DESIGN AND PROTOTYPE DEVELOPMENT OF MECHANICAL SAFFRON HARVESTING MACHINE

A Final Year Project Report

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Department of Mechanical Engineering

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In Partial Fulfillment

of the Requirements for the Degree of

Bachelor of Mechanical Engineering

by

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June 2023

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Titled: "***DESIGN AND PROTOTYPE DEVELOPMENT OF MECHANICAL SAFFRON HARVESTING MACHINE***"

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ABSTRACT

This report presents the work done in the design and prototype development of a mechanical saffron harvesting machine. Saffron is a spice that is derived from the flower of the Crocus sativus plant. It is one of the most expensive spices in the world, mainly because of the amount of labor required to harvest the threads from the flowers. Each flower produces only three stigmas, which are handpicked and then dried to make saffron. Saffron production can potentially have a positive impact on the GDP of Pakistan, although it may not be a significant contributor to the overall economy. Saffron is a highly valued spice, used for various culinary and medicinal purposes, and is known to be one of the most expensive spices in the world. However, saffron production is highly labor- intensive. Pakistan has suitable climatic and soil conditions for saffron cultivation, particularly in the northern areas of the country. However, saffron production in Pakistan is still in its early stages and limited in scale. There is a dire need for mechanization in thisdomain. Efforts have been made in this regard and different models have been developed across the world, however they have their own shortcomings. We hereby present our mechanical model with a view to catering to such limitations. Our model comprises a vehicle mountable machine with a rotating gripper that carefully plucks the saffron flower withoutdamaging the stigmas and then safe transportation of the flower to a container or a basket.The design was made on Solid works and the necessary calculations e.g., gear ratios, plucking force, stresses on the flower stems were done. Eventually, the prototype was developed using the engineering knowledge that was acquired during the degree.

ACKNOWLEDGEMENTS

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Abbreviations and Nomenclature

Name	*Symbol*
Bending Moment $(ft\ lb)$	M
Torsion $(ft\ lb)$	T
Horsepower	HP
Equivalent Bending Moment $(ft\ lb)$	M_e
Equivalent Twisting Moment $(ft\ lb)$	T_e
Maximum Normal Stress (psi)	σ_{max}
Maximum Shear Stress (psi)	τ_{max}
Catalog Rating (lb_f)	C_{10}
Rating Life	L_{10}
Desired Radial Bearing Load (lb_f)	F_D
Desired Bearing Life	L_D
Pressure Angle	φ
Transmitted Load	F_T
Diametral Pitch $(inch^{-1})$	P_d
Number of teeth	N
Pitch Diameter $(inch)$	d_P
Angular Speed (rad/s)	ω
Quality Number of Gear	Q_v
Stress Cycle Factor for Bending Strength	Y_N
Stress Cycle Factor for Pitting Resistance	Z_N
Factor of Safety for Bending Stress	FOS_b

Factor of Safety for Contact Stress	FOS_c
Allowable Bending Stress (psi)	S_t
Allowable Contact Stress (psi)	S_c
AGMA Bending Stress (psi)	$\sigma_{bending}$
AGMA Contact Stress (psi)	$\sigma_{contact}$
Surface Condition Factor	C_f
Hardness Ratio Factor	C_H
Elastic Coefficient	C_p
Face Width of narrowest member	F
Brinell Hardness	H_B
Total gear tooth depth	h_t
Geometry Factor of Pitting Resistance	I
Geometry Factor for Bending Strength	J
Rim thickness factor	K_B
Load Distribution factor	K_m
Reliability factor	K_R
Temperature factor	K_T
Dynamic factor	K_v
Module	m
Backup ratio	m_B

CHAPTER 1

INTRODUCTION

Motivation of work

The agricultural sector is a vital contributor to the GDP of Pakistan. According to the latest available data from 2020, the agricultural sector contributed about 22.04% to Pakistan's GDP. It is the largest sector of the economy and employs around 38.5% of the country's labor force. The agricultural sector plays a crucial role in the economy of Pakistan by providing food, raw materials for industries, and export earnings. It also helps to mitigate poverty in rural areas by providing employment opportunities and improving the living standards of rural communities.

However, the sector faces numerous challenges such as water scarcity, soil degradation, climate change, and outdated farming practices. Addressing these challenges and promoting sustainable agriculture practices could help further improve the contribution of the agricultural sector to Pakistan's economy.

Saffron, also known as "Red Gold", is one of the most expensive spices in the world. According to a report by IMARC Group, the global saffron market size was valued at around USD 1.4 billion in 2020 and is expected to reach USD 2.8 billion by 2026, growing at a compound annual growth rate (CAGR) of around 12% during the forecast period (2021-2026).Iran is the largest producer of saffron, accounting for around 90% of the global production. Spain, India, Greece, and Morocco are other major producers of saffron. These countries also export significant quantities of saffron to other countries. The major importers of saffron are the United States, Spain, France, the United Arab Emirates, and Germany. Saffron is used in various industries, including food and beverage, pharmaceutical, and cosmetic industries. Its use in the treatment of various diseases such as depression, anxiety, and Alzheimer's disease has also contributed to the growing demand for saffron in the global market.

Figure 1 Global Market Graph

Saffron production can potentially contribute to the GDP of Pakistan, but it is currently not a major crop in the country. Pakistan has a small saffron production, which is mainly concentrated in the Kashmir region. According to the Food and Agriculture Organization (FAO), Pakistan produced around 1.5 metric tons of saffron in 2020.However, saffron production has the potential to contribute significantly to the economy of Pakistan. It is a high-value crop that can provide a substantial income to farmers and increase exports earnings for the country. Saffron production requires specific climatic conditions, and the Kashmir region in Pakistan has favorable conditions for its cultivation.

Pakistan can learn from the experiences of other countries such as Iran and Spain, which are major saffron producers and have developed successful saffron cultivation and marketing strategies. By improving agricultural practices, investing in research and development, and promoting the production and export of saffron, Pakistan can potentially increase its contribution to the global saffron market.

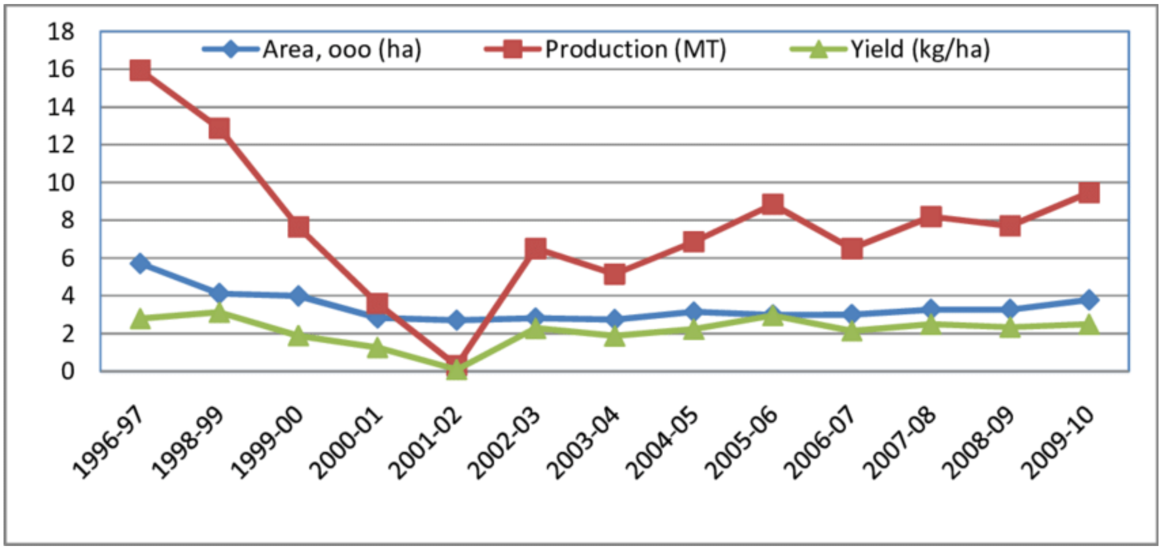


Figure 2 saffron production in Pakistan (Kashmir) over the years

Overall, saffron production can be an important contributor to Pakistan's economy, particularly in rural areas, but **significant investments and efforts are required to develop and promote its production.**

Problem Statement

Manual picking of saffron is a laborious process because saffron is obtained from the stigma of the saffron crocus flower which is a very delicate and tiny part of the flower. Each flower contains only three stigmas, and these stigmas have to be carefully handpicked using tweezers or similar tools. Furthermore, the flowers bloom for only a short period each year, usually for two to three weeks, and the stigmas must be harvested during this time. The timing of the harvest is crucial because the stigmas lose their potency soon after the flower is picked. Additionally, saffron cultivation is mainly carried out in developing countries where labor is still largely manual, and mechanized methods of harvesting are not feasible due to the delicate nature of the flowers and stigmas. Therefore, the process of manual picking of saffron is time-consuming, labor-intensive, and requires a great deal of skill and precision to ensure that the stigmas are not damaged or wasted. All these factors contribute to why manual picking of saffron is a very laborious process.

In a nutshell, "*to do away with the old obsolete saffron harvesting methods there is a dire need of mechanizing this process using a harvesting machine that ensures the safe plucking of the delicate saffron and is cost efficient, time-saving and easier to operate from the perspective of a layman farmer*".

Objectives

The following are the objectives that we aim to meet:

- Plucking the flower safely (which includes cutting to a precise level)
- Safe transfer to the collection tank/container without damaging the delicate flower stigmas.
- Aligning the flowers for automated corolla separation
- Separating the red stigma from the petals and yellow stigma to obtain saffron (This step and the next depend on budget and time constraints)
- Cleaning and drying the obtained Stigmas.

CHAPTER 2

LITERATURE REVIEW

Manual methods of harvesting

Harvesting saffron involves several steps that require careful attention and delicacy. Here are the steps involved in saffron harvesting:

Flowering: Saffron comes from the stigmas of the Crocus sativus flower. The flowers bloom in the fall, typically in October or November.

Figure 3 Saffron flowers

Harvesting the flowers: The flowers are picked early in the morning when they are still closed to ensure that they do not wilt or lose their aroma. They are carefully picked by hand, without damaging the stigmas, which are delicate and easily bruised.

Separating the stigmas: Once the flowers are picked, the stigmas are separated from the rest of the flower. This is done carefully, again by hand, to ensure that the stigmas remain intact.

Drying the stigmas: After the stigmas are separated, they are dried in the sun or in a warm, dry place for several days. This helps to intensify their color and flavor and preserve them for longer periods.

Packaging the saffron: Once the stigmas are dry, they are weighed and packaged for sale. The saffron is usually packaged in small amounts, as it is expensive and used sparingly in cooking.

Mechanized Harvesting models

Models based on electromagnetism, machine vision and artificial neural networks.

The first article "Development of a new harvesting module for saffron flower detachment" was published in a journal "Romanian Review Precision Mechanics, Optics and Mechatronics" in 2011.

The Zaffyagri robot is a specialized machine designed to harvest saffron flowers in a precise and efficient manner. The robot is built on a four-wheeler vehicle that is able to drive through the rows of saffron plants, with the flowers located between the right and left wheels. The robot's harvesting mechanism is based on a gripper with fingers that are able to pick the flowers using electromagnetic actuation. This is achieved through the use of two solenoids, which are devices that use an electric current to create a magnetic field that moves a metal plunger back and forth. By controlling the electric current to the solenoids, the robot is able to precisely move the gripper fingers and pick the saffron flowers without damaging them. In addition to the solenoids, the Zaffy robot also uses photodetectors or monochrome optical sensors to detect the saffron flowers. These sensors are placed on the robot's frame and are used to detect the flowers' color, shape, and location. This information is then used to guide the robot's gripper to pick the flowers with accuracy and efficiency. (4) .

Overall, the Zaffyagri robot is a sophisticated machine that combines multiple technologies to create an effective and efficient system for harvesting saffron flowers. The robot's use of electromagnetic actuation and photodetectors demonstrates the potential of robotics and automation in agriculture, providing an innovative solution to the challenges of harvesting delicate crops.

Strength: The strength of this mode was that there was a very gripping force by the use of high frequency electromagnetic fields inducing eddy currents.

Limitation: Complexities of machine vision and image processing were involved including variability in images in that images can vary widely in terms of lighting, color, texture, orientation, and other factors, which can make it difficult to extract information.

Figure 4 Agri-robot Zaffy

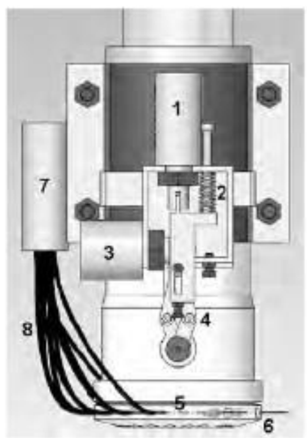


Fig. 5. The new module: 1) opening solenoid; 2) closing spring; 3) brake solenoid; 4) double lever mechanism; 5) scan plane; 6) plastic ring; 7) darkroom; 8) plastic fibre wires

Figure 5 Arrangement of solenoids and other components

Table 2. Closing force of the gripper for 2 couples solenoid-spring

Opening solenoid **BLP 122-420-610-620** - Spring **D11290**				
Type of fingers	Average payload vs. stem material [N]			Average pay load [N]
	plastic	wood	cardboard	
Internal	**1,30**	**1,32**	**1,40**	**1,34**
External	**0,72**	**0,65**	**1,08**	**0,82**

Opening solenoid **BLP 124-420-610-620** - Spring **D12300**				
Type of fingers	Average pay load vs. stem material [N]			Average pay load [N]
	plastic	wood	cardboard	
Internal	**2,81**	**2,91**	**3,41**	**3,04**
External	**2,47**	**2,04**	**1,09**	**1,87**

The second article "Integration of color features and Artificial Neural Networks for In-field recognition of Saffron Flower" was published in journal " Iran Agricultural Research " in 2013.

To detect saffron flowers for harvesting, two different algorithms based on the hue (H) and blue color difference (Cb) components of images have been developed. These algorithms aim to detect the flowers' position accurately, so they can be fed to the plucking robot for efficient harvesting. In their experiments, the researchers found that the algorithm based on the Cb component yielded better results than the algorithm based on the H component. This is likely because the Cb component is better at distinguishing between the color of the flowers and the surrounding background. Once the flowers are detected, artificial neural networks (ANNs) are utilized to detect and segment the flowers from other objects such as leaves, soil, and residues. ANNs are a type of machine learning algorithm that can analyze large amounts of data and learn patterns in the data. In this case, the ANNs are trained on a large dataset of images of saffron flowers to identify and segment the flowers from the background. The use of ANNs allows for more accurate detection and segmentation of the flowers, which is critical for efficient and effective harvesting. By separating the flowers from other objects in the image, the plucking robot can accurately locate and harvest the flowers without damaging the surrounding plants or soil. (5)

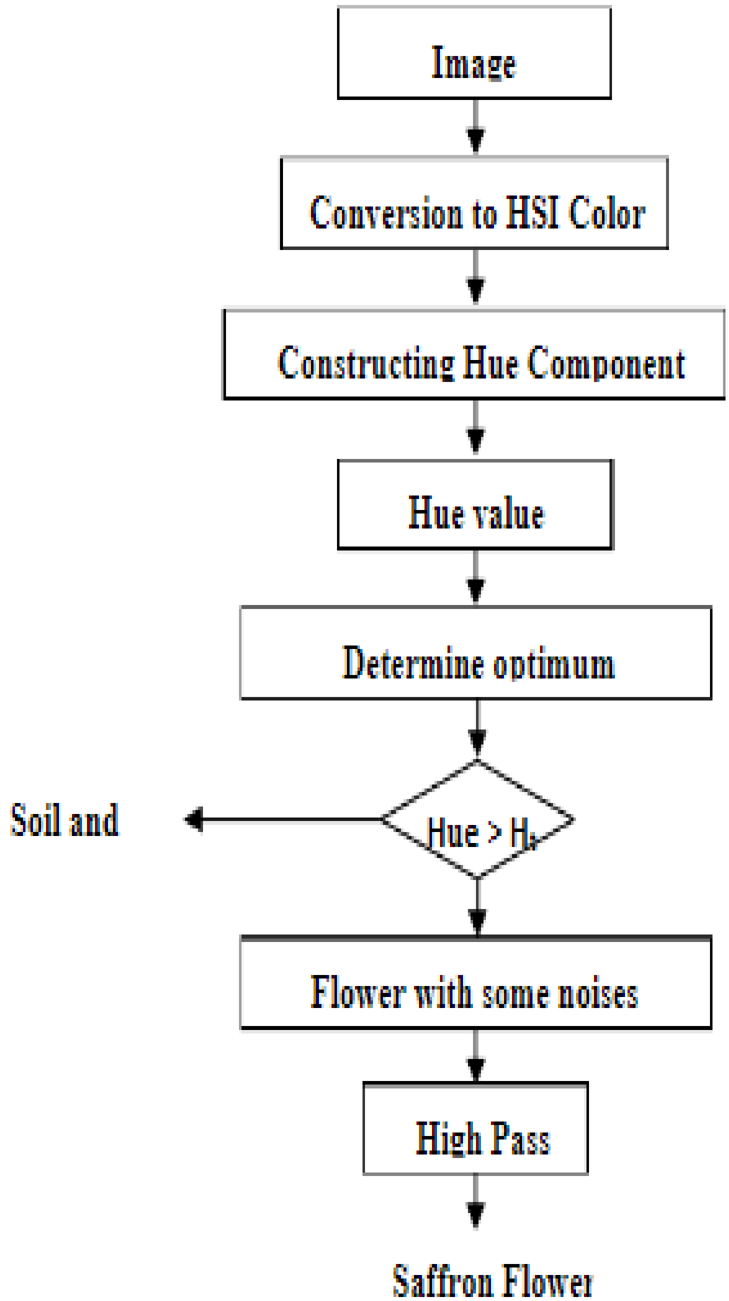


Figure 6 Flower segmentation algorithm based on Hue

Strength: These algorithms and ANNs provide an innovative solution for detecting and harvesting saffron flowers using automation and machine learning technologies.

Limitation: There is a need for high-quality and unbiased training data, potential overfitting, and the black box nature of the model. Additionally, for the detection of saffron flowers, the quality and resolution of the input images used as input to the ANN would be crucial for achieving accurate results.Models based on pneumatic systems

The first article "A mechanical flower harvesting system" was published in journal "Meccanica" in December 2014.

The device is a lightweight, portable system designed for efficient saffron harvesting in the field. The system is comprised of several components, each with a specific function. The handle of the system is equipped with a manually operated pneumatic valve that is used to perform the pneumatic gripper step. The body of the system supports an electric motor that is equipped with a fan to generate the vacuum that inhales the detached flower. The suspender is designed to allow harvesting without bending over, which can reduce strain on the body and increase efficiency. The integrated pneumatic pipe is used to drive the pneumatic actuator that is assembled in the gripper body. The vacuum tube, which includes a suction port, is used to collect the flowers. The link to the gripper body includes two fingers that detach the saffron flowers by breaking the flower stem. This link has a hinge that is elastically wound around a horizontal axis, which allows for rapid rotation of the gripper body when the flower is detached. This movement allows the flower to approach the vacuum system inlet, which is necessary for efficient collection. The gripper, which is the end effector of the device, is a one-degree-of-freedom pneumatically actuated device. This means that it is capable of moving in one direction only, which simplifies the design and reduces the complexity of the system. The gripper's actuation is pneumatically powered, which is a suitable power supply for operation in agricultural fields. Pneumatic power is often preferred for this type of application because it is simple, reliable, and easy to maintain. In addition, it is less likely to cause damage to the delicate saffron flowers, which can be a concern with other types of power sources. (6) Overall, the lightweight, portable system is an innovative solution to the labor-intensive process of saffron harvesting. By automating the process, the system can increase efficiency and reduce the physical strain on workers.

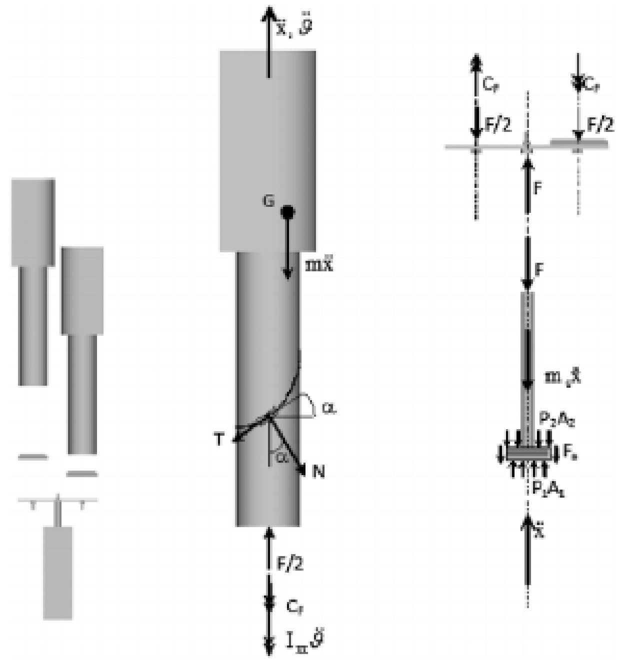


Figure 7 The free body diagram of the left finger, the cross bar and the moving parts of pneumatic cylinder

m	Finger mass	6.70×10^{-2} kg
I_{xx}	Finger moment of inertia around the finger axis of rotation	11.28×10^{-6} kg/m^2
m_s	Cylinder moving parts mass	3.15×10^{-2} kg
p	Helix pitch	4.50×10^{-2} m
r	Helix cylinder radius	1.35×10^{-2} m
f	Friction coefficient on the helix constraint	0.20
f_F	Friction coefficient on the Clutch	0.04
R_i	Internal radius of the clutch disk	5.0×10^{-3} m
R_e	External radius of the clutch disk	17.0×10^{-3} m
A_1	Piston posterior area	1.131×10^{-4} m^2
A_2	Piston anterior area	0.848×10^{-4} m^2

Figure 8 The numerical value of the characteristics of the gripper prototype

Strength: The advantage of pneumatic saffron grippers is that they provide a gentle and non-invasive method for harvesting delicate saffron flowers without causing damage to the surrounding plant material. The grippers work by using a vacuum technique to detach the flowers from the stem, allowing for minimal contact and reducing the risk of damage or bruising.

Limitation: One potential drawback of pneumatic saffron grippers is that they require a source of regulated compressed air or gas to operate. This means that an additional piece of equipment, such as an air compressor or gas cylinder, may be needed to power the gripper in the field.

Figure 9 Pneumatic Gripper

The second article "An Integrated Device for Saffron Flowers Detaching and Harvesting" was published in journal "19th International Workshop on Robotics in Alpe-Adria-Danube Region".

A model like the one proposed in the first article was proposed in this article. The portable device shown in Figure is designed to harvest Crocus Sativus flowers using a onedegree of freedom pneumatically actuated gripper. The device consists of several components that work together to effectively detach the flowers from the plants.The handle1 is equipped with a pneumatic valve that is manually operated to activate the gripper's pneumatic actuation. This allows the gripper to open and close around the flowers. The body 2 of the device supports an electrical motor equipped with a fan, which generates the vacuum necessary to inhale the detached flowers. Suspender 3 allows for harvesting without bending, reducing strain on the worker's back. The device also has an integrated pneumatic pipe to supply the pneumatic actuator assembled in the gripper body. This actuator is responsible for controlling the opening and closing of the gripper's fingers 9, which are used to detach the saffron flowers from the plants. Vacuum tube 6 collects the flowers once they are detached. Link 7 connects the device body to the gripper body8, allowing for rapid rotation of the gripper when the flower is detached. This movement enables the vacuum system inlet to approach the flower, making it easier to inhale. The hinge that connects the link to the gripper body is elastically wound around a horizontal axis, providing flexibility and durability. In summary, the portable device is an efficient and effective tool for harvesting Crocus Sativus flowers. The gripper's one degree of freedom pneumatically actuated design, along with the vacuum system, allows for precise and controlled detachment of the flowers. The device's integrated components work together to provide a comfortable and efficient harvesting experience for the user. (7)

Strength: As in the previous model, the vacuum technique allows for undamaged plucking of the saffron flower.

Limitation: There is a continuous need for regulation of compressed air flow or gas supply.

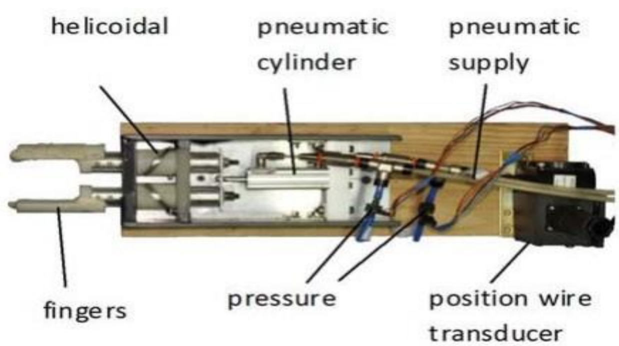


Figure 10 Pneumatic Gripper

Models based on electromechanical systems

The first article "Perspectives in the mechanization of saffron (Crocus Sativus L.)" was published in journal "International Journal of Mechanics and Control" in 2013.

The cam striker type of saffron harvester is a mechanical device that is widely used for harvesting saffron flowers from the Crocus sativus plant. The harvester is simple in design and consists of a handle, a shaft, a set of cams, and a striker plate. The striker plate is attached to the end of the harvester and is used to strike the flowers to detach them from the plant.The handle of the harvester is the main component that is used to hold and operate the device. The shaft is attached to the handle and runs through the center of the harvester. The set of cams is positioned along the shaft, and each cam has a different shape and size to control the force and timing of the striker plate's movement. When the user grips the handle and applies pressure to the shaft, the cams rotate, causing the striker plate to strike the saffron flowers with a controlled force. This controlled force is necessary to detach the flowers without damaging them, as saffron is a delicate spice that requires careful handling. (8)

Strengths: One of the key advantages of the cam striker type of saffron harvester is its simplicity and low cost. It does not require any external power source, making it a simple and affordable tool for small-scale farmers and harvesters. It is also easy to maintain and repair, as it does not have any complex components.

Limitations: There are some limitations to using this type of harvester. It requires skilled labor to operate effectively, as the force and timing of the striker plate must be carefully controlled to avoid damaging the saffron flowers. The harvester is also a time-consuming process, as each flower must be harvested individually.

Another limitation of the cam striker type of saffron harvester is its low efficiency. It can only harvest a small number of flowers at a time, making it unsuitable for large-scale operations. Additionally, the harvester is not suitable for harvesting saffron that is grown in rocky or uneven terrain, as the striker plate may hit the ground and cause damage.

Figure 11 Steps of cutting process in the tests on the saffron flower field: (a) Flower selection (b) Approach (c) Oscillating and cutting

The second article "Designing a Low-cost Mechatronic Device for Semi-automatic Saffron Harvesting" was published in journal "Machines" in 2021.

Here a two-finger gripper design for saffron harvesting has been proposed. Designed to grasp the stem of the saffron flower while keeping a minimum distance of 1.5 mm between the fingers. The distance is regulated by a regulating screw and can be adjusted to fit the average stem diameter, which ranges from 1.5 mm to 4 mm. The surface of the fingers is modeled with a round cross-section shape, and the finger inter-axis distance regulation is achieved by a rotoidal joint on the rear side that creates a leaf spring by means of a specially designed hinge. The leaf spring is made from an aluminum plate that works also as a structural frame element to hold the other components. To protect the components of the end-effector from the work environment, an external body has been created using plastic material. The body essentially consists of two elements that can be inserted one on top of the other, which will envelop the device with limited additional weight. The upper side of the body has a hole for the cables, equipped with a special gasket to prevent any rainwater or earth residues from entering the instrument. The external body of the end-effector also connects the end-effector to a maneuver rod made using the rigid section of the suction duct. The suction head is modeled as a separate element, connected to the external body by means of a hinge coupling and positioned exactly above the two finger gripping elements. An adjustable length tie rod is inserted on the back side, connected at one end to the hood itself and at the other to the body of the end-effector. By manually rotating the central body of the tie rod, the operator can adjust the angle between the ground and the maneuvering rod in a range from 30 ° to 45 °. (9)

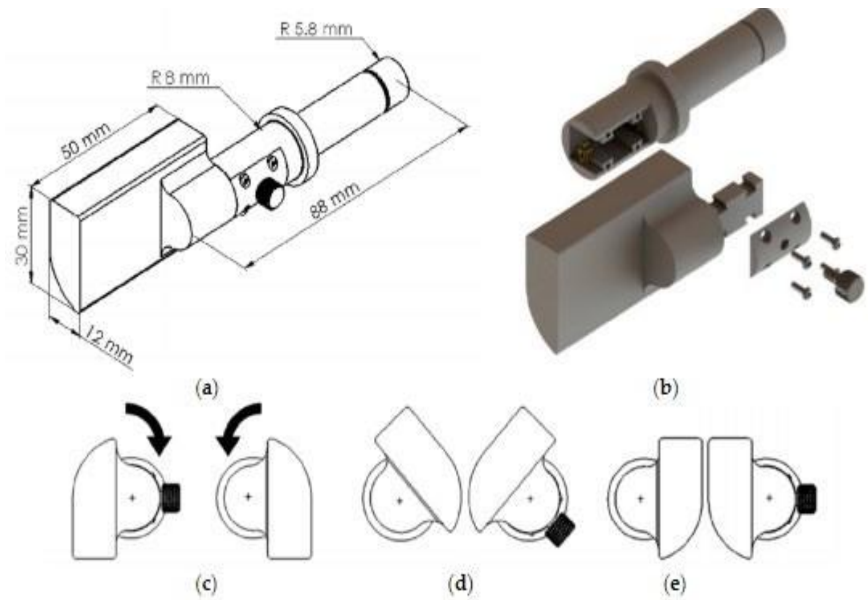


Figure 12 Grasping elements architecture: 6) main sizes; (b) regulation system exploded view; (c) open configuration with indication of fingers rotation directions; (d) intermediate configuration; (e) fully closed configuration.

	Value	Notes
Harvest Time	2 – 5 s/flower	Positioning, cutting, suction.
Shape	Gardening Tool	Manual unit connected with a shoulder-mounted element.
Weight	3 – 5 kg	Total Weight.
Implementation	Electrical	For suction system and end-effector.
Power Supply	18 – 40 V	Rechargeable electric battery.
Autonomy	3 – 6 h	Half a working day.
Materials	Aluminum – Plastic	Maybe rubber, fabric or steel.
Operating Temperature	18 °C – 28 °C	Room temperature.
Work Environment	Open Field	Moisture, organic materials, atmospheric precipitation.
Production Cost	300 – 500 €	Average cost range.

Figure 13 Technical specifications of the proposed device

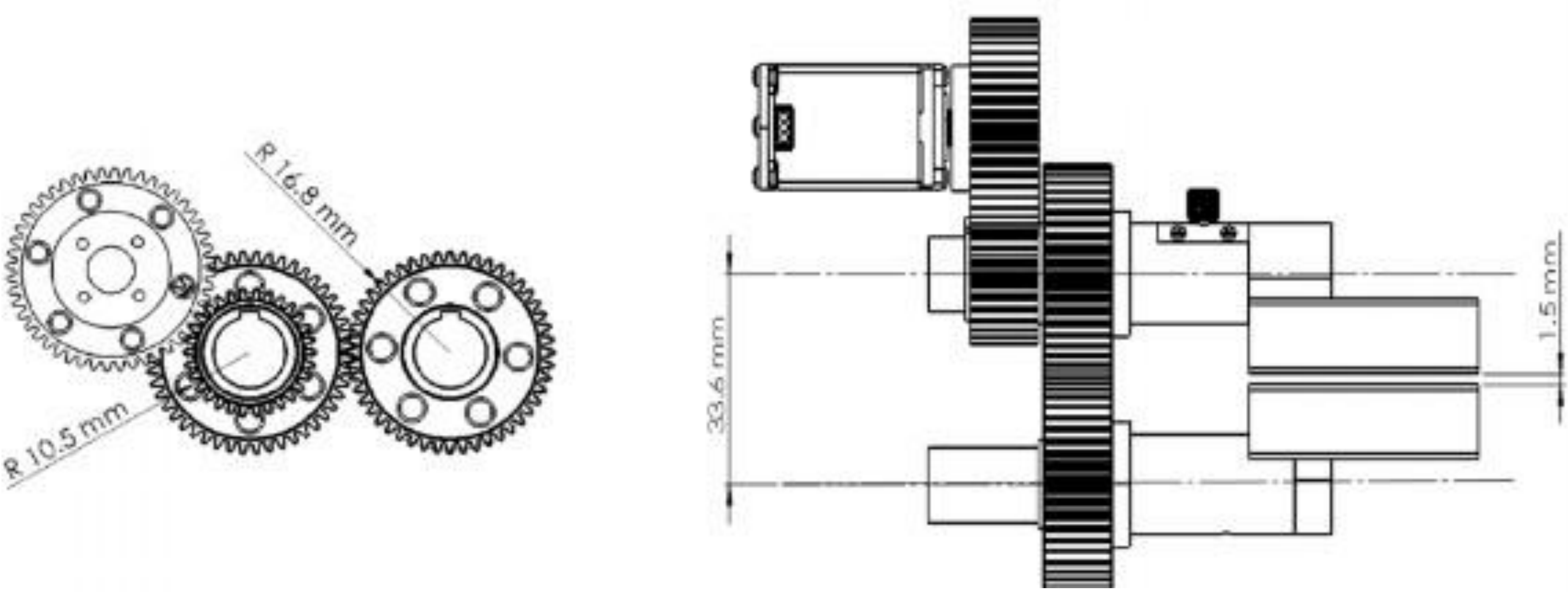


Figure 14 Proposed transmissions architecture

CHAPTER 3

METHODOLOGY

Plan for Prototyping

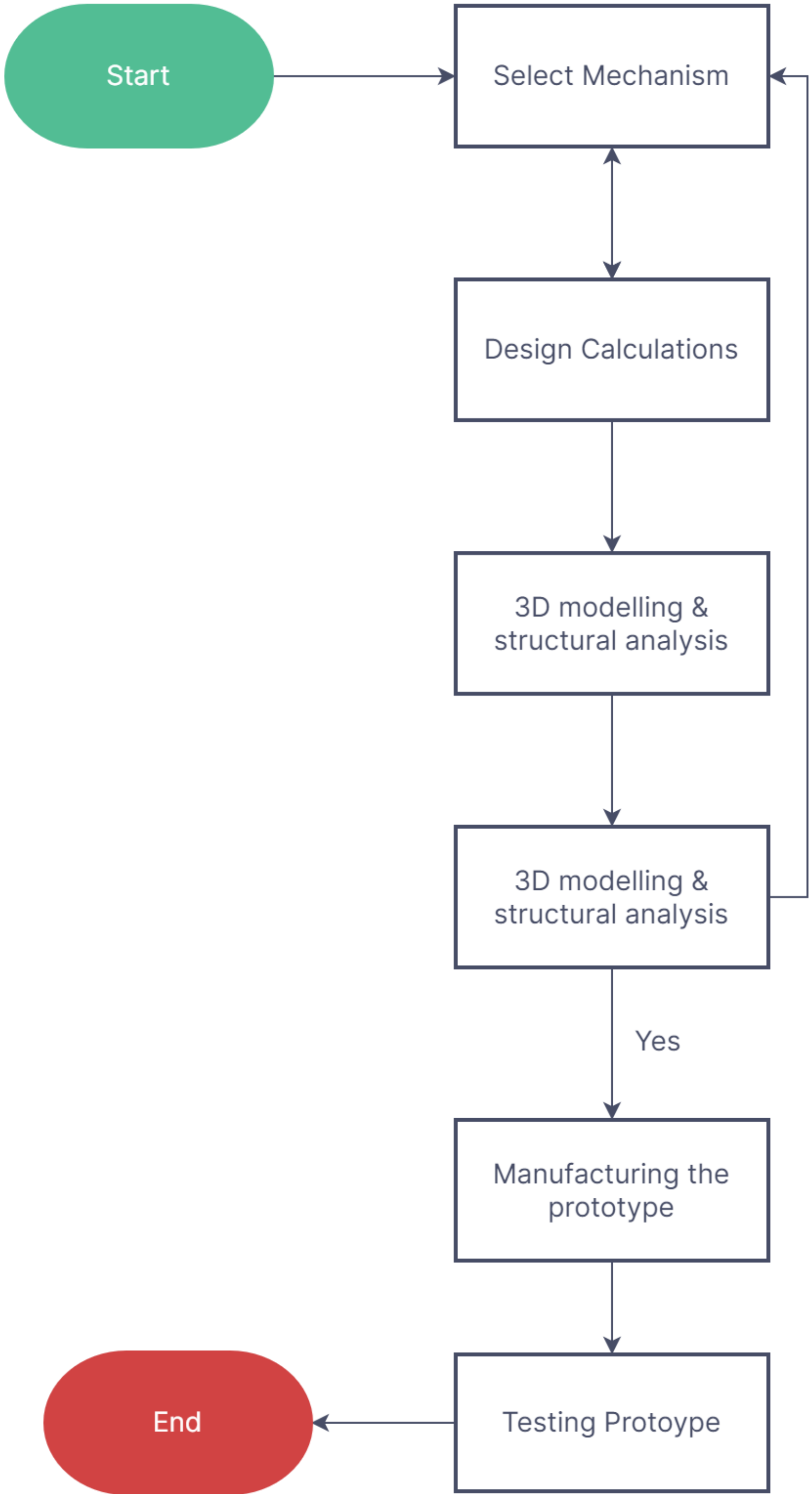
The design of the saffron harvester prioritizes the safety and preservation of the saffron itself. The delicate and sensitive nature of the saffron plant makes it susceptible to damage if not handled properly. Hence, the main goal of the design is to ensure that the saffron remains intact and undamaged throughout the harvesting process.

One of the biggest challenges faced in this project is the fact that the harvester is mostly mechanical based. This means that access to advanced technologies such as image processing or pneumatic harvesters is not available, which could potentially reduce the risk of saffron damage. Therefore, reliance is placed solely on mechanical design and precise calculations to ensure the safety of the saffron.

To address this challenge, the initial harvester design was made with basic grippers that could not potentially harm the saffron. This was done with the aim of reducing the risk of damage to the saffron during the harvesting process. By prioritizing the safety of the saffron, the team hoped to create a design that would minimize the risk of loss or damage to this valuable and delicate plant. Trial-and-error methods were used until the final gripper design for the saffron harvester was reached.

However, without the use of electronics or other advanced technologies, the team must rely on precise calculations to ensure that the saffron is not damaged during the harvesting process. This involves considering a wide range of factors, including the weight and density of the saffron, the speed of the harvester, and the angle and force of the harvester's movements. By carefully considering these factors and making accurate calculations, the harvester is optimized for saffron safety and preservation.

In summary, the design of a saffron harvester is a complex and challenging task, especially when working with a mechanical-based design. However, by prioritizing the safety of the saffron and making accurate calculations to ensure its preservation, an effective and safe harvester can be created for this delicate and valuable plant.


Start
Select Mechanism
Design Calculations
3D modelling & structural analysis
3D modelling & structural analysis
Yes
Manufacturing the prototype
Testing Protoype
End

Mechanism Selection

After conducting the literature review, four intuitive mechanisms were identified, each with its own features and requiring different fabrication techniques. Upon careful consideration of the pros and cons of each mechanism, the decision was made to move forward with the Outboard Wing Hinge design for the following reasons:

- Optimal spacing between grippers (1.5cm).
- Easy power transmission
- Less chances of damage to the flower

Introduction to Harvester Parameters

Several key parameters critical to the success of the saffron harvester design were identified. These include the spacing between grippers, the RPM of the grippers, and the height of both the gearbox and the grippers from the ground. Careful consideration of these factors is necessary to ensure that the harvester is optimized for saffron preservation and yield.

Optimal Spacing Between Grippers

Based on the literature review conducted, it was determined that the spacing between the grippers was a critical factor in preventing damage to the saffron during the harvesting process. To verify the optimal spacing, finite element analysis (FEA) using ANSYS Workbench R2021 was conducted. This analysis allowed for the determination of the optimal spacing between the grippers that would allow for safe and effective saffron harvesting without causing damage to the plant.

RPM of Grippers and Gearbox Design

Another critical factor that was considered in the design of the saffron harvester was the RPM of the grippers. To test this parameter, the Millat 240 tractor was selected as it had a PTO shaft with an RPM of 540. To achieve the desired RPM of 420 at the grippers, a gearbox consisting of four spur gears was designed to transmit power from the PTO shaft to the grippers.

Height of Gearbox and Grippers from the Ground

The height of both the gearbox and the grippers from the ground was another crucial factor that was carefully considered in the design of the saffron harvester. If the gearbox was too low to the ground, it could damage the saffron stems and reduce the yield of flowers from those plants in the future. Similarly, if the grippers were set too high, they could pluck the entire stem, which would destroy the field and prevent further growth of saffron in that area. Additionally, only the saffron flower and stigma were needed, not the entire stem.

In summary, the design of a saffron harvester requires careful consideration of several key parameters, including the spacing between grippers, the RPM of the grippers, and the height of both the gearbox and the grippers from the ground. By carefully optimizing these parameters, the harvester can be optimized for saffron preservation and yield, and to ensure that it will not cause damage to this delicate and valuable plant.

Fan

Our first idea was to use a 12V DC fan for collecting saffron after being plucked by our harvester. Although there are certain parameters that we need to consider like speed, power, and angle of the fan because saffron flowers are delicate and need to be handled carefully to avoid damagingthe valuable stigmas inside. Using a fan at high speed and power or at lower angle may cause the flowers to be blown around and potentially damaged.

A low-speed, low-power fan is ideal for this purpose. The fan should not have sharp edges or blades that could damage the flowers. Moreover, a low-speed, low-power fan is ideal for this purpose. The fan should not have sharp edges or blades that could damage the flowers. The angle of the fan should be adjusted so that the airflow is directed towards the saffron flowers, but not too strong that it blows the flowers away.

Figure 15 12V DC Fan

Source of input rpm

PTO shaft of tractor

In the development of our prototype harvester, we have encountered some challenges in obtaining the required input rpm for our equipment. Specifically, one of our plans was to connect our drive shaft with the PTO shaft of the tractor itself. This could prove to be an effective way of obtaining the desired input rpms and the desired input torque needed for the smooth working of our system.

DC Motor

Our second was to make use of a DC motor as an alternative source of input rpm and rid ourselves of the toil of having to attach the driver shaft with the PTO shaft of the tractor. The motor shown below can produce up to 1000 rpm.

Figure 16 DC Motor

It is worth noting that the seemingly high revolutions per minute (rpm) of the DC motor can be modified by adjusting the voltage on the power supply's potentiometer. This adjustment allows us to attain the desired rpm value suitable for our harvesting machine. By manipulating the voltage, we can effectively regulate the rotational speed of the DC motor to meet the specific requirements.

One might question the omission of an AC motor in favor of a DC motor. While AC motors are indeed more cost-effective, they tend to be bulkier, resulting in heightened vibrations. These vibrations necessitate further adjustments in design and calculations to maintain optimal functionality of the harvester. Ultimately, the selection of a motor for our prototype harvester entailed meticulous evaluation of factors encompassing input rpm, cost, weight, and potential design modifications.

Initial 3D Designs

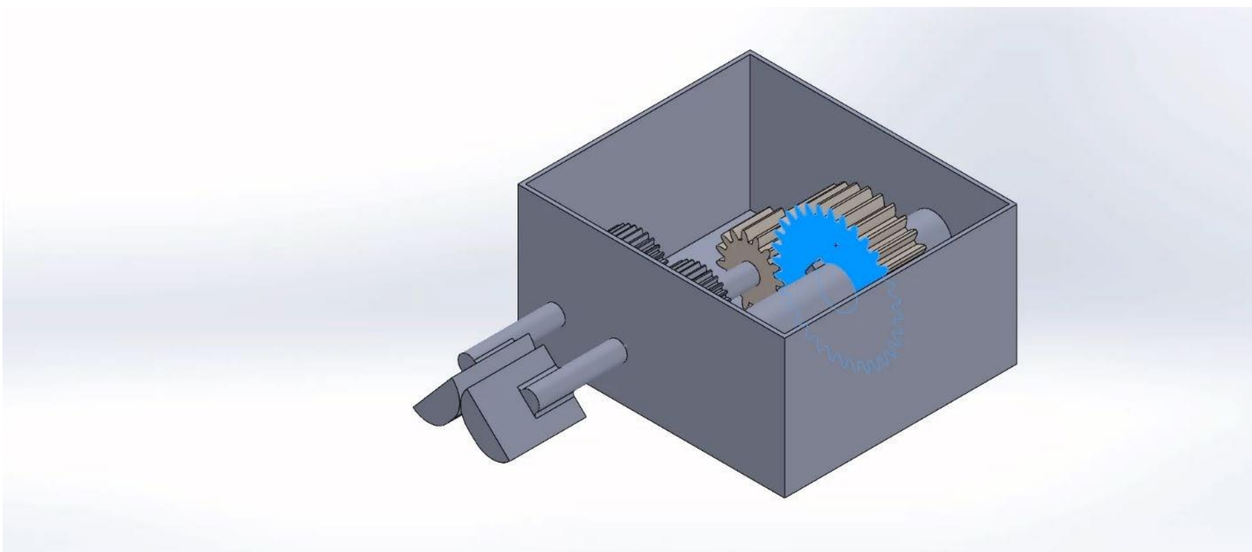
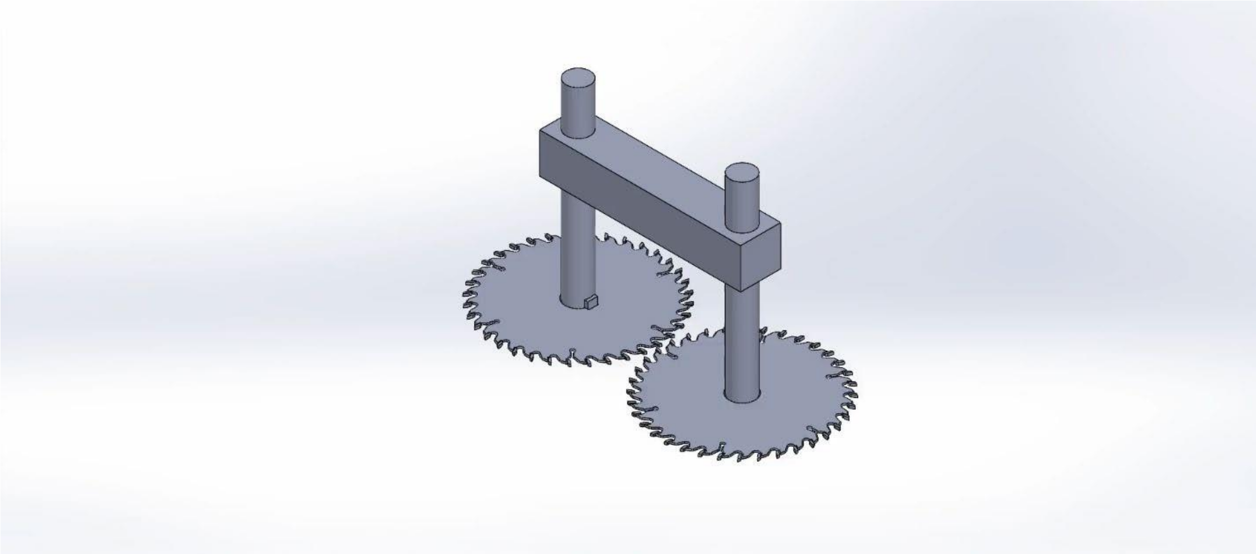


Figure 17 3D Design 1



Design 1:

Figure 18 3D Design 2

Design 1 is composed of a gearbox and a pair of grippers that work in sync to pluck saffron flowers with care and precision. The power output and speed of the PTO shaft from the tractor driving the gearbox can be adjusted to meet the specific needs of the task. The gearbox then regulates the power to ensure that the grippers operate at the required speed and torque.

The grippers are designed to rotate in opposite directions, which results in an efficient flower plucking operation. This coordinated movement minimizes any harm to the plant while guaranteeing a safe and dependable plucking process. The utilization of this design ensures higher yields and better plant health while maintaining efficiency, effectiveness, and safety.

Design 2:

Design 2 is an alternate design that utilizes a pair of cutters directly attached to an electric motor for stem cutting. Although this design is simple, it has several drawbacks. The primary concern is the possibility of unintentionally cutting the plant itself, which could impede future growth and development. In contrast, design 1 assures the safety of the plant while ensuring maximum yield and plant health.

Chosen Design:

After thorough deliberation, we made the deliberate decision to opt for design 1. Our choice stemmed from a firm belief that utilizing rotating grippers would ensure a significantly safer plucking process when compared to the use of cutter heads featured in design 2. It is our understanding that cutter heads have the potential to inflict damage upon the plants and their delicate leaves. By embracing the first design, our primary objective is to establish a saffron harvesting operation that is entirely free from risks, while simultaneously upholding the paramount importance of preserving plant health and optimizing overall yield.

1st Iteration for plucking mechanism

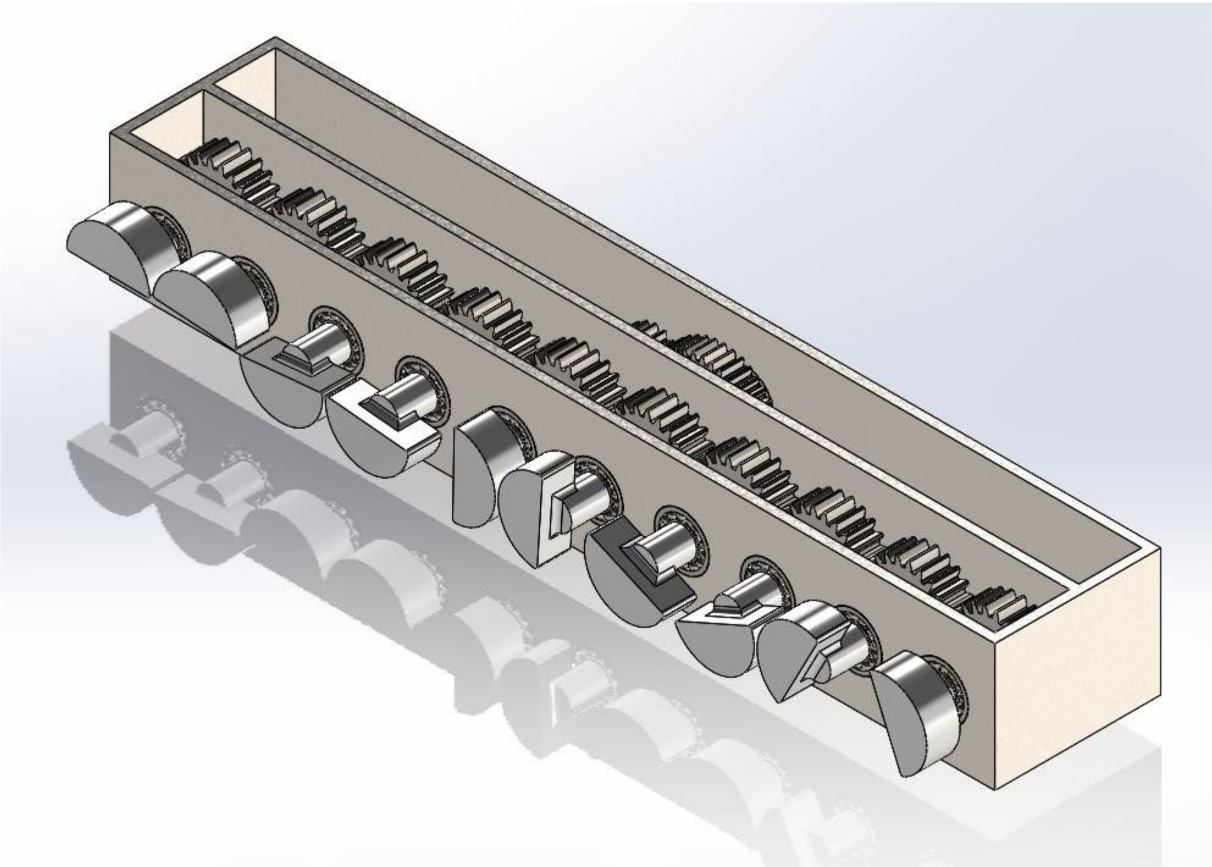


Figure 19 Initial Design

The design features a gearbox powered by a PTO (Power Take-Off) shaft from a Millat Tractor, which is a commonly used tractor in Pakistan.

Casing

Dimensions of the Gearbox: To match the standard Millat Tractor, the width of the gearbox has been adjusted to 1600mm. The height of the box is set at 230mm, and its length is around 300mm. These dimensions have been chosen to ensure that the gearbox fits perfectly with the tractor.

Gears and Grippers: The gearbox has been designed to include a set of gears and grippers, which are used to transfer power from the engine to the wheels. To accommodate the grippers, 10 holes have been made inside the box to install 5 pairs of grippers. The holes are circular with a radius of 50mm and are spaced at a distance of 156mm from the center of one circle to the center of the next circle. This arrangement ensures that the grippers are evenly distributed and can be easily installed.

Support for the Shaft: To provide support for the shaft and reduce the risk of bending in the shafts, a wall has been added in the middle of the gearbox. This is an important consideration as any misalignment or bending of the shafts can cause the gearbox to fail. The wall ensures that the shafts remain straight and aligned, thereby increasing the efficiency of the gearbox.

Entrance for PTO Shaft: The hole at the backside of the gearbox is circular with a radius of 50mm and is the spot where the PTO (Power Take-Off) shaft enters the gearbox. This ensures that the shaft is securely attached to the gearbox and can transfer power effectively. The design of the entrance also ensures that the shaft is easy to install and remove, thereby facilitating maintenance and repairs.

Overall, the design of the gearbox has taken into consideration various factors such as the dimensions of the tractor, the arrangement of the gears and grippers, the support for the shaft, and the entrance for the PTO shaft. These features ensure that the gearbox is efficient, reliable, and easy to maintain, thereby contributing to the overall performance of the Millat Tractor.

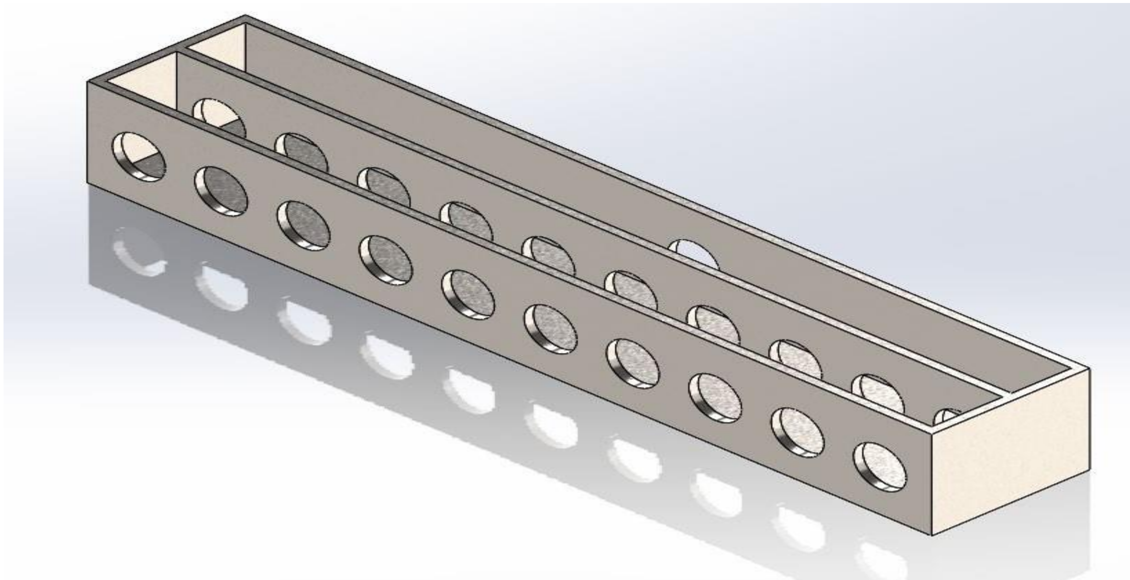


Figure 20 Gearbox Casing

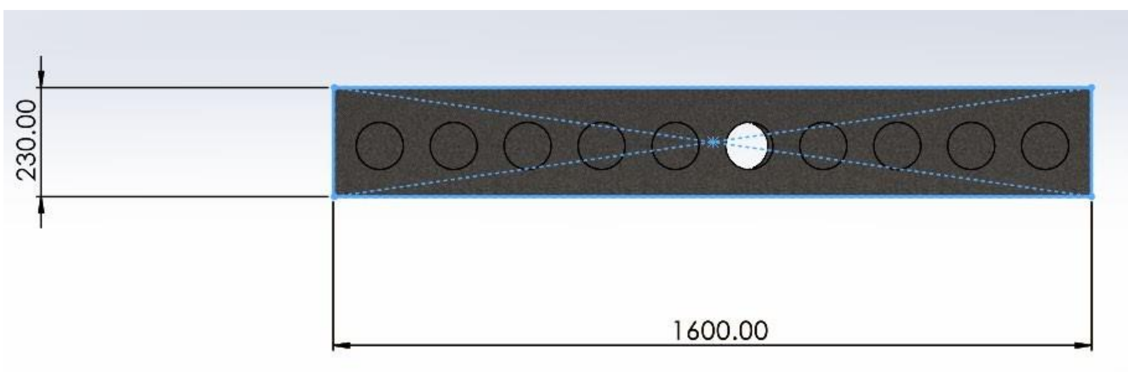


Figure 21 Casing Dimensions

Gear 1

The first gear or drive gear in our design is the primary gear that is connected to the PTO shaft. It has a total of 40 teeth and a face width of 1.5 inches. The gear's pitch diameter measures approximately 5 inches.

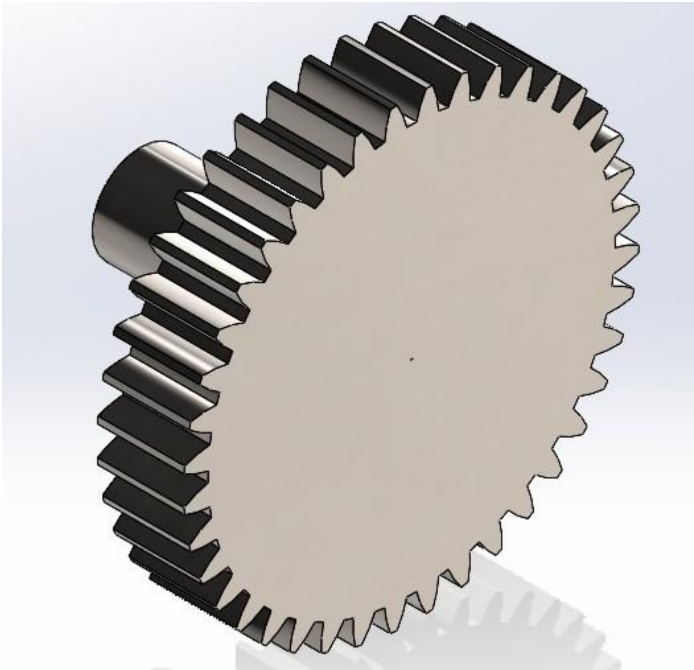


Figure 22 Gear 1

Gear 2

Gear 2 is the gear next to the drive gear and is called the pinion gear. It has 18 teeth, a diametric pitch of 5 inches and a face width of 2 inches.

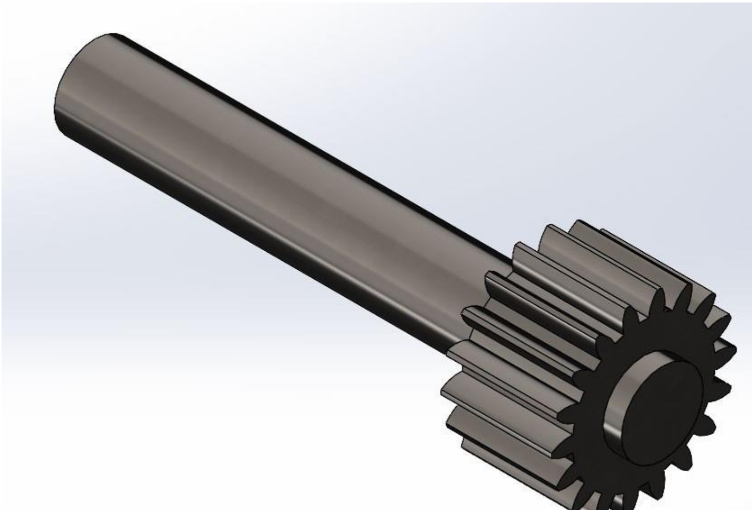


Figure 23 Gear 2 with shaft

The longer side of the shaft is about 9.5inches and the shorter side is about 0.5 inches. The thickness of the shaft is kept 45mm for all the gears.

Gear 3

The gear 3 are the gears which are attached to the grippers. The number of teeth is 24 and diametral pitch and faced widths are 4 and 2 respectively.

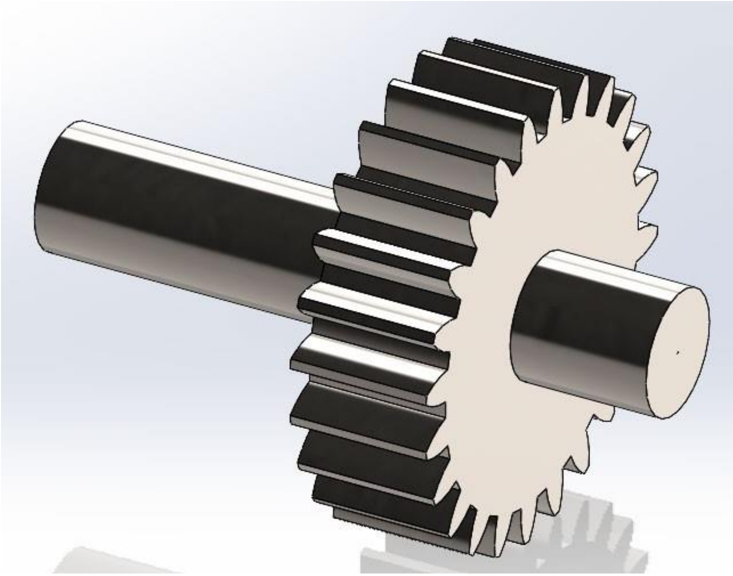


Figure 24 Gear 3 with shaft

The longer side of the shaft is about 5 inches, and the shorter side is about 2 inches.

Bearings

The bearings are selected according to the **NSK standard** after careful design and load considerations. The following are the specifications of the bearings:

Bearing	**6309**
Diameter	100mm
Bore	45 mm
Thickness	17mm/0.66921in

Figure 25 Bearing design

Gripper

The gripper contains a set of two semicircle objects that rotate in opposite directions to perform the function of the plucking. When both grippers reach a specific position, they hold the flower in between them and then the force plucks the flowers from the ground. The dimensions are shown in the figure below:

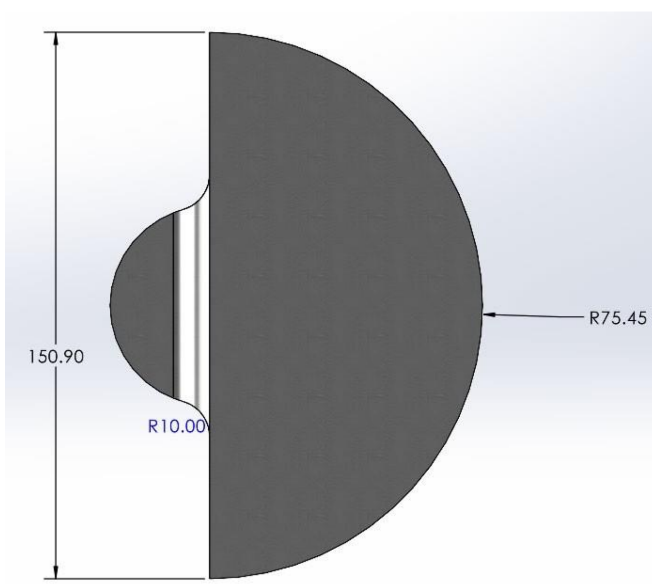


Figure 26 Gripper Dimensions

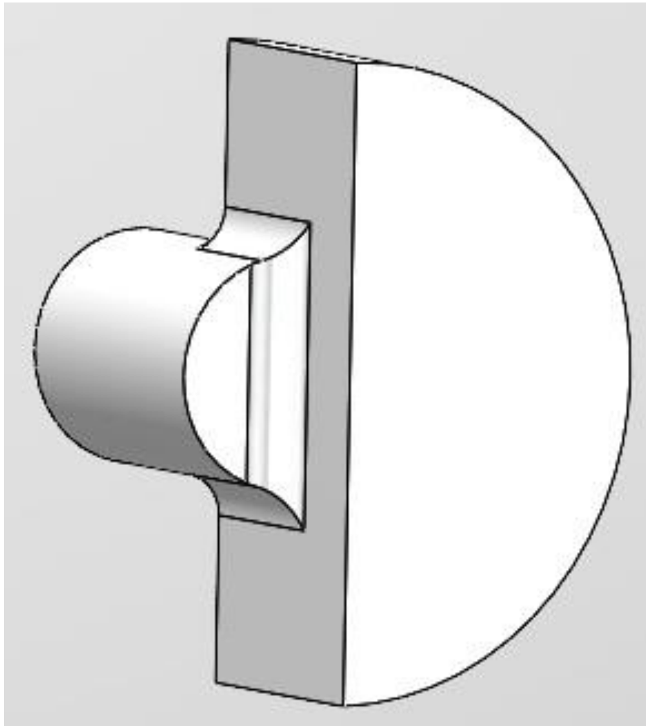


Figure 27 3D Gripper Design

Gripper Pair

The gripper mechanism has been designed that rotates in opposite directions to generate an upward force, allowing for the stem to be plucked without being cut, thereby minimizing damage to the plant.

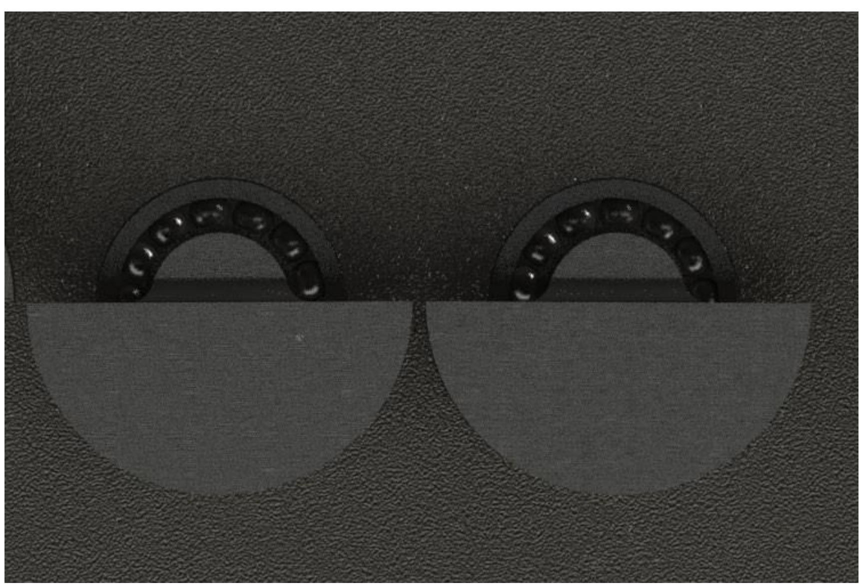


Figure 28 3D gripper Pair design

To achieve optimal performance, the gripper pair was carefully designed with a spacing of 1.5cm at the horizontal position. This configuration was determined through a rigorous process of stress and compression analysis, wherein the force required to pluck a saffron flower (8N) was used as input. The spacing was then iteratively adjusted until the best value was obtained, which resulted in the least amount of damage to the flower stem.

Despite the success of this design, it was found that the gripper mechanism still caused some damage to the plant. Thus, further improvements were required to minimize damage as much as possible. This necessitates a more nuanced understanding of the underlying factors that contribute to stem damage during the plucking process. By addressing these issues, the need to develop an even more effective gripper mechanisms were felt that allows for the delicate and precise plucking of flowers while minimizing damage to the plant.

2nd Iteration for plucking mechanism

It was found that the initial design still caused some damage to the stem, indicating the need for further improvements. In response to this challenge, a series of experiments were undertaken to re-evaluate and refine the gripper design and rotation per minute (RPM) of the cutter.

Gripper Design Modifications

This involved careful observation of the gripper design, and a number of modifications were tested in an effort to reduce damage. These included making the gripper a complete cylinder or reducing the contact area between the gripper and stem, but none of these modifications were found to be effective. Eventually, a minor modification was made to the gripper design by adding a fillet to the outer edges and avoiding sharp edges, which significantly reduced damage as shown in figure []. Despite this improvement, further refinement was still necessary.

Change in RPM:

In this attempt, attention was turned to the RPM of the cutter, which was identified as a major factor in the plucking mechanism. It was observed that the initial RPM of 800 was significantly higher than what was necessary. By lowering the RPM to 400, the amount of damage caused by the gripper mechanism was greatly reduced. However, this modification also gave rise to a new problem, which required additional refinement.

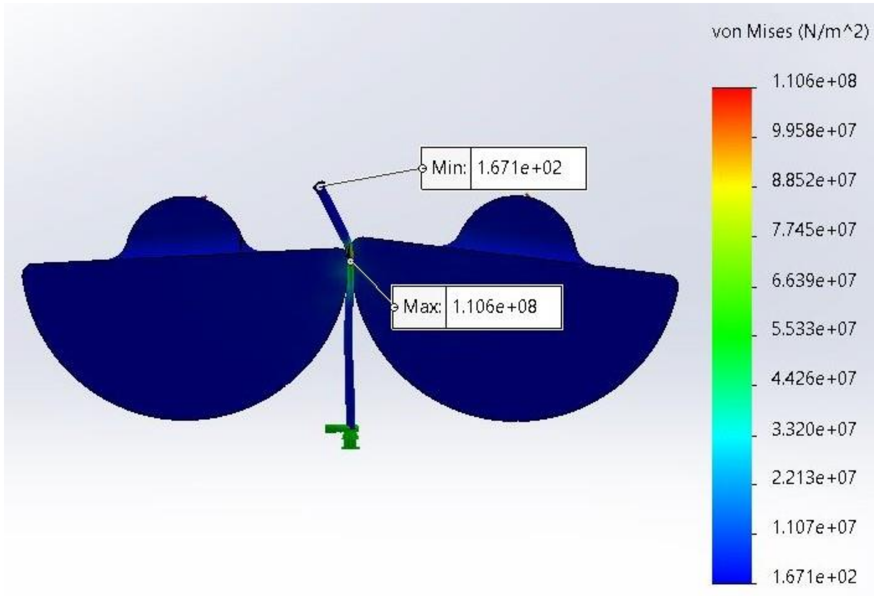


Figure 29 Filleted Gripper at 400 RPM

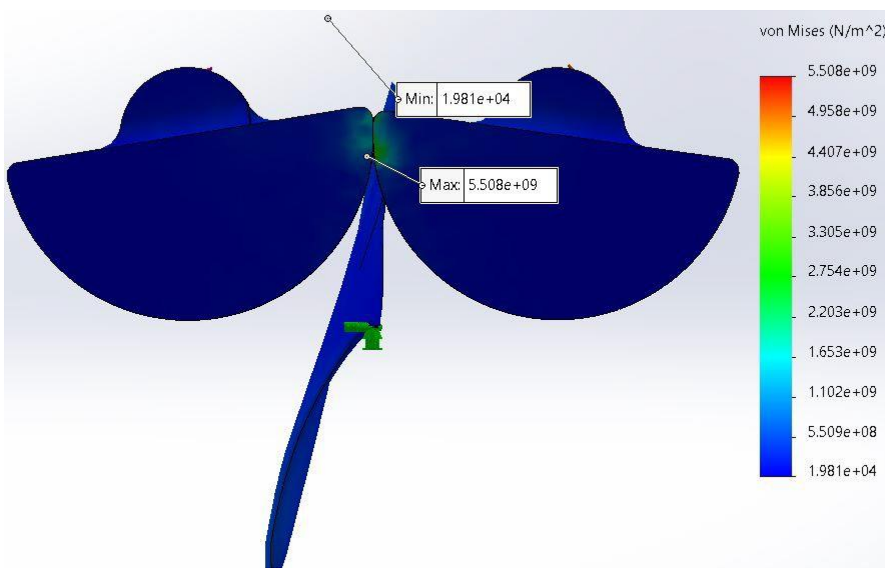


Figure 30 Filleted Gripper at 800 RPM

3rd iteration for plucking mechanism

Upon further investigation, it was determined that the desired rotational speed (RPM) could not be achieved using the tractor's Power Take-Off (PTO) shaft. Additionally, The gear ratio that was selected during the second iteration of the design was found to be unsuitable for the intended application.

In order to address these issues, the team responsible for the design made modifications during the third iteration. Specifically, the gear ratio was adjusted, and gears of appropriate dimensions were sourced from the market to meet the new requirements.

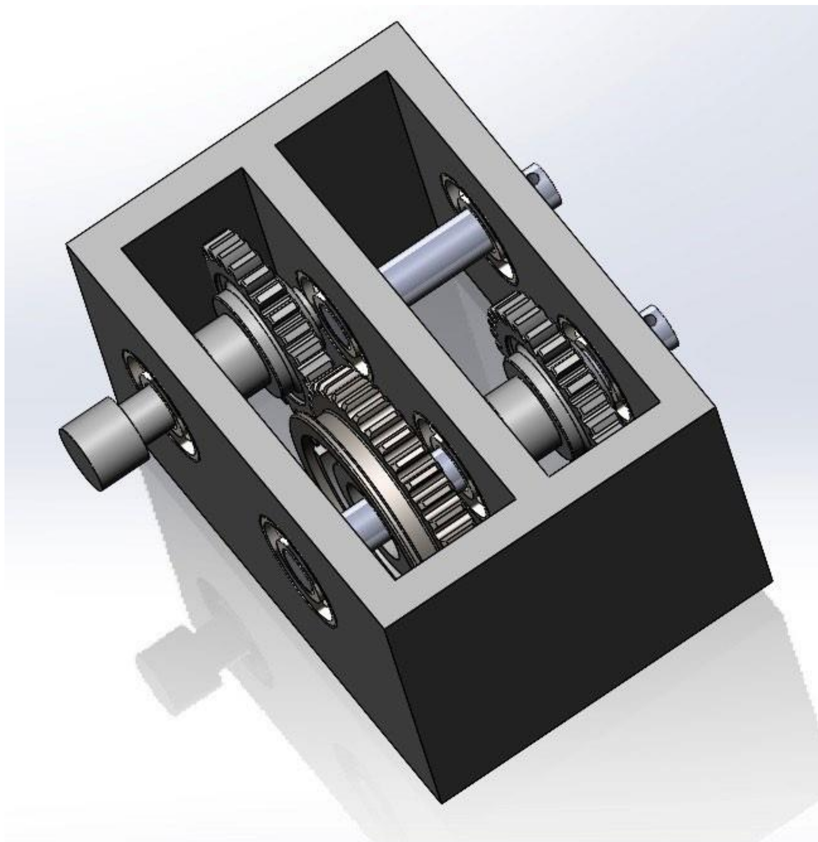


Figure 31 3D model

Figure 32 3 similar gears without sleeves

Figure 33 Driver Gear with the sleeve

Final Design

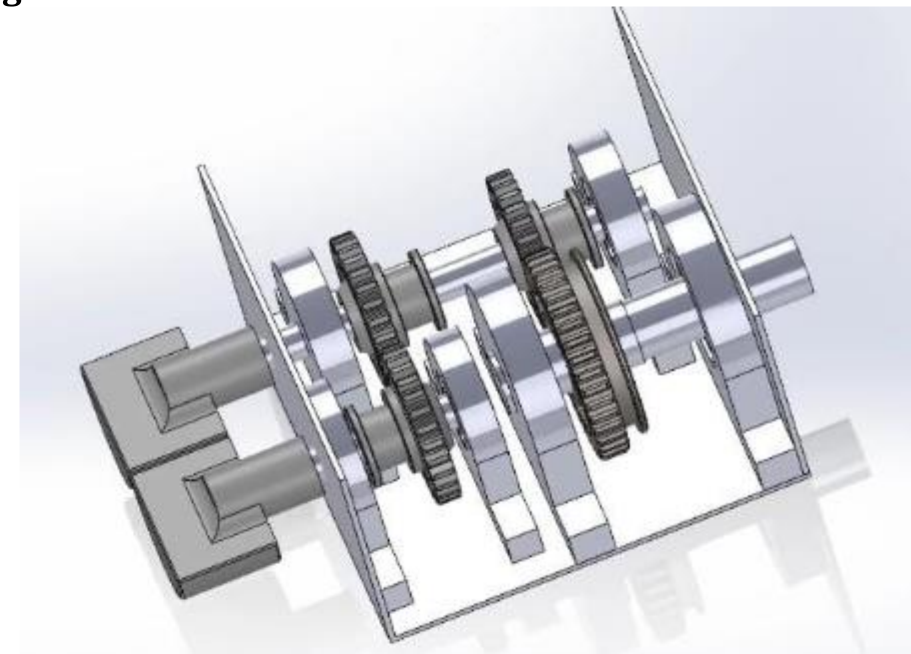


Figure 34 Finalized with real parts dimensions.

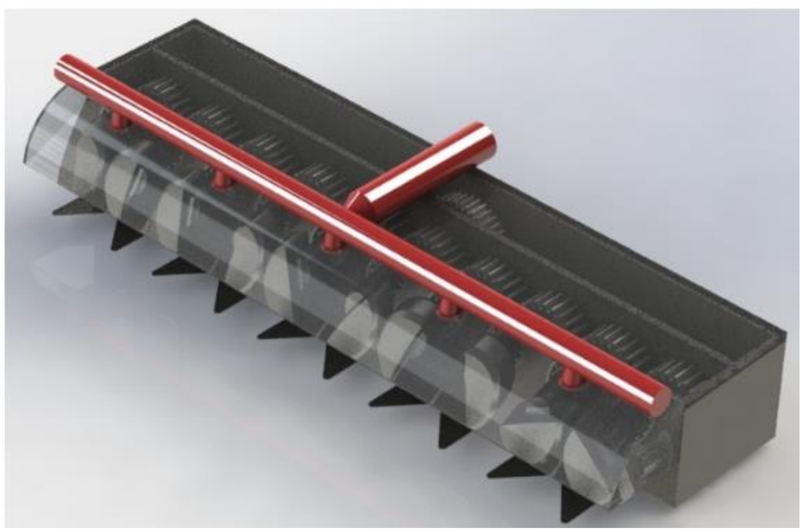


Figure 35 Tractor mounted multiple gripper design.

Development of Prototype

Lawn Mower Frame

Initially, a tractor was selected as the input RPM source for our prototype. However, after conducting a market survey, it was discovered that the cost of procuring the necessary materials and processing them through welding would be prohibitively high. In addition to this, the PTO shafts of commonly available tractors are found at their rear ends whereas it was desired to mount the machine at the front end for ease of visibility of the tractor driver or farmer. Moreover, bringing this PTO shaft to the front end was a challenging job in itself.

As an alternative, a manual lawn mower was sought out whose casing appeared to be suitable formounting our prototype. Further market research led to the discovery of a used lawn mower, which was more cost-effective than the initial approach and did not require much tedious welding expenses as the initially proposed model did.

Upon inspection, the lawn mower was found to be heavily rusted. To address this, a decision was made to completely disassemble the device. The rust on the components was taken care of using sandpaper and kerosene oil. As the cutter was not required for our purposes, the blade was removed, and the remaining components were reassembled.

Subsequently, a 3D design was created for the mounting of our prototype on the lawn mower, along with the inclusion of a DC motor to provide the necessary input RPM and a DC fan for the collection system.

Figure 36 Lawnmower

The frame height of the lawn mower also needed to be adjusted according to that of the harvesting machine from the ground. This was done by making additional holes on the tires of the mower and enabling the support hooks to make their way through them.

Solidworks Model

Figure 37 view 1

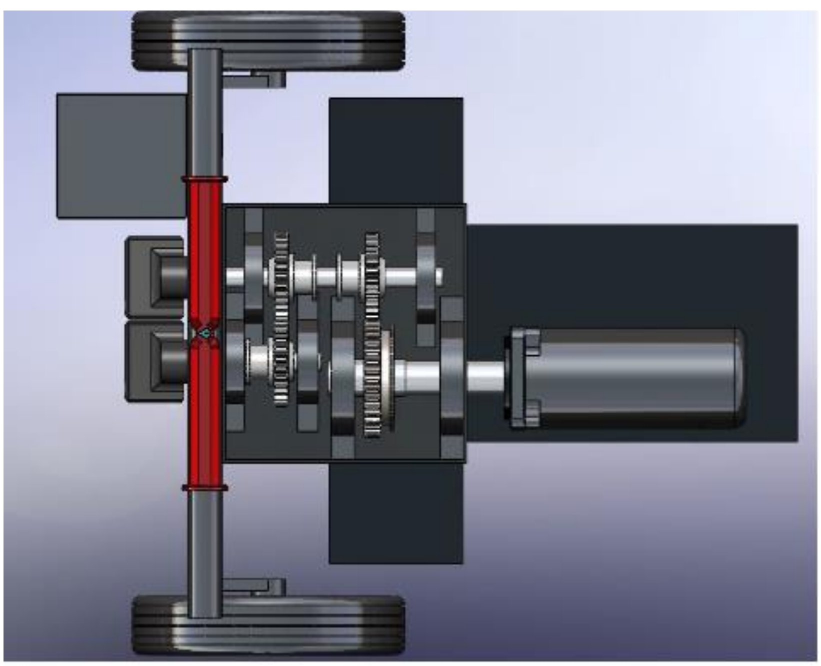


Figure 38 Top View

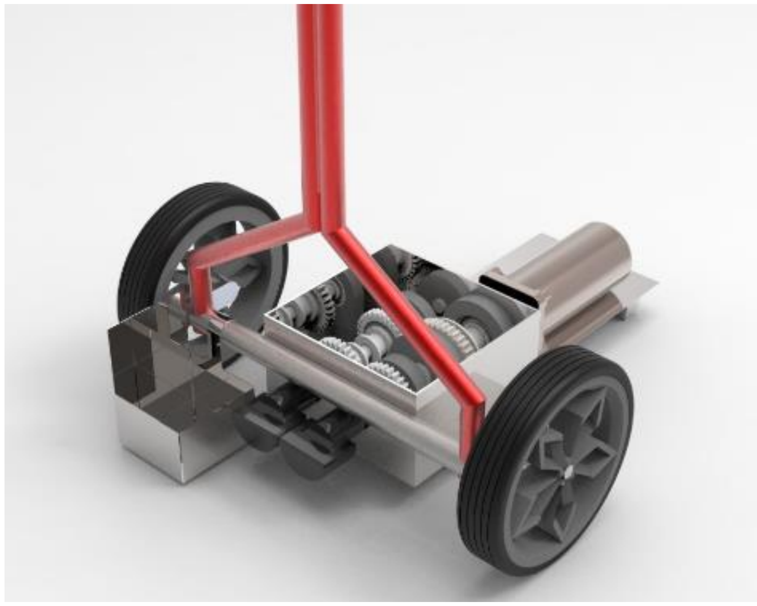


Figure 39 Rendered 3D model

Mounting of gears and bearings on shafts

All the relevant details about the gears, bearings and the shafts have been provided above and the prototype was made accordingly. The gears were first press fitted and then spot welded directly on the shafts and no provision was provided for any keyways on the following grounds: requirement of extra space on the shaft, additional cost, and increased complexity in machining of keyways. Next came the bearings that were press-fitted on the shaft, ensuring that the shafts rotated freely inside them, the bearing stayed securely in place during operation and handled the required load and vibration.

Figure 40 Top view of gearbox

Fabrication of bearing housings

Bearing housings of mild steel were fabricated with from an engineering works' shop. The reason for not buying the housings was that after a complete market survey, we found that the only bearing house available there of our interest, was for our largest bearing i.e., 6206 and no housings were available for our smaller bearings i.e., 6203 and 6202. Moreover, the housing available in the market was expensive and heavy with standard heights not suitable for the limited head space available in our gear box. Therefore, getting the bearing housing fabricated did the job for us in terms of cost and purpose fulfilment (with small rectangular wood slices placed beneath the housing stands so that the shafts reached the desired height). Coming to the bolts used for clamping housings on the base of the box, M10 bolts were used for the two bigger bearings 6206 and 6303 and M08 bolts were used for bearing 6203.

Construction of Gear Box (Casing)

The gear box was made from sheet metal, gauge 16 (1.6mm thick) measuring 700mm by 500mm. First a piece of the sheet measuring 669.12 mm by 463.08 mm (as per the dimensions of the CAD model) was cut out and bent. As far as the bending is concerned, due to the unavailability of advanced bending machine in the Manufacturing Research Centre (MRC), NUST, only two of the sides could be bent on the available machine.

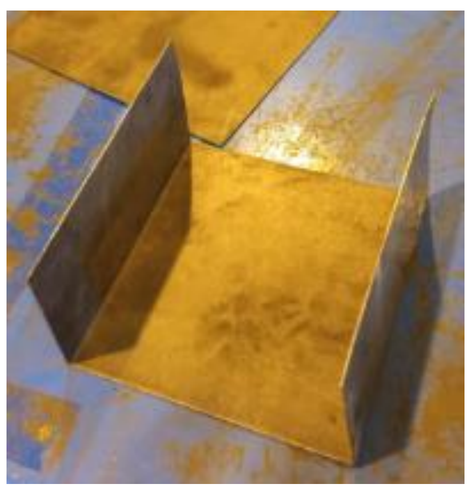


Figure 41 Gearbox

The remaining two sides of the same dimensions as the previously bent sides were cut out from the original sheet and welded with the two previous sides to make a box with 4 walls. As far as the roof was concerned, another side was cut out and hinged to one of the sides. This ensured that the roof was openable and gear box accessible for any unanticipated changes to the system. After these two holes were drilled on one of the walls of the gear box which was decided to be the front side and the two shafts were to pass through them on which the two gripper heads were to be mounted. Afterwards, the gearbox was welded with the machine frame. The gear box needed to be a very robust structure which provided good stability to the heavy system comprising gear and bearing mounted shafts along with the housings.

Placement of motor

After careful pondering over the placement of the motor and its alignment with the driver shaft, it was agreed that the motor would be placed on another piece of sheet metal with 4 caster wheels attached beneath to maneuver the platform. To keep the motor stable and prevent undesired vibrations, a long piece of sheet metal of thickness 0.8mm was arched over the motor acting as a supporting medium for the motor with its ends bolted to the platform. As far as the connection of the motor rotor with the driver shaft is concerned, a coupling could have been used. However, considering the complexities to the motor-shaft that would have been added, the increased manufacturing or purchasing costs, additional space and size requirements, a simpler approach known as “direct drive configuration” was adopted in which a hole was made in the end of the driver shaft with the motor rotor finding its way inside it (ensuring that the motor and shaft were perfectly aligned nullifying any chances of increased vibration and reduced efficiency).

The 300W, 90V DC motor necessitated a power source capable of delivering approximately 4.2 Amps of current. To circumvent the associated expense of acquiring a costly and weighty battery, it was decided that the DC power supply accessible in the electronics lab at SMME be used.

Fabrication of Grippers

The Grippers were produced through the utilization of 3D printing, selected as a favorable alternative to metal manufacturing to attain a solution that is both lightweight and cost-effective. Despite the initial target distance between the grippers being 1.5mm, the actual measurement resulted in 2mm, which comfortably fell within the specified tolerance range.

Fabrication and placement of Collection box

The fabrication process for the collection box mirrored that of the gear box, featuring two sides that were bent and two sides that were welded. However, a deliberate variation was introduced to the design, as the back side of the collection box was made larger than the other sides. This modification ensured that when the flower was subjected to the fan's effect, it would be halted by the larger back side, preventing it from falling away from the box. The size of the collection box was kept compact, considering that the completed prototype consisted of only one pair of grippers. It should be noted that the size of the box would have increased if an additional gripper pair was included.

The collection box is positioned to the right of the grippers. It is important to mention that the original concept for a tractor-mountable design involved placing the collection box at the back of the gear box, utilizing a sliding mechanism to direct the flower into the box.

Placement of Fan

To accommodate the single gripper pair in the prototype, a compact DC fan was employed, considering the operational requirements. The fan's speed was appropriately set to effectively guide a single flower from the gripper into the designated collection box. It should be noted that as the number of gripper pairs increased, the fan size would naturally be scaled up accordingly to maintain optimal performance.

Assembly

Upon reaching the final assembly stage, our focus shifted towards tying all the loose ends together. The first crucial step involved placing the bearings into their respective housing, which demanded some effort on our part. Through a process of press fitting, we carefully inserted the bearings into their designated housings. Occasionally, we had to apply gentle hammering to the shaft ends to assist in this task. However, we encountered instances where the bearings became stuck within their housing due to insufficient lubrication. To address this issue, we ensured proper lubrication of the bearings.

Moving forward, the next step involved positioning the two shafts, along with their gears and bearings, into the gearbox casing. The shafts protruded through two pre-drilled holes in the casing, allowing the grippers to access the exterior. During this stage, we encountered a challenge whereby the height of the housing from the base of the housing was insufficient for the shafts to pass through the holes. To overcome this obstacle, we utilized rectangular strips of plywood. By drilling two holes on each side of the strips, we were able to place the housings on them. Subsequently, the combined assemblies of the housings and strips were securely bolted to the base of the gearbox casing, ensuring that the shafts reached the desired height.

With these elements in place, the next task involved reattaching the motor, which had been detached earlier for the preceding tasks. We press-fitted the motor shaft into the driver shaft and positioned the motor on a metal frame equipped with caster wheels for maneuverability.

Following this, we proceeded to weld the gearbox casing onto the base frame of the lawn mower. To achieve this, we utilized spot welding to secure the four ends of the casing onto the frame. To maintain accessibility, we incorporated a hinged opening using a metal sheet to serve as the roof of the casing.

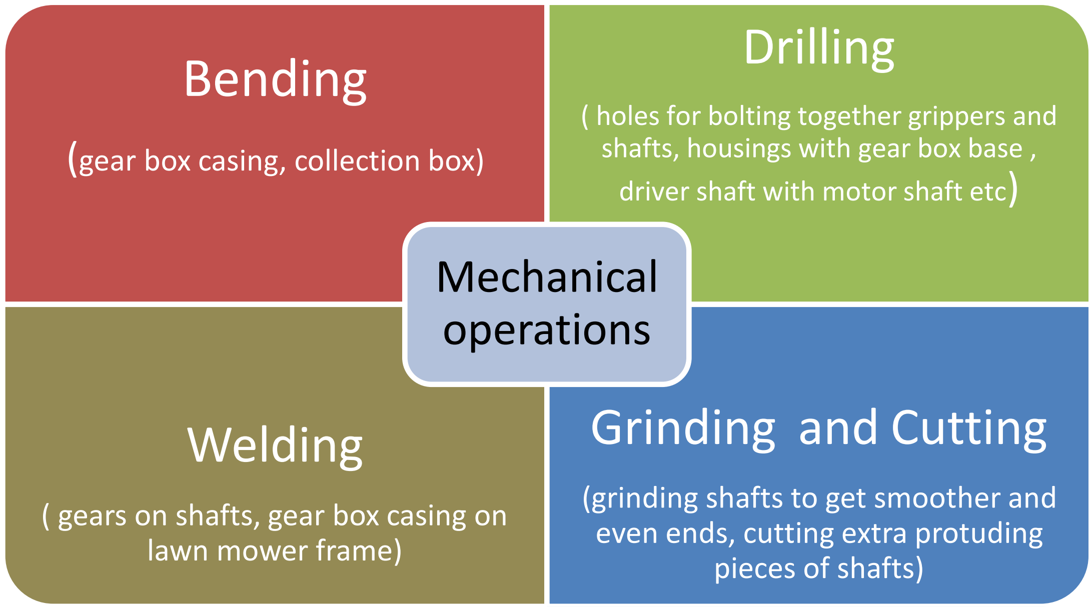
To ensure a neat and functional arrangement, any excess or protruding ends of the shafts were carefully removed using a hex saw. The final task involved affixing the grippers onto the shafts. This entailed preparing the shaft ends to be smooth by performing grinding operations. For a secure grip, the grippers and shafts were drilled at matching distances from their ends using the drill press available in the bench press section of the MRC. Subsequently, they were firmly bolted together.

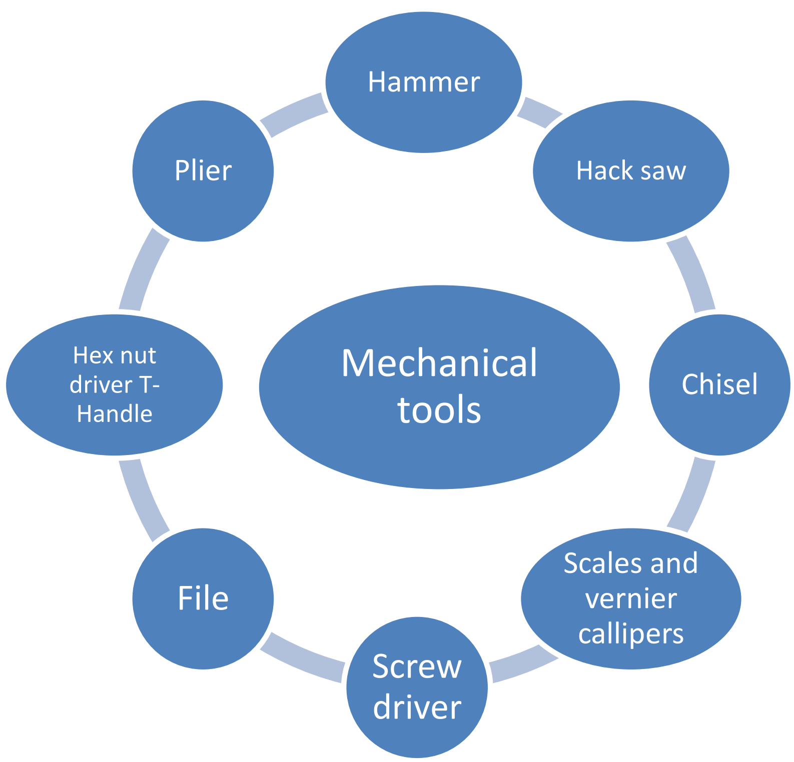
Throughout the process, meticulous attention was paid to detail, and necessary measures were taken to ensure the precise alignment and functionality of each component.

Figure 42 Assembled machine.

Figure 43 Front view

Mechanical operations and tools used





Calculations

Shaft

Given maximum bending moment M and maximum torsion T in a shaft were calculated using bending moment diagram and the given formula respectively, equivalent twisting moment and equivalent bending moments can be calculated using the derived expressions shown.

$$Torque\ (in\ lb\ ft) = 5252 \times \frac{HP}{RPM}$$

$$Equivalent\ Twisting\ Moment = T_e = \sqrt{M^2 + T^2}$$

$$Equivalent\ Bending\ Moment = M_e = \frac{1}{2}\left(M + \sqrt{M^2 + T^2}\right)$$

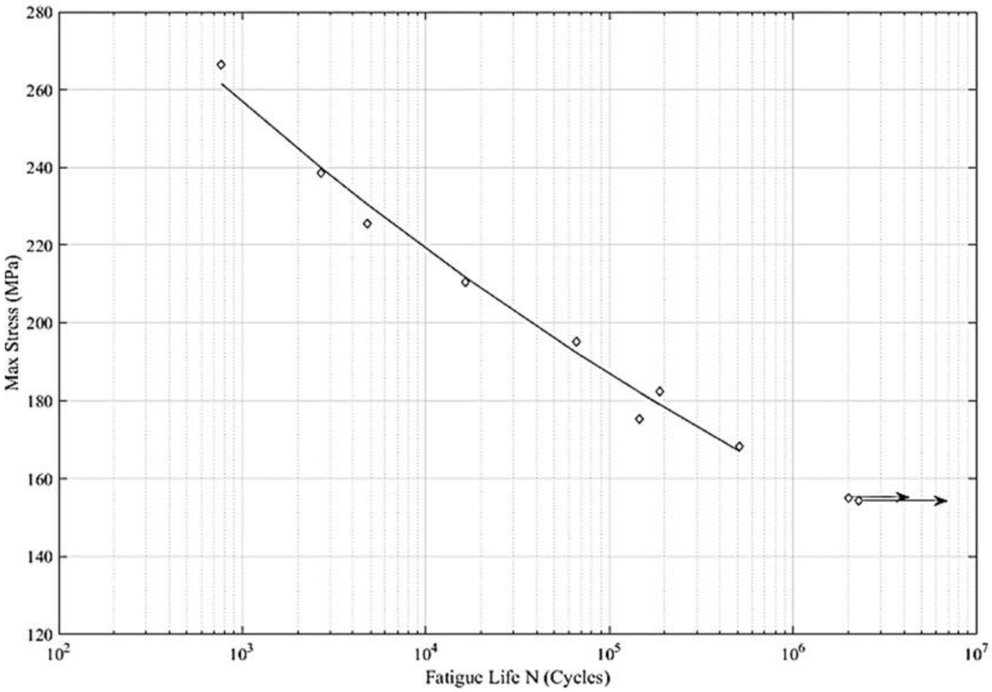
According to maximum shear stress theory, the maximum shear stress τ_{max} induced in the shaft,

$$\tau_{max}(in\ psi) = T_e \times \frac{16}{\pi d^3}$$

According to maximum normal stress theory, the maximum normal stress σ_{max} induced in the shaft,

$$\sigma_{max}(in\ psi) = M_e \times \frac{32}{\pi d^3}$$

Considering that our stresses did not exceed 1600 psi. Considering the yield strength of mild steel to be 250 MPa (36260 psi), it was concluded that mild steel was adequate for our purpose. When checking for fatigue at our designated life cycle rating of 10^5 cycles, it was discovered that our maximum stress amounted to 180 MPa (26107 psi), which remained significantly below the given stresses. Consequently, we opted for mild steel as the material for our shaft, instead of AISI 4140 steel commonly utilized in gearboxes. This decision was based on factors such as ease of availability, machinability, and sufficiency inn requirement.



Bearings

Bearings were chosen depending upon the diameter of required shafts and the catalog rating C1 of bearings. Chosen bearings were single row deep groove ball bearings due to common availability, sufficient reliability, and lower cost.

A suitable load factor for precision gearing, a life adjustment factor corresponding to 90 percent reliability, and hour life for intermittent use application was chosen and the given formula used to calculate equivalent catalog rating C_{10} which represents a constant radial load that a NSK bearing would support for L_{10} life. For NSK ball bearings this equals 10^6 cycles, denoting the number of cycles 90 percent of NSK ball bearings will complete before developing the first signs of failure at desired radial load F_D. L_D is life in hours and $n_D$is rpm of shaft.

$$C_{10} = F_D \times \left(\frac{L_D n_D 60}{L_{10}}\right)^{1/a}$$

A bearing was then chosen from NSK catalog that satisfies the C_{10} rating. In our case bearings 1 and 3 turn out to be 6303 and bearing 2 is 6303.

Gears

The governing equations shown were used throughout.

$$\frac{N_1}{N_2} = \frac{\omega_1}{\omega_2} = \frac{T_2}{T_1}\ ,\ F_T = \frac{2T}{d}$$

And

$$Diameteral\ Pitch\ (P_d) = \frac{Number\ of\ teeth\ (N)}{Pitch\ Diameter\ (d_P)}$$

The AGMA bending stress was calculated using.

$$\sigma_{bending} = F_T K_O K_V K_S \frac{P_d K_m K_B}{F\ J}$$

The AGMA contact stresses are given by.

$$\sigma_{contact} = C_p \sqrt{F_T K_O K_V K_S \frac{K_m C_f}{d_P\ F\ I}}$$

Where $K_O, K_V, K_S,\ K_m, K_B, and\ C_f$ are factors that need to be calculated separately. J is geometry factor.

The allowable bending stress, based on material of gears and surrounding conditions is given by.

$$S_t = \frac{Y_N}{K_T K_R} S_t$$

The allowable contact stress is given by.

$$S_c = \frac{Z_N C_H}{K_T K_R} S_c$$

Factor of safety for bending stresses on gear

$$FOS_b = \frac{\sigma_{bending}}{S_t}$$

Factor of safety for contact stresses on gear under scrutiny

$$FOS_c = \frac{\sigma_{contact}}{S_c}$$

Calculation results

The team involved in the project completed all necessary calculations for the gears, bearings, and torque and RPM requirements. A comprehensive Excel file was createdto document all aspects of the design, and the following tables contain the results of the team's calculations.

Input Data

The following estimations were made or obtained through research from different online sources, based on the specific requirements of the project:

- Material properties of gears and bearings
- Coefficient of friction between gears and bearings
- Design life of gears and bearings
- Input torque and rotational speed requirements
- Desired gear ratio
- Efficiency of the gear train
- Allowable stress of the materials used.
- Tolerances for manufacturing and assembly

Bearing Calculations

Bearing 1				
Life in hours	2000	**Fe**	**39.16198**	**lbf**
Load Factor Ka	1	**C10**	**162.9204**	**lbf**
a	3			
Reliability Factor	1			

Bearing 2				
Life in hours	2000	**Fe**	**13.50413**	**lbf**
Load Factor Ka	1	**C10**	**50.89658**	**lbf**
a	3			
Reliability Factor	1			

Bearing 3				
Life in hours	2000	Fe	52.66611	lbf
Load Factor Ka	1	C10	198.4966	lbf
a	3			
Reliability Factor	1			

Shaft Calculations

Spacing between adjacent components on Shafts		Diameter of shaft	
L1	1.220472	S1	1.181102
L2	2.244094	S2	0.669291
L3	1.023622	S3	0.669291

Shaft 1(gear 1)		
Torque	4.376666667	lb ft
Shear Stress due to twisting moment	162.3424938	
Normal Stress due to bending moment	101.0605738	
Equivalent Twisting Moment	4.583774559	lb ft
Equivalent Twisting Moment	2.973022013	lb ft
Maximum Shear Stress	170.02469	psi
Maximum Normal Stress	220.5549769	psi
Bending Moment at start of shaft	0	
Bending Moment at first gear	1.362269466	lb ft

Shaft 2(gears 2 and 3)		
Torque	5.885862	lb ft
Shear Stress due to twisting moment	1199.819	
Normal Stress due to bending moment	1373.341	
Equivalent Twisting Moment	6.781629	lb ft
Equivalent Twisting Moment	5.075089	lb ft
Maximum Shear Stress	1382.419	psi
Maximum Normal Stress	2069.09	psi
Bending Moment at start of shaft	0	
Bending Moment at first gear	-0.46975	
Bending Moment at second gear	3.368548	
Maximum Moment	3.368548	lb ft

Shaft 3(gear 4)		
Torque	5.885862	lb ft
Shear Stress due to twisting moment	1199.819	
Normal Stress due to bending moment	626.4365	
Equivalent Twisting Moment	6.083116	lb ft
Equivalent Twisting Moment	3.809823	lb ft
Maximum Shear Stress	1240.029	psi
Maximum Normal Stress	1553.247	psi
Bending Moment at start of shaft	0	
Bending Moment at first gear	1.536531	lb ft

Gear Calculations

Parameters	
N1=	**29**
N2=	**39**
N3=	**29**
N4=	**29**
Pd1=	**10.16**
Pd2=	**10.16**
Hp=	**0.5**
RPM1=	**600**

Here, Gear 1 represents the Driver gear and Gear 2 represents the other 3 gears because they are identical.

Gear 1		Gear 2	
Ko	1.5	**Ko**	1.25
Y	0.356	**Y**	0.387
Qv	8	**Qv**	8
F	0.56	**F**	1.063
J	0.38	**J**	0.39
Km	1.06926	**Km**	1.0845
Cp	2300	**Cp**	2300
Cf	1	**Cf**	1
Kr	1	**Kr**	1
CH	1	**CH**	1
Kt	1	**Kt**	1
Yn	0.9825	**Yn**	0.9876
Zn	0.9556	**Zn**	0.962
d	0.629921	**d**	1.259843
Kb	1	**Kb**	1
mg	1.344828	**mg**	1.344828
All. Bending	54037.5	**All. Bending**	54318
All. Contact	181564	**All. Contact**	182780

Calculated Values	
Dp1	2.854331
Dp2	3.838583
Dp3	2.854331
Dp4	2.854331
RPM2	446.1538
T1	4.376667
T2	5.885862
T3	5.885862
T4	5.885862

Ft1	**36.80022**	**Fn1**	**13.39418**	**Fr1**	**39.16198**
Ft2	36.80022	**Fn2**	13.39418	**Fr2**	39.16198
Ft3	49.48995	**Fn3**	18.01287	**Fr3**	52.66611
Ft4	49.48995	**Fn4**	18.01287	**Fr4**	52.66611

Gear 1		
I	0.092164	
V	448.3572	
B	0.629961	
A	70.72221	
Kv	1.179381	
Ks	1.031361	
mb	4.466667	
AGMA bending		3427.772
AGMA contact		50774.42
F.S Bending		15.76461
F.s Contact		3.575895
Gear 2		
I	0.092164	
V	448.3572	
B	0.629961	
A	70.72221	
Kv	1.179381	
Ks	1.069725	
mb	5.266667	
AGMA bending		1542.454
AGMA contact		29754.48
F.S Bending		35.21532
F.s Contact		6.142941
Gear 3 and 4		
I	0.080348	
V	333.3938	
B	0.629961	
A	70.72221	
Kv	1.155671	
Ks	0.992972	
mb	3.044444	
AGMA bending		5164.38
AGMA contact		61252.55
F.S Bending		10.51782
F.s Contact		2.984039

These are the calculations and methodology we have adopted so far. According to the results obtained we decided to proceed with the 3rd iteration with a spacing of 1.5 mm between the grippers and a height of 6cm fromthe ground which can possibly perform our desired output of plucking the flower.

CHAPTER 4

Results and Conclusions

Testing

The functionality of the motor was thoroughly tested to ensure smooth operation. Special attention was given to the motor's ability to efficiently transfer torque to the gears, which, in turn, drove the grippers. To achieve the desired rotation speed of the grippers, a voltage of 30V was applied, as confirmed by the tachometer readings. Any existing vibrations were successfully eliminated by rectifying the misalignment between the motor shaft and the driver shaft.

Regarding the testing of the actual saffron plucking process, it was unfortunately not possible due to the unavailability of saffron fields. However, an attempt was made to replicate the plucking process using a random flower found in the nearby lawn of the MRC (Mechanical Research Center). The flower, along with its stem and leaves, was carefully plucked, ensuring it remained intact. Holding the flower securely from the bottom, it was positioned between the gripper heads. Upon activation, the gripper heads performed the plucking action, safely removing the flower from a specific length of its stem without causing any harm to the petals, the remaining stem, or the leaves. With the assistance of a fan, the plucked flower was then transferred to a collection box placed at a certain distance from the grippers. This successful demonstration indicated significant progress towards achieving the desired outcome.

By meticulously testing and fine-tuning the motor's performance, we ensured that it functioned smoothly and effectively transmitted torque to the gears and grippers. The carefully measured voltage of 30V proved to be optimal, enabling the grippers to rotate at the desired speed as indicated by the tachometer, a reliable instrument for measuring rotational velocity. The painstaking effort to eliminate vibrations paid off, as we painstakingly rectified the misalignment between the motor shaft and the driver shaft, guaranteeing a stable and vibration-free operation.

Regrettably, due to the unavailability of saffron fields, we were unable to conduct direct testing of the plucking process for saffron flowers. However, our commitment to progress led us to improvise by selecting a suitable alternative: a flower discovered within our proximity which is dimensionally similar to saffron. To replicate the real-world plucking scenario, we made sure to pluck the flower along with its stem and leaves, mimicking the delicate nature of saffron harvesting. Holding the flower firmly from its base, we positioned it precisely between the gripper heads, meticulously recreating the grip required for successful plucking.

With great anticipation, we initiated the gripping mechanism, and to our delight, the gripper heads accomplished the task flawlessly. Employing a gentle yet secure grip, they effectively plucked the flower from a designated section of the stem, displaying remarkable precision. Importantly, this plucking action did not cause any damage to the delicate petals, the remaining portion of the stem, or the attached leaves. We attribute this success to the careful design and engineering of the gripper heads, which ensured a controlled and non-intrusive plucking process.

To complete the experimental setup, we introduced the element of transfer by incorporating a fan into the system. Through the coordinated action of the grippers and the fan, the plucked flower was smoothly and safely transferred from its original position to a designated collection box located a short distance away. This successful transfer validated the efficiency and accuracy of the grippers in moving the plucked material without compromising its integrity or causing any harm.

Although the substitution of saffron flowers with a random flower was not an ideal scenario, this experiment demonstrated our significant advancement towards achieving the desired outcome. By successfully replicating the plucking process and ensuring the safe handling and transfer of the flower, we have taken significant strides towards realizing our goal. This breakthrough brings us much closer to the successful implementation of saffron plucking.

Conclusion

After a year-long arduous journey, we have triumphed in creating a prototype for a mechanical saffron harvesting machine, marking the culmination of our tireless efforts. This transformative experience has been nothing short of enlightening, as it has provided us with invaluable lessons and knowledge. While our prototype stands as a testament to our accomplishment, it is only the beginning, for it holds immense potential for further refinement and embellishment, particularly through the incorporation of automation.

Looking ahead, envisioning a future where our machine plays a pivotal role in saffron harvesting, we contemplate its integration with existing agricultural practices. As we delve into the possibilities, mounting the machine onto a tractor emerges as a promising option, subject to the prerequisite provision of well-defined pathways in saffron fields to accommodate the tractor's tires. This strategic collaboration would not only enhance efficiency but also facilitate seamless mobility during the harvesting process.

Furthermore, we explore the concept of specially designed field vehicles, equipped with solar panels, to serve as platforms for our machine. By harnessing the boundless energy of the sun, these vehicles could effectively maneuver our invention, all while championing the noble cause of environmental sustainability. This eco-friendly approach aligns harmoniously with the urgent global need to conserve energy and reduce carbon footprints. Introducing solar-powered automation into the saffron industry represents a profound opportunity, particularly for agrarian economies like Pakistan, where this sector holds immense potential for growth and revitalization.

The implications of automating saffron harvesting are far-reaching and transformative. The introduction of efficient and advanced technology promises to revolutionize an industry that has traditionally relied heavily on manual labor. Automation can lead to significant gains in productivity, quality, and cost-effectiveness, propelling Pakistan's agricultural sector towards new horizons of success. By streamlining and optimizing the harvesting process, we can unlock untapped potential, ensuring greater profitability and sustainability for saffron farmers and contributing to the overall economic development of the country.

In conclusion, our year-long struggle has borne fruit in the form of a mechanical saffron harvesting machine prototype. However, our journey does not end here. The true embellishment of our invention lies in its future refinement and integration with automation. Whether mounted on tractors or specially designed field vehicles powered by solar energy, the potential for growth and progress in the saffron industry is immense. By embracing automation, we can usher in a new era of efficiency, sustainability, and prosperity for saffron farmers and contribute to the transformation of Pakistan's agricultural landscape.

CHAPTER 5

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