angle of the cutter is obtained as output to PI controlled and that output is sent feedback to the system so that it knows which angle initially cutter is and according to that the proportional gain and integral gain of a body get improved [14].

The results are obtained in closed loop response in which R-locus of open loop response is shown below and in which controller is defined with parameters like phase margin of 35° and with gain margin. The time response would be get decreased while having higher oscillation in response. To find stable response PI controller is tuned to get desired output at very less time. So, the output of a system and their results are as follows.

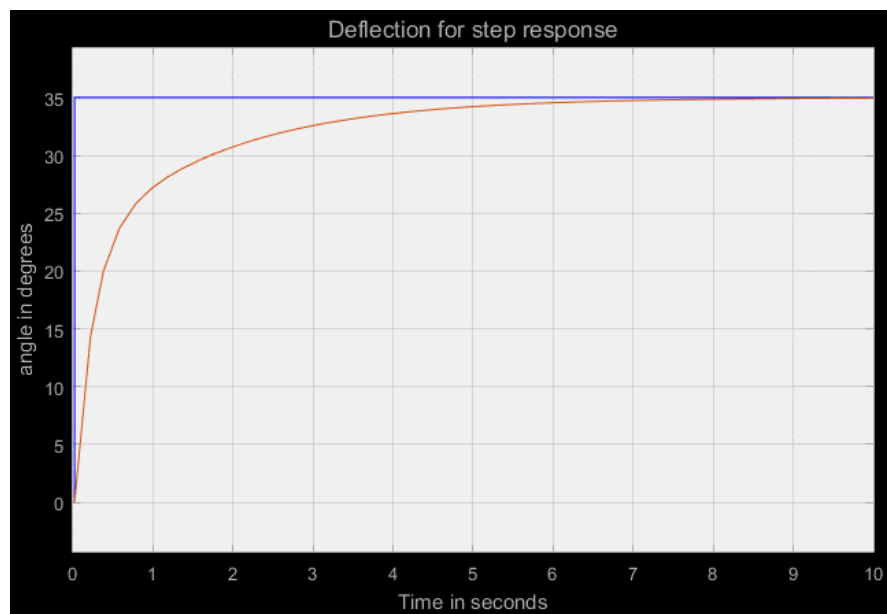


Figure 5.1 Deflection angle of the brushwood cutter

In the above Figure 5.1, it is clearly showed that the movement of the cutter is less than the 35° as per the given step input to the system. It is initially taking the time response of 0.2 sec to reach the state and after at the stage of 6sec, its reach the normal state. From the Figure, it clearly states that there is no overshoot in the system, from this the system responds perfectly without any bugs and it is occurred due to the friction coefficient in the system. The appropriate results of the deflected angle from a transform sensor of a system is shown below.

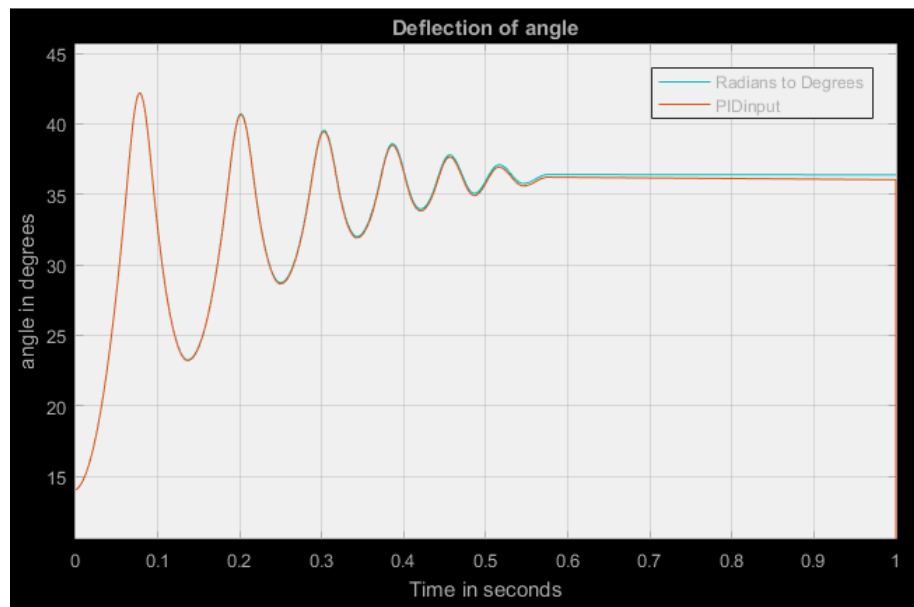


Figure 5.2 Deflection angle from the feedback of the cutter

From the above Figure 5.2, it clearly states that the signal which sends to the Proportional Integral controller (PI) to the system and the responding of the system are at the same level of deviation and it should not exceed more than the 40° . So, the maximum angle of deflection of the system in which is designed for the controller is lies between 35° to 40° . It is not exceeding more than the desired range of expected results from the manufacturers.

5.2 Results from AMESIM model

From the AIMSIM model running condition results are obtained and it is in x-axis and y-axis from which results like angular position and angular velocity and angular acceleration are determined and it is used. From this, the result from the Simulink model is compared with result that obtained from the AMESIM model and it contains linear signal source. As far in concern of step and sine signal, the result obtained from the MATLAB is taken and compared with this result. The real-time simulation model of the system is shown in Figure 4.5.

The results are in the form of graphical representation and input data's like pressure to the chamber, the area of piston and type of fluids used, friction coefficient, type of signal as an input, damping coefficient etc., are given as per the norms of the usewood Oy Finland. From graph the acceleration, velocity, and angle of cutter could able to move is exactly triggered and its implemented in a real-time machine by using a Graphical user interface GUI and by converting a model into machine-readable language by using the C++ in order to implement this in the real-time machinery to see behavior of a forestry machine how it react to output of modeled system [18].

5.2.1 Varying the orifice diameter

By starting with a 1.5 orifice diameter and then we study the angular position of the brushwood cutter on doing so.

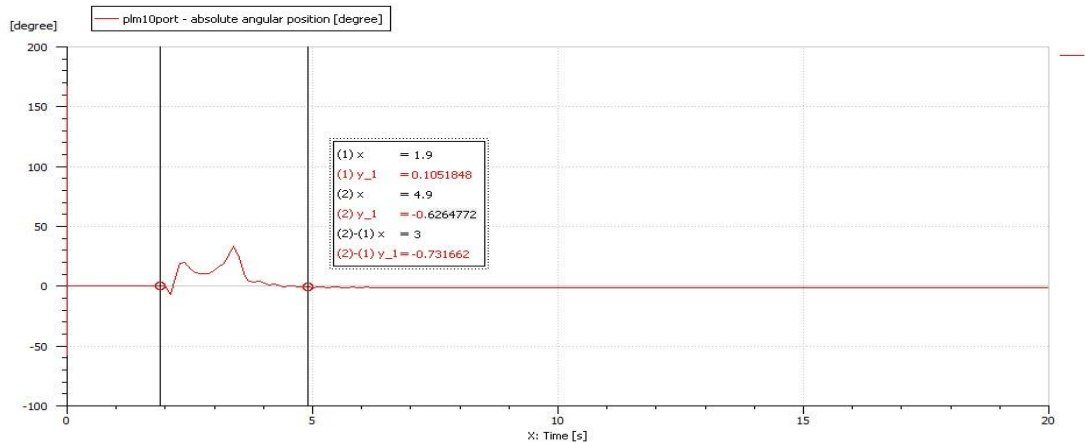


Figure 5.3 Response of system at 1.5mm diameter

From the Figure 5.3 the response of the system by varying the orifice diameter at 1.5mm and the by simulating the model in the real the response of the system which is calculated in seconds for the different diameters as 3sec. Like this, the results are obtained for various diameter and their responses.

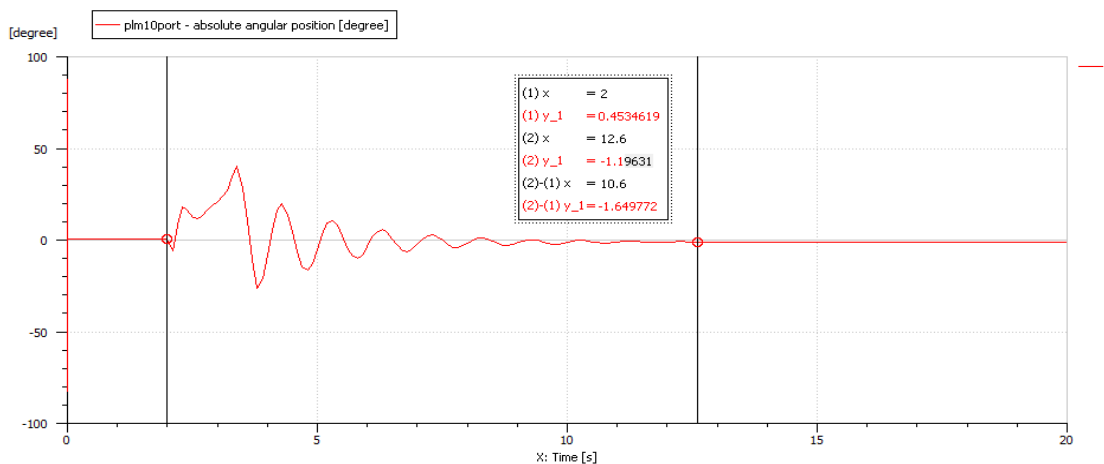


Figure 5.4 Response of system at 1.3mm diameter

The time taken to reach the desired position is the least for the orifice diameter of 1.5 mm. From the graph, this condition corresponds closely to a critically damped scenario, with very fast settling time and little to no sway. Now, as the orifice diameter is changed, the damping force changes allowing more time to settle and a larger sway. Given the case of 1.3 mm, the underdamped situation causes the cutter to sway more and takes a long time to reach the desired position. The orifice diameters or 2, 3, 5 mm, show a steady increase in the settling time. This is due to the overdamped situation, where the damper acts its own damping leading to oscillations and therefore longer settling

time. As can be seen from the left axis, the overall sway during the cutter movement gets higher as with the orifice diameter. This follows the same logic as the other cases in Figures 5.3-5.5.

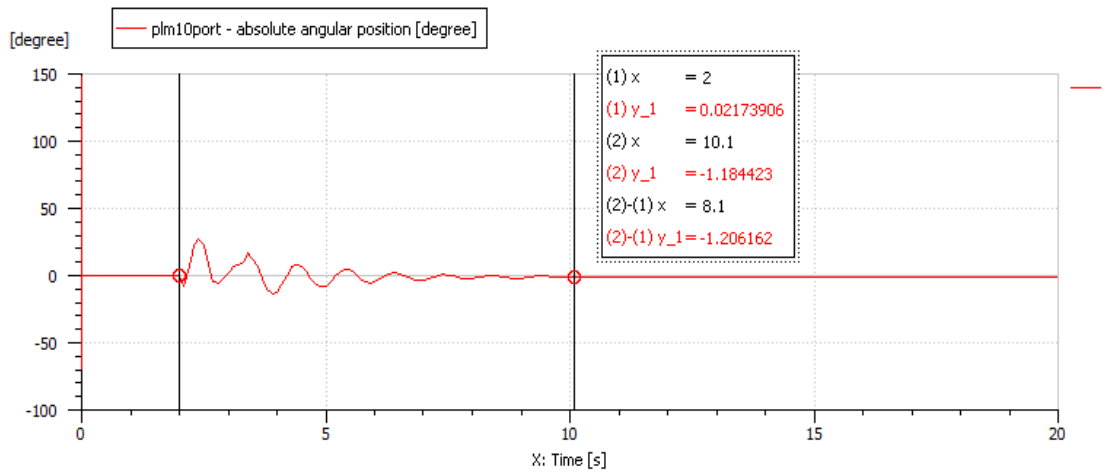


Figure 5.5 Response of system at 2mm diameter

The result of varying the diameter into 2mm and the response of the system is 8.1 sec as shown in the Figure 5.5

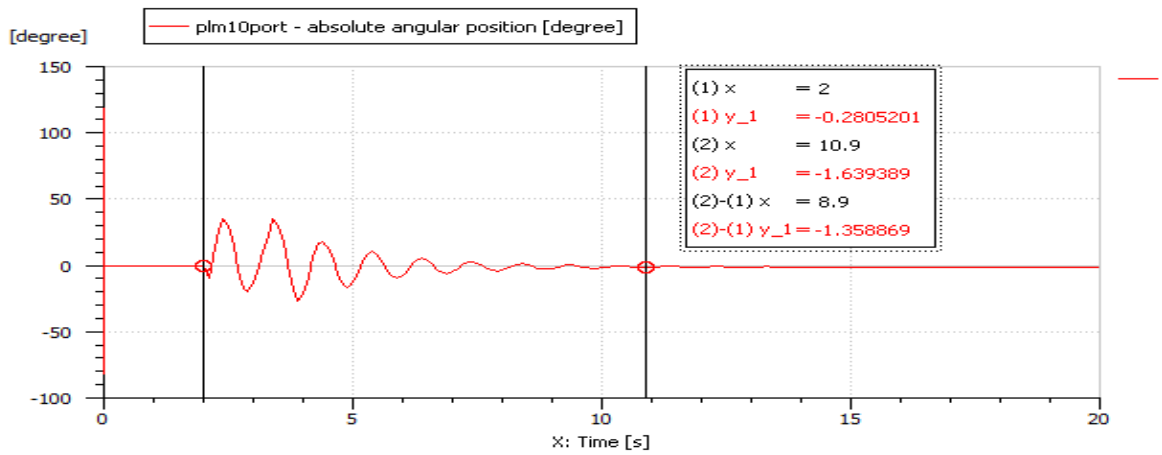


Figure 5.6 Response of the system at 3mm diameter

The result of varying the diameter into 3mm and the response of the system is 8.9 sec as shown in the Figure 5.6 and it is too high when compared to the 2mm diameter orifice of the model.

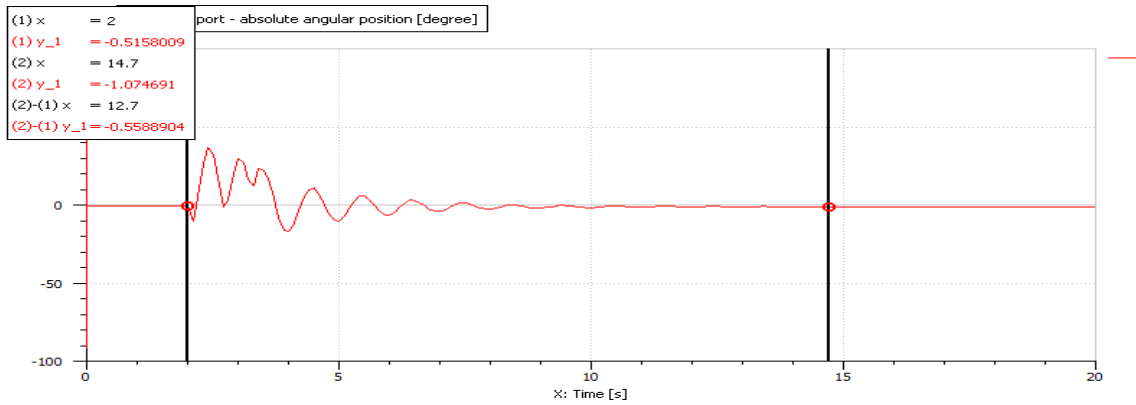


Figure 5.7 Response of the system at 5mm diameter

The result of varying the diameter into 5mm and the response of the system is 12.7 sec as shown in the Figure 5.7 and it is too high when compared to rest all the diameter orifice of the model. the various output of them is shown in Table 5.1

Table 5.1 Result from varying diameter of orifice

Orifice	Time is taken to reach horizontal position
1.5 mm	3 s
1.3 mm	10.6 s
2 mm	8.1 s
3 mm	8.9 s
5 mm	12.7 s

As a conclusion by varying the different diameters in the orifice of the model. The response of the time is less than 13sec. But in the real life, the quick response of the system is considered to avoid the unwanted damages and also its useful for time-consuming to the large-scale harvesters. Hence from the table 5.1 the 1.5mm diameter and with 3sec time response is the perfect diameter to get a quick response from the system.

5.2.2 Varying the Piston Diameter

Now by keep the orifice constant at $\text{Ø}1.5$ and vary the piston diameter and study the effects of the system from the following Figures 5.8,5.9 and 5.10.

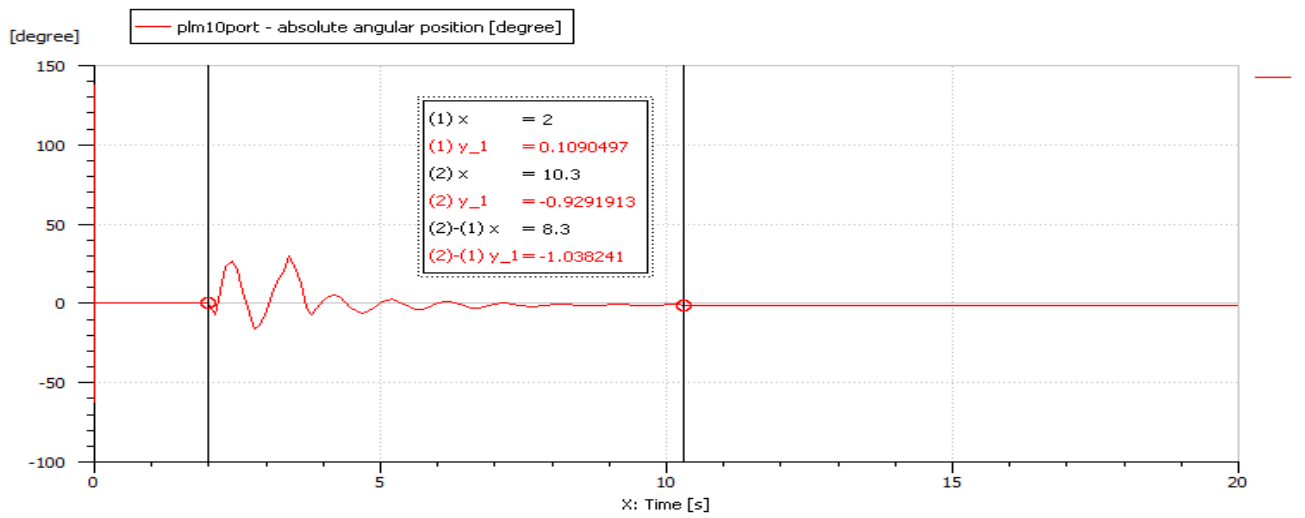


Figure 5.8 Response for 30 mm piston diameter

From the Figure 5.8 the response of the system by varying the piston diameter at 30 mm and then by simulating the model in the real the response of the system which is calculated in seconds for the different diameters as 3sec. Like this, the results are obtained for various diameter and their responses.

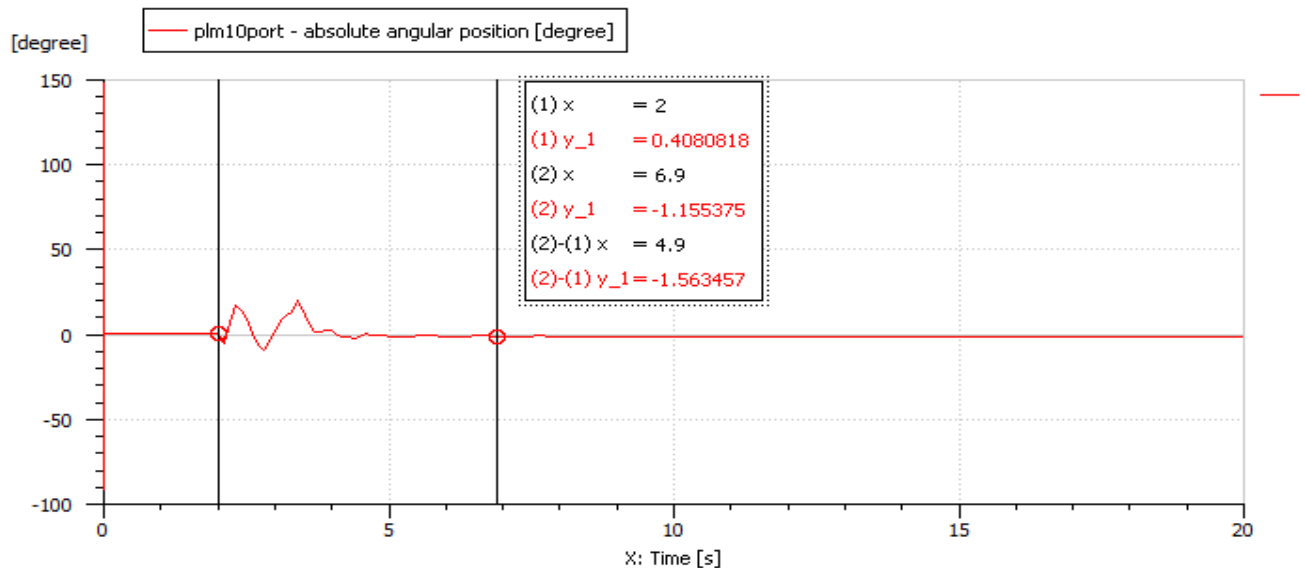


Figure 5.9 Response for 34 mm piston diameter

Similarly, for the cases from changing the orifice diameter, changing the piston diameter results in changes in settling time and the sway of the system. This follows the same principles as the other case, from the graphs, the system is critically damped when the diameter is set to 34 mm and slightly underdamped when the diameter is set to 32 mm.

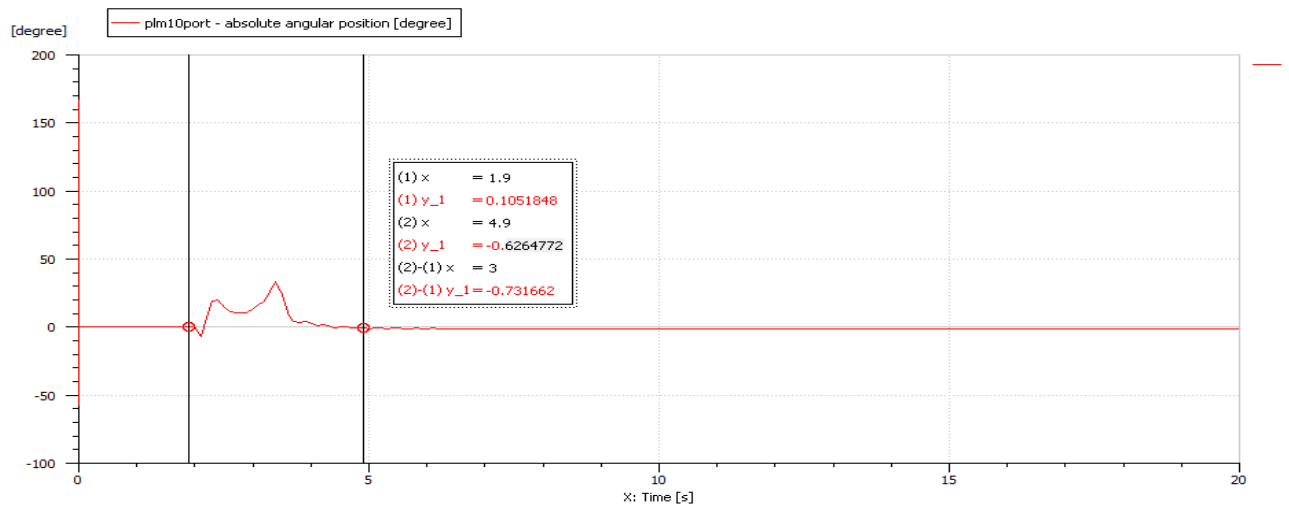


Figure 5.10 Response for 32 mm Piston diameter

From varying the orifice diameter and the piston diameter, by varying the force that the subsystem applies as a damper. Since the force, the cutter applies back from the movement of the cutter is constant and exclusive, and find the result in critically damped (1.5 mm/32 mm), underdamped (1.3 mm/32 mm) and overdamped in the other cases. The system being underdamped or overdamped causes longer settling time.

Table 5.2 Response of varying piston diameter

Piston diameter	Time is taken to reach horizontal position
30 mm	10.3 s
32 mm	6.4 s
34 mm	6.9 s

In the above table 5.2, it clearly states that the 32mm diameter is having the quick response of 6.4 sec when compared to the other results. Hence the critically damped one is the best to apply in the real-time application of forestry machine.

6. DISCUSSION AND FUTURE IMPLEMENTATION

Once advanced modeling is done by simulation tool it is possible to check accuracy and repeatability of the system. From above result, the position of the simple controller is relevant so that brushwood cutter is moving with the desired rate of angle and it concluded as it should not exceed more than the desired angle and by considering time response to the system wherein ideal condition. From this, each part of machines has been modeled and studied and simulated and some simplification process is taken in cutter angle and trajectory line and in hydraulic lines of the system. As a consequence, it is important to implement this in the real-time machine by applying the rate of pressure and with source configuration. The simplification model from MATLAB and AMESIM are to convert to machine language in order to implement machine in real time.

Due to simplifying pressure source, flow rates and pressure included in the system. In future, in components from sensing element, the response of the system is analyzed. It means that non-linearity of models should be studied completely in order to get accurate results. According to the forestry machine structure, joints are controlled by obtaining a 2-dimensional movement. The complete work of articulated manipulator includes three joints structures as shown in above structures and it will work in the 3-dimensional environment and every part is accessible. However, the intelligent controlling which done in this thesis work is good enough to apply in the real machine. As it contains all the hydraulics part only the Proportional integral controller is added to the integrated circuit to control the real machine.

7. CONCLUSIONS

1. The various types of the cutters, as well as control methods, have been analyzed and their advantages and disadvantages have been defined. The angular trajectory control methods which provide the possibility to improve the response time have been considered.
2. The simplified model for the cutter trajectory angle control was developed using Simulink and AMESIM software. The SolidWorks model was developed for the implementation into created MATLAB and AMESIM models. The kinematics and the hydraulic calculation have been done to get the angular trajectory, precision of the arm, and the area of discharge in the valves.
3. The modernization of forestry brushwood cutter is done. The sensors are introduced to get the cutter angle data of the cutter and send as a feedback signal to the PI controller to achieve the desired angle. It is proposed to introduce the dampers into the AMESIM model of the cutter. By varying the cylinder and orifice diameter of the damper the stable condition under the desired response time was obtained in the real-time.
4. The real-time simulation testing was carried out and the maximum 35° angular deflection of the cutter was obtained and the stability of the system was improved under the 1.5mm orifice and 32mm cylinder diameter of the damper respectively with the desired response time of 3sec.

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9. APPENDIX

The MATLAB for the Brushwood cutter model is shown below

```
% Brushwood cutter simscape multibody and simhydraulics parameters
% praveen karuppanpillai Somasundaram
% Tampere university of technology (TUT)
```

```

%----- Hydraulic parameters-----%
L_1 = 3.560 % in m length of the system
L_2 = 1.725
L_3 = 0.650
q_1 = 30% in degree angle of the arm
q_2 = 45
q_3 = 60
P = 190 % in bar pressure of the system
P_ma= 1e^-4% in m^2 the maximum passage area of the relief valve
V_p = 50e^5 % in pascal the valve pressure settings
V_rr = 5e^5 % in pascal the regulation range of the valve
C_d= 0.1 % flow discharge coefficient
R= 12 % Reynolds number
L_a = 1e^-12 % in m^2 leakage area of the module
%-----hydraulic fluid parameters-----%
R_ta = 0.005 % the relative amount of trapped air
C = 60 % system temperature of the hydraulic fluid
V_df = 1 % viscosity of derating factor
%-----4_way_valve_parameters-----%
V_ma = 3e^-4 % in the m^2 the maximum valve passage area
V_mo = 0.05 % in m the maximum valve openings
% the flow discharge coefficient, Reynolds-number, leakage area is
%described
% above in the general hydraulic parameters
%-----double acting cylinder properties-----%
P_A = 7.85e^-5 % in m^2 the piston area A
P_B = 7.85e^-5 % in m^2 the piston area B
P_s = 0.03 % in m the stroke length of the piston
D_A = 1e^-4 % in m^3 dead volume of the piston
D_B = 1e^-4 % in m^3 dead volume of the piston b
S_H = 1.4 % specific heat ratio of the cylinder
C_s = 1e^6 % in n/m contact stiffness of cylinder
D_d = 150 % in N/(m/s) the damping coefficient
%----- sim mechanics properties-----%
% these are the parameters to design the basic model of the cutter in the
% MATLAB simscape multibody
%-----%
G = [0 0 -9.81] % in m/s^2 the gravity which acting in z-axis

```

```

L_ld = 0.001 %linearization delta
%-----all the dimensions in m-----%
Bar = [0.107 0.0535 1.42] % size of arm
rho = 1000 % in kg/(m^3) density
% R_n... -----are the rigid transform of the system-----%
R_1 = [0.35 0 -0.05]
R_2 = 0.71
R_3 = 0.6225
R_angle = 31 %in degrees
R_4 = [0.005 0 0.6225]
R_5 = [0.35 0 -0.05]
R_6 = [-0.35 0 0.1]
R_7 = R_2
%-----parameters of the pin in m-----%
r = 0.004
L = 0.08
r_c= r
L_c = 0.06
%-----parameters for the cutter in m-----%
cut= [0.015 0.85 0.45]
L_small= [0.05 0.05 0.005]
R_small = L_small
L_big = [0.21 0.08 0.005] % dimension of the cutter
R_big = L_big
R_8 = [0.035 0.237 -0.023] % transform of lsb
R_9= [0.035 0.237 0.023] % transform of rsb
R_10 = [0.11 0 -0.035] % transform of lbb
R_11 = [0.0375 0.237 0] % transform of cylinder pin
R_12 = 0.2 % transform of the cutter
%-----tilt_actuator_properties, parameters-----%
% piston properties
R_13 = 25 % in degree at z axis
R_14 = 0.08 % in m at-y axis
S_rt = [0.02 0.02 0.02] % support design parameters
r1= 0.005 % radius of the piston in m'
L1 = 0.1485 % length of the piston in m
% cylinder properties
r_cyl = 0.006 % in m

```

```

L_cyl = L1
s_rt2 = s_rt
R_15 = 0.08 % in m at z axis
R_16 = 27 % in degree at Z axis
%----these cylinder and piston are connected by using the prismatic
%joint--- and its connected with the interface to connect the
% hydraulic part to mechanical part from the module.
%-----prismatic joint properties-----%
s_v = 0.01 % in m/s specified velocity of the prismatic joint
%-----revolute joint parameters-----%
% these revolute joints are act as a connector in between the arm and the
% feedback of the system is taken from this module
s_v1= 30 % in degrees
s_v2 = 15 % in degrees
%transform sensor is connected between them to get feedback
%-----%
%-----control parameters-----%
R2D = 180*pi/r % degree to radian conversion
%-----input of the system-----%
s_t = 0.01 % step time
I_t = 0 % initial value
F_t = 35 % final value
s_t = 0.1 % sample time
%-----PID controller parameters-----%
k_p = 3.1072
K_I = 0.1568
%-----solver configuration -----%
T_c = 1e^-09 % consistency tolerance of the model
D_b = 1024 % delay memory of the model
F_t = 0.001 % filtering time constant

```