Report on development of

Sweet Sorghum Leaf Removal Machine

Project Report by

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INTRODUCTION-

Sweet sorghum [*Sorghum bicolor* (L.)Moench] is the best multipurpose crop for simultaneous production of (i) grain from its earhead as food, (ii) sugary juice from its stalk for making syrup, 4iggery or ethanol and (iii) bagasse and green foliage as an excellent fodder for animals, as biomass for gasification system, as organic fertilizer or for paper manufacturing. Moreover, sweet sorghum has a great tolerance to a wide range of climatic and soil conditions. It is a short duration crop of 110-130 days as compared to 12-18 months in sugarcane. In addition its water and fertilizer requirement is much less, resulting in lower cost of cultivation than sugarcane. Sweet sorghum is a plant with C_4 photosynthetic pathway, so its photosynthetic rate and dry matter production in g/m^2/day per unit of inputs are more than those of other sugar producing crops like sugarcane and sugarbeet. These characteristics make sweet sorghum an ideal crop for syrup and 4iggery production. Existing sugar mills, small factories and *„gurhals'* (4iggery-making units) running on sugarcane can be used during off-season for processing sweet sorghum (as it can be grown round the year as a supplementary feedstock) to make these units more economical. Like sugarcane syrup („kakViin Marathi), sweet sorghum syrup can be used as a liquid sweetener in various food products due to its excellent taste. It is a better source of calcium than honey.

<u>Processing of the sweet sorghum stalk</u>

Steps required-

1. Stripping of stalks:
2. Extraction of juice:
3. Filtration and settling of the juice:
4. Juice evaporation:
5. Cooling of finished syrup:
6. Storage of syrup:

We are interested in stripping of stalks and this report focuses on it

Figure [1]: Hand stripping by women

<u>Stripping of stalks:</u>

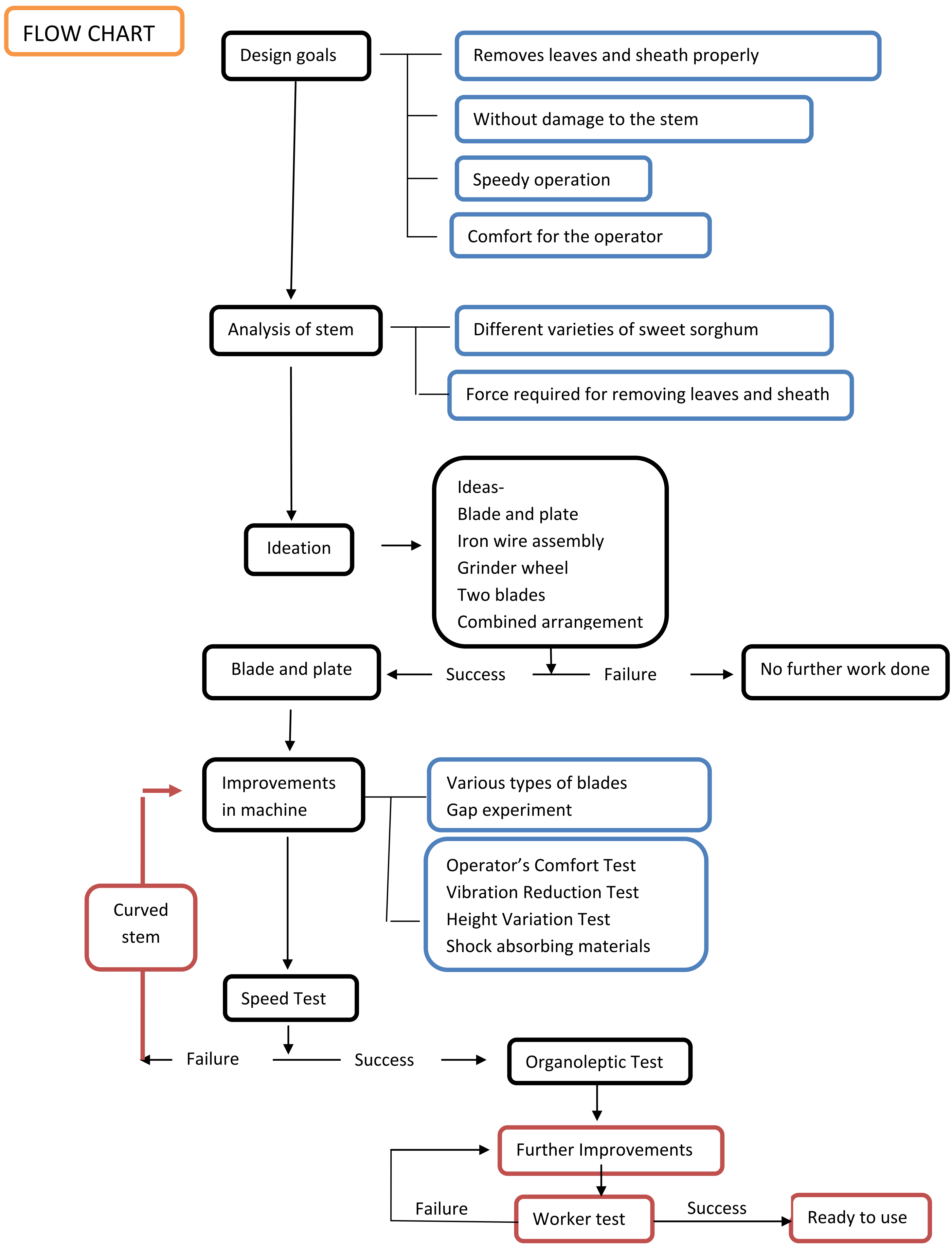
Harvested stalks are stripped by removing the leaf lamina along with the sheath and panicles with peduncle as these contain very little sugar. The stalks are stored in shade for one or two days before milling for juice extraction. This conditioning allows the inversion of sucrose to reducing sugars and thus improves the quality of juice. Conditioning of stalks before milling also removes excess moisture from the stalks and increases the brix of juice which ultimately helps to reduce the time and fuel required for syrup concentration. Currently hand stripping is done and a machine has not yet been designed to do so. Hence we attempted to make leaf and sheath removal machine for sweet sorghum plant.

Four important factors must be considered while designing the machine. They are as follows:-

1. Quality of leaf removal
2. Damage to stem
3. Speed of operation
4. Comfort to operator

This report explains the experiments we did to tackle these problems.

Given on the next page is the flow chart explaining the design process. Those in the black boxes have been completed. Those in the red boxes are still remaining.


FLOW CHART
Design goals
Removes leaves and sheath properly
Without damage to the stem
Speedy operation
Comfort for the operator
Analysis of stem
Different varieties of sweet sorghum
Force required for removing leaves and sheath
Ideation
Ideas-
Blade and plate
Iron wire assembly
Grinder wheel
Two blades
Combined arrangement
Blade and plate
Success
Failure
No further work done
Improvements in machine
Various types of blades
Gap experiment
Operator's Comfort Test
Vibration Reduction Test
Height Variation Test
Shock absorbing materials
Curved stem
Speed Test
Failure
Success
Organoleptic Test
Further Improvements
Failure
Worker test
Success
Ready to use

SECTION 1

Objective- The objective of this section is to understand differences between varieties of sweet sorghum and force required to remove their leaves and sheaths.

1. **Stem analysis**

At NARI three different varieties of sweet sorghum are cultivated i.e Madhura, Madhura 2 and Madhura 3. Stalk diameters of these varieties have different ranges. In order to find out the frequency of occurrence of stems having a specific diameter, a test was conducted in which diameters of stems were measured from random samples. The black line is the second degree polynomial trend line which represents the general trend.

Following data was taken for Madhura.

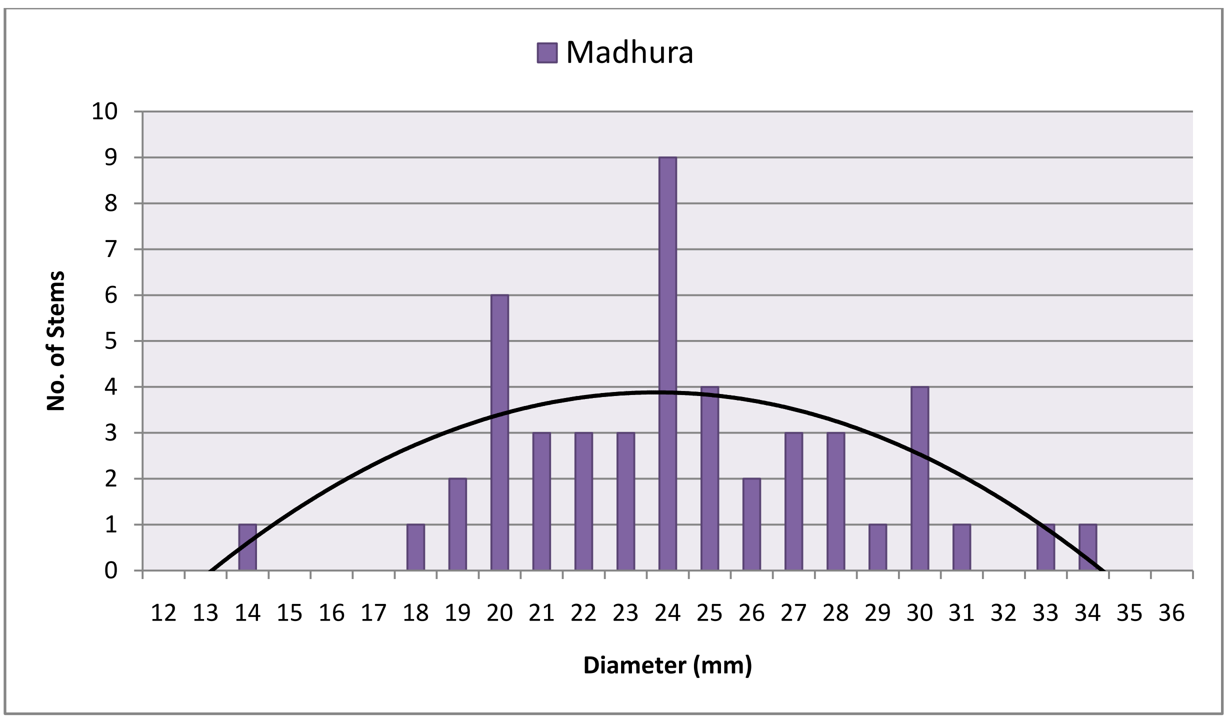


Figure [2]: Frequency of occurrence of stems having a specific diameter for Madhura

As is shown in the graph above, Madhura’s stem diameter varied from 14mm to 35mm but majority of stems fell in the 20mm to 30mm range. 24 mm diameter had the maximum frequency of occurrence.

Following data was taken for Madhura 2

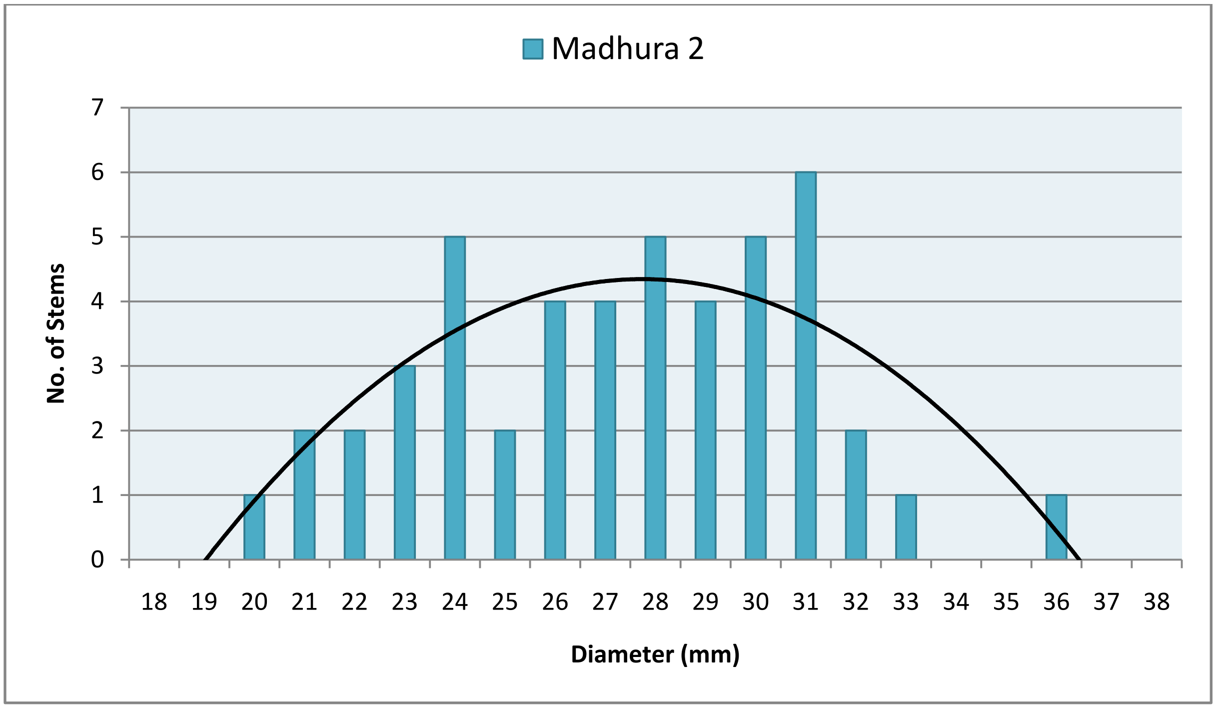


Figure [3]: Frequency of occurrence of stems having a specific diameter for Madhura 2

As is shown in the graph abovec, Madhura 2's stem diameter varied from 19mm to 36mm but majority of the stems fell in the 24mm to 31mm range. 31 mm diameter had the maximum frequency of occurrence.

Following data was taken for Madhura 3

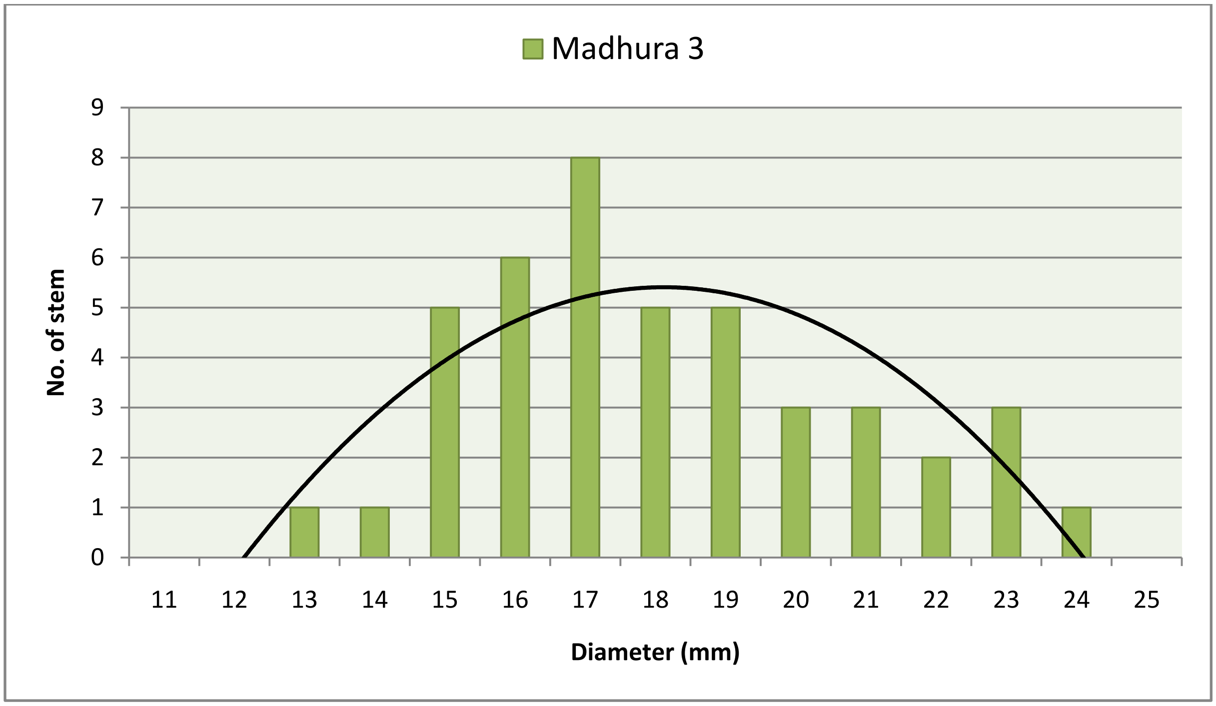


Figure [4]: Frequency of occurrence of stems having a specific diameter for Madhura 3

As is shown in the graph above, Madhura 3's stem diameter varied from 13mm to 24mm but majority of the stems fell in the 15mm to 19mm range. 17 mm stem diameter had the maximum frequency of occurrence.

From these graphics we notice that madhura 3's stem diameter is the smallest and Madhura 2 has the largest stem diameter

2. **Force required for removing sheath and leaves**

To measure the force required to remove leaves and sheath. A small experiment was conducted. In this experiment the stalk was passed in a ring made of iron wire. The ring was attached to two ends of the rope and the rope passed through hook attacked to spring balance. The stalk was then pulled and the maximum deflection in spring balance was noted which gave us the required force.

Figure [5]: Ring is attached to rope

Figure [6] Rope attached to spring balance

All the data observed during the experiment is summarized in Appendix [1].

Maximum force of 200N was observed for both cases i.e leaves and sheath and machine has been designed considering it. Also it must be noted that wet sheath tends to stick to the stem but in our experiment ring is passed beneath the sheath manually and then the force was measured. Data for wet sheath doesn't represent that factor.

Results

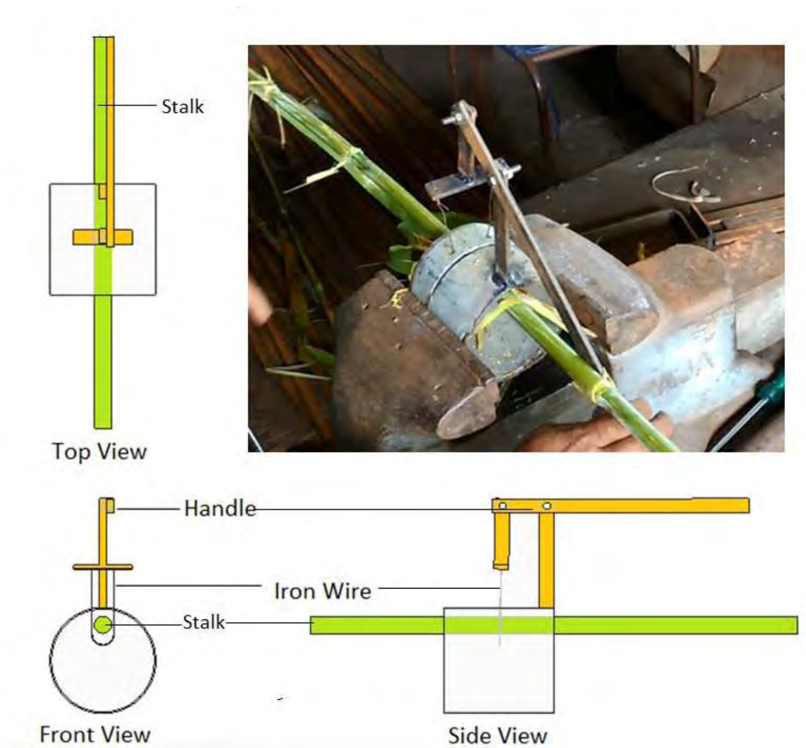
Max force required to remove leaves and sheath	200 N
Madhura varies from	12 mm to 35 mm
Madhura 2 varies from	18 mm to 36 mm
Madhura 3 varies from	12 mm to 24 mm

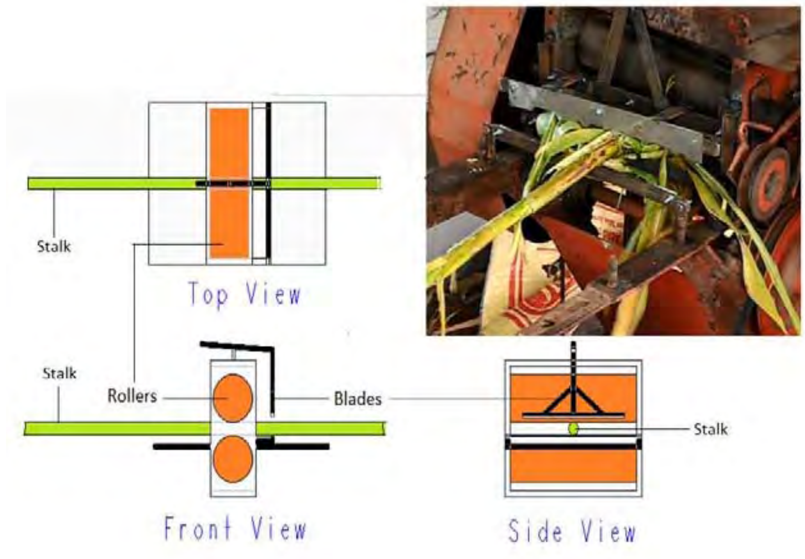
SECTION 2

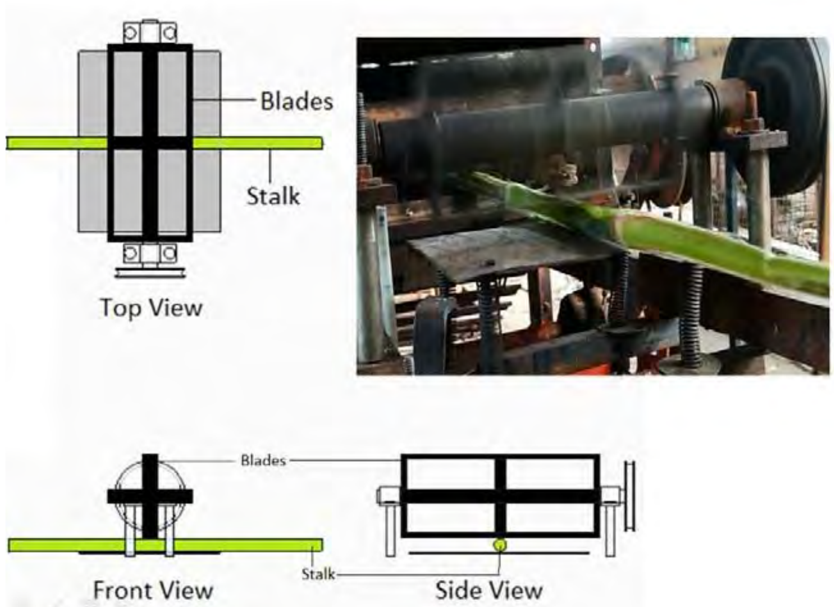
Objective- The objective of this section is to discuss various small experiments performed to check the validity of different ideas for leaf removal.

<u>Ideation</u>

Table [1]: Advantages and Disadvantages of various ideas

Idea	Disadvantage	Advantage
 Description- An iron wire assembly is used to remove leaves in this case	Doesn't remove leaves in one go. Need to send the stalk in the assembly at least three times.	The stalk need not be rotated in the assembly Removes the leaves and sheath.
\		

<table>
<tr><th></th><th></th><th></th></tr>
<tr><td>

Description-The stalk is passed in between the two blades</td><td>Not possible to remove leaves and sheath properly.
.</td><td>Useful for leaves attached at the top</td></tr>
<tr><td>

Description- The stalk is passed between the blade and the plate</td><td>The stalk has to be rotated with hand
Not possible to remove leaves attached at the top.</td><td>Removes leaves and sheath properly</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

 Description- Combination of 1 and 2	Manual work increases Not useful for curved stems	
 Description- Grinding wheel was used	More time is required for removing leaves and sheath.	Less vibrations

Keeping in mind our primary objective of proper leaf removal we found out that the blades and plates arrangement described in idea.3 works very well for our purpose. It not only requires less manual work, but also has the potential to be developed into a fully automatic machine.

Machine in brief

Figure [7]: Image of the machine

As discussed above the machine has a blade and plate arrangement and the stalk is passed between them. To get desired quality of leaf removal without any damage to the stem the gap between those two plays a very important role. The machine is operated manually with a 1hp, 1450 rpm motor manufactured by Crompton Greaves. In the next section all the design parameters of the machine have been discussed in detail.

Result

In this section the ideation process was discussed.

SECTION 3-

Objective-

Five important factors must be considered while designing a leaf-stripping machine. They are as follows:-

1. *Quality of leaf removal*
2. *Damage to stem*
3. *Speed of operation*
4. *Comfort of operator*
5. *Taste of syrup*

In this section all the experiments performed to improve these factors have been discussed.

Experiments and observations

1. *Quality of leaf removal and damage to stem*

Table [2]: Three types of Damage

Sr No.	Name	Image
1	Inside Cut	
2	Outside Cut	

3	Bend	

Quality of stripped stalk can be classified in four ways-

Perfect (P)	All the leaves have been removed (100% removal)
Good (G)	Some leaves left which can be removed by hand(80% removal)
Average (A)	Some leaves left and the stalk has to be reinserted into the machine
Bad (B)	None of the leaves have been removed (0% removal)

<u>Experiment 1- Gap Experiment</u>

In this experiment we changed the gap between the blade and the plate from 1cm to 4 cm in steps of 0.5cm and collected the data. Observational data is given in Appendix [2].

In order to have a better visualization of the data it has been represented in the graph below:-

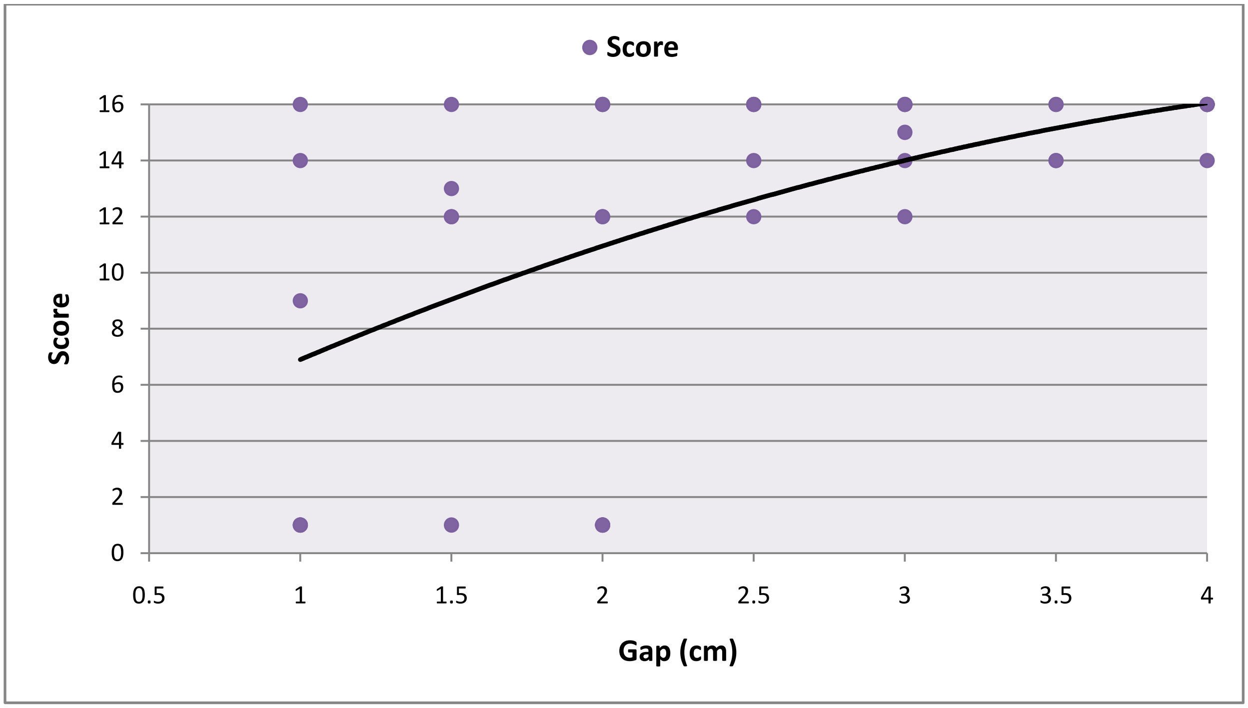


Figure [8]: Stripped stalk quality score for different gaps

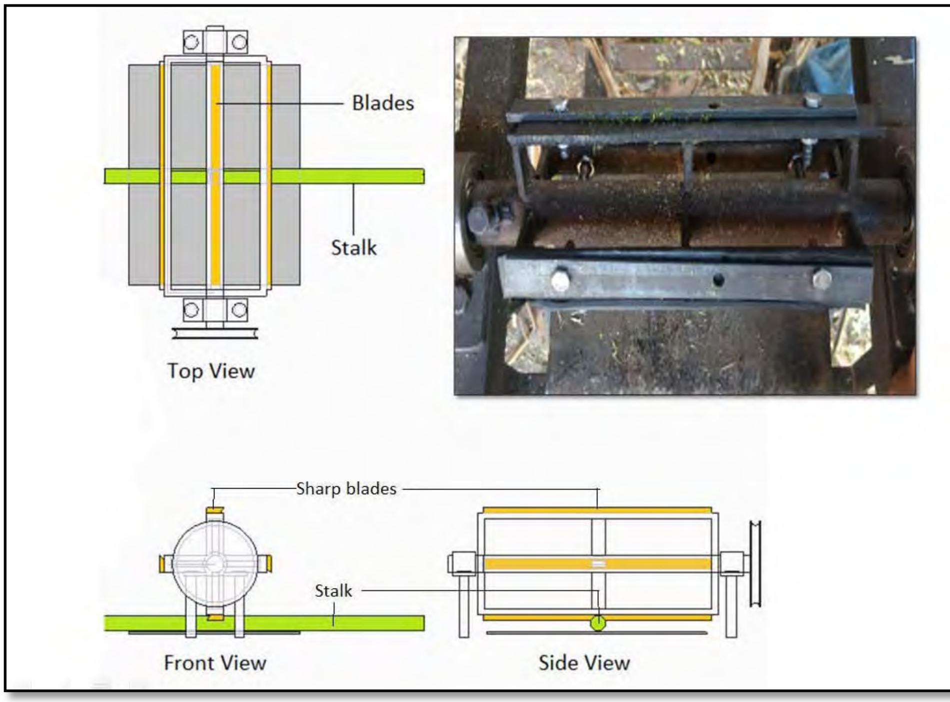
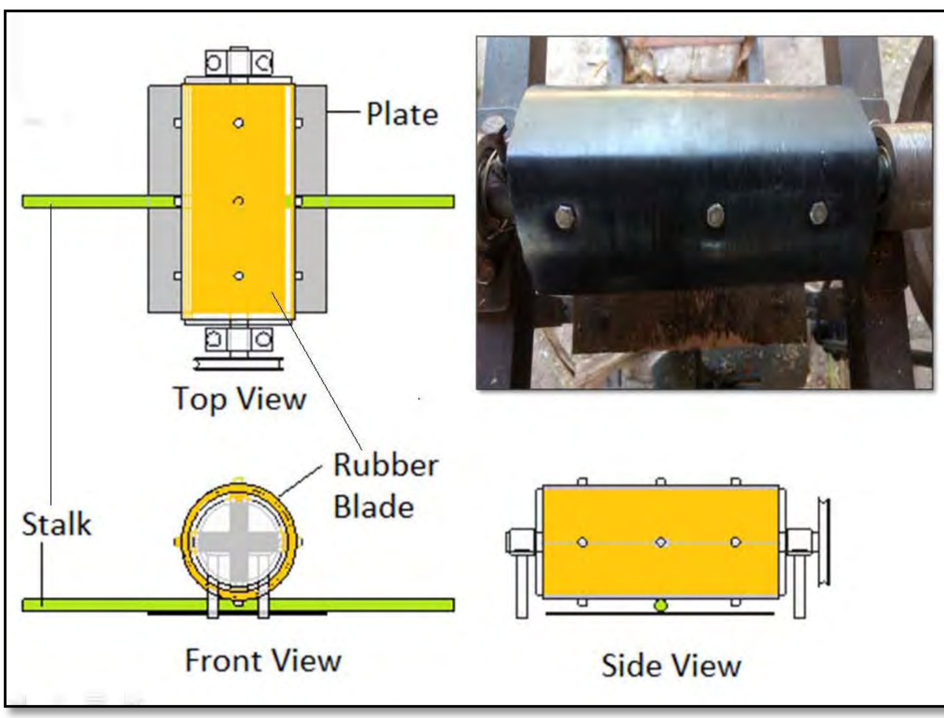
It was observed that for narrower gap the quality score is poor and as the gap increased the quality score improved. The black line is a second degree polynomial trend line which represents the general trend of the quality score of the stripped stalk.

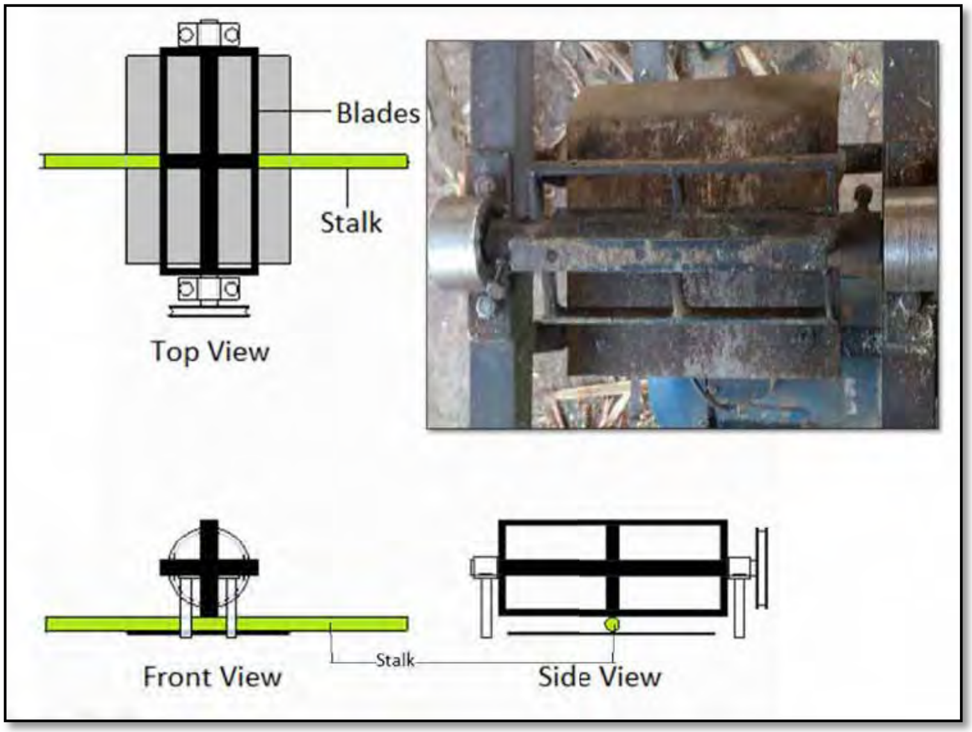
Experiment 2- Different types of blade

Different types of blade such as rubber blade, sharp and blunt metal blades were tested for quality of and damage to the stripped stalk. The following table summarizes it in brief:

Table [3]: Reason of failure/success of different types of blade

Sr No.	Photo	Reason of failure or success

1-Sharp Metal Blades		Damage to the stem increased especially outside cut
2- Rubber Blades		Unable to remove wet sheath also it has maintenance issues

3- Blunt Metal Blades		Worked well

Blunt Metal Blades were selected for our machine.

2. Speed of operation

Depending on type of stem i.e straight or a curved, the operational speed varies. The following table gives the time required for stripping of 25kg stalks.

Method and stem used	Time required (mins)
Hand stripping/ All types of stem	46
Machine stripping / Straight stems	23
Machine stripping / Curved stems	32

It is clear from this data that our machine gives satisfactory results for straight stems but not for curved stems. More efforts are needed to improve the operational speed for curved stems.

3. *Comfort of operator*

Vibrations are caused due to the action of the blades on the stalk. As the operator holds the stem these vibrations get transferred to his hand. Hence it is necessary to reduce them. In this section we discuss in detail various experiments performed to reduce vibrations.

Experiment 3- Effect of gap size on the vibrations and pulling force

In this experiment the operator rated the vibrations and pulling force in one of the three categories viz. low (L), medium (M) and high (H). Observational data is given in Appendix [3].

The pulling force and vibrations increase when the gap is less than the diameter of the stem. Hence for operator's comfort diameter of the stem must be less than the gap size.

Experiment 4- Shock absorbing material

In the first experiment shock absorbing materials were clamped onto the plate and it was checked to see whether this reduced the vibrations. The following table gives detail about the materials used and the results.

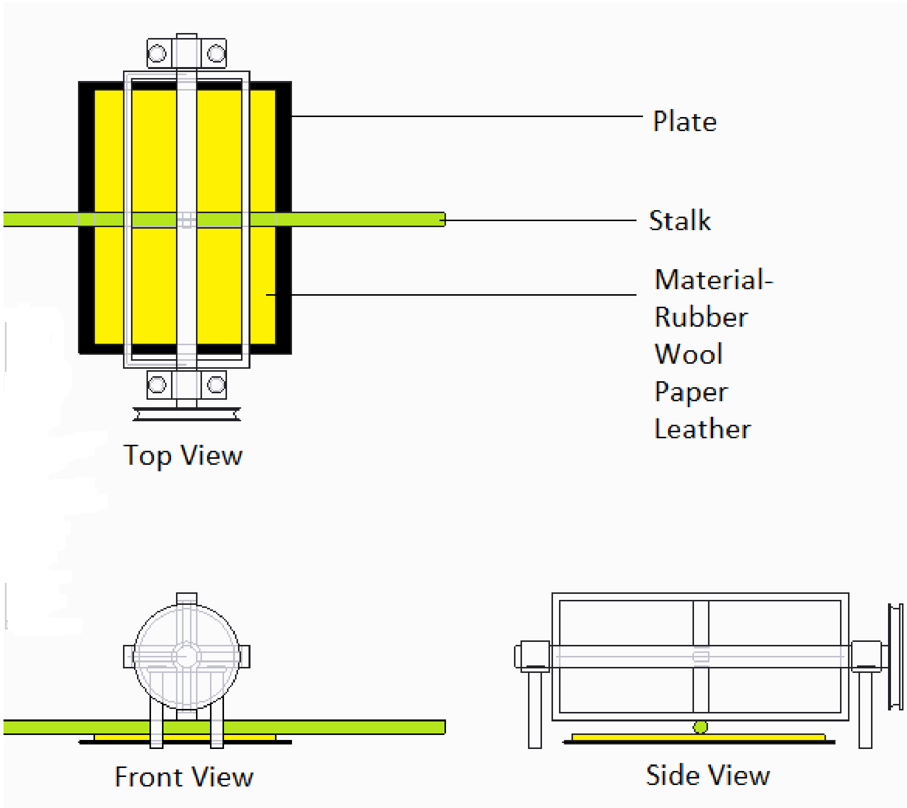


Figure [9]: Line diagram explaining the arrangement of shock absorbing materials.

Shock absorbing materials			
			
Wool	Rubber	Leather	Paper

Table [4]: Shock absorbing materials

None of the above materials helped in reducing the vibrations.

Experiment 5- RPM Reduction test-

It was observed that by reducing angular velocity of blades the vibration could be reduced but we were concerned that this may affect operational speed; hence two tests were performed. In the first test the angular velocity of the blades was 362 rpm and in the second case it was 181 rpm. Results are given in the following table:

Angular Velocity	Time	Weight
362	14 min	14 kg
181	15 min	14.6 kg

4. *Taste of syrup*

Experiment 6- Organoleptic test

The ultimate aim of our project is to make good quality syrup which has similar properties as those of syrup made after stripping the stalks with hand. An organoleptic test was performed to check the syrup. Grade 1 is given to very good quality with grade 5 for very poor quality. The results are summarized in the following table:-

Table [5]: Organoleptic test data

		Hand Stripping	Machine Stripping
Singh	Taste	2	2
	Colour	2	1
	Transparency	2	1
	Odour	1	1
Gadekar	Taste	2	2
	Colour	2	1
	Transparency	2	1
	Odour	1	1

Despande	Taste	1	1
	Colour	3	1
	Transparency	3	1
	Odour	2	1
Jadhav	Taste	2	2
	Colour	3	1
	Transparency	3	2
	Odour	1	2
Average	Taste	1.75	1.75
	Colour	2.5	1
	Transparency	2.5	1.25
	Odour	1.25	1.25

A single test is insufficient to predict which method is better for stripping but from above data it is sufficient to prove that the machine can be used to make good quality syrup

In this section we have covered all the important experiments carried out to improve various factors which affect leaf and sheath removal.

Results-

1. Quality of leaf removal	By increasing the gap between the blade and the plate quality score increases
2. Damage to stem	
3. Speed of operation	More efforts are needed for curved stem
4. Comfort to operator	By reducing angular velocity of blades comfort to the operator increases Diameter of stem must be less than the gap to reduce the vibration.
5. Taste of syrup	Syrup made after stripping by the machine is as good as that made after hand stripping

Section 5

Objective –In this section cost analysis of machine is done. It is then compared with cost of hand stripping.

Cost Analysis Of Machine

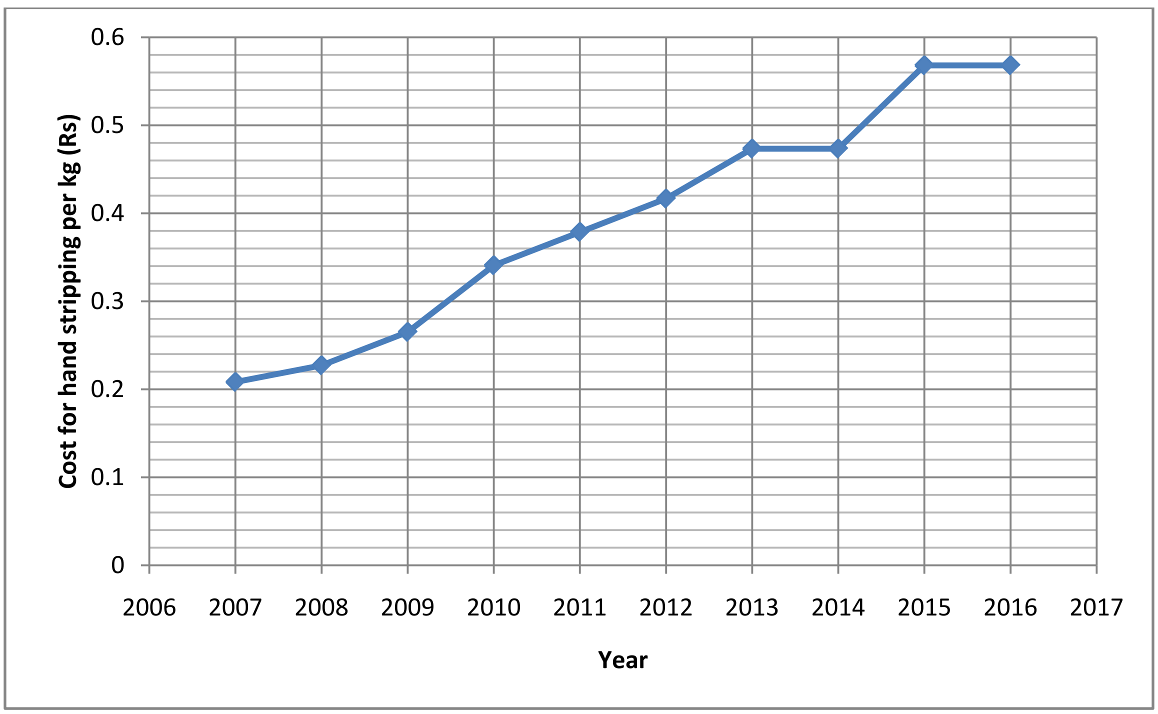
Cost of hand stripping-

Following table represents the data-

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Wage	55	60	70	90	100	110	125	125	150	150

We have assumed the rate of hand stripping = .55kg/min.

The following graph tells us the cost of hand stripping of 1kg of sweet sorghum plant-



Fig[10]: Cost of hand stripping per kg vs years

Presently Rs .57 is required to remove leaves per kg of sweet sorghum.

Cost of machine-

Capital Cost-

Item	Rate	Quantity	Cost (Rs)
1.5 inch angle bars	Rs36/kg	20 kg	720
Belt		1	150
Pulley	Rs35/inch	10 inch	350
Motor		1	4500
Bearing	Rs150/piece	2	300
Technician Cost/Person	Rs 400/day	2 technician worked for 3 days	2400
Springs		4	150
Bearing Pedal	Rs 300/piece	2	600
Nut/bolt	Rs 20/piece	4	80
Covering			300
Blades			150
		Total	9700

Table [11]: Cost of machine

Capital cost- Rs 9700

Maintenance cost- Rs 970

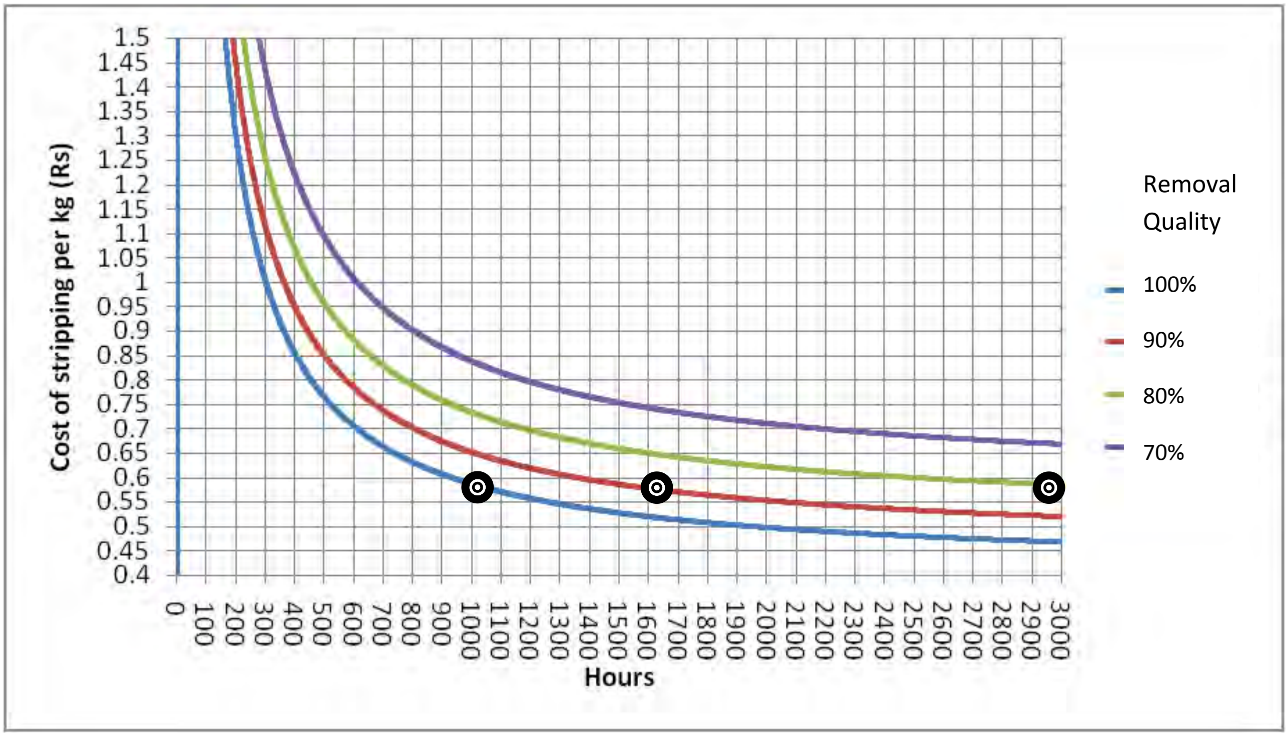
Electricity cost- Rs 6/unit

Worker cost- Rs 150/day

Rate of machine stripping- 1kg/min.

$$\text{Cost of stripping/ kg} = \frac{\text{Capital Cost + Maintenance Cost + Electricity charges + Workers charges}}{\text{Rate of stripping * No. of Hours}}$$

The following graph tells us the cost of machine stripping of 1kg of sweet sorghum plant-



Fig[11]: Cost of stripping 1kg of stock in machine vs time for machine with different leaf removal quality.

From fig it is clear that 100% effective machine will take around 1000hr before it turns profitable. 90% effective machine will take around 1600 hr and 80% effective will take around 3000 hr.

In 2015 stripping was done for about 130hr hence if we assume the same quantity of yield is harvested every year and if wages and electricity charges remain same it will take around 7.5 years before the machine turns profitable for 100% effective machine, 12.5 years for 90% effective machine and 23.5 years for 80% effective machine.

Section 6

Objective- Ideation to make machine automated

Experimental Work-

In the following table we discuss ideas for auto rotation of stalk and their advantages and disadvantages-

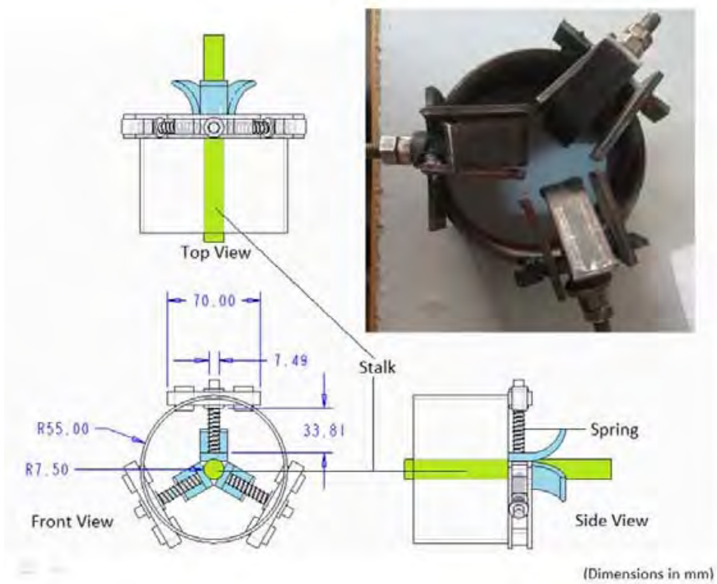
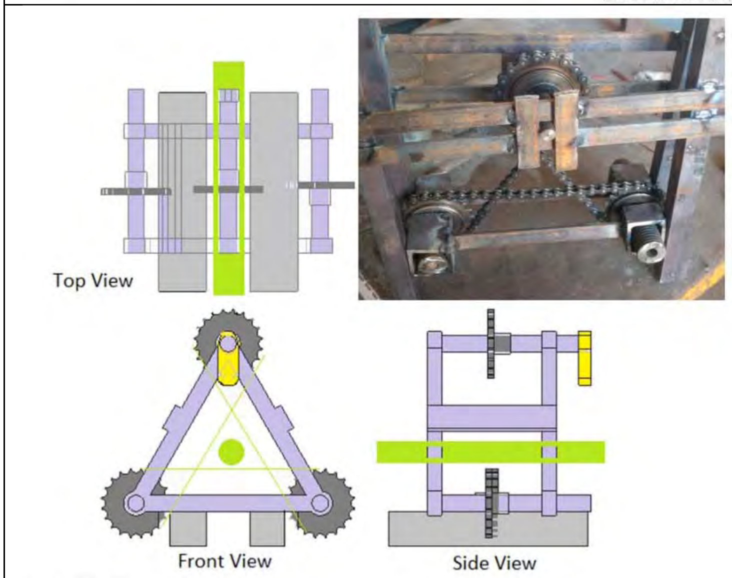
Image	Advantage	Disadvantage
	Assembly did grip the stalk at the nodes. It has potential to be used in autorotation mechanism	The stalk has to be properly guided to the entrance
	No need to force the stem inside the assembly	The mechanism didn't work as the chain didn't move Similar experiment must be tried but with a rope

Table [12]: Ideas for auto rotation

RSEULTS

- For straight stems the machine gives very good results
- For curved stems the operational speed of the machine is low, hence more time is required for leaf removal

CONCLUSION-

The machine designed and built is capable of removing leaves and sheaths from sweet sorghum plants. The quality of stalk after leaf removal is very good and most of the time there is no damage to the stem. The speed of operation by the machine is greater than that of hand stripping; however it depends on the type of stem and is better for straight stems. The syrup produced from the juice of machine-stripped stalks also passed the organoleptic taste test.

FUTURE WORK-

1. Increase the speed of operation for curved stems.
2. Make the machine automatic.

Appendix [1]: Observational data of force required to remove leaves and sheaths

Table [6]: Force required for leaf removal

Sr. No.	Force (N)
1	70
2	150
3	110
4	200
5	140
6	130
7	100
8	200
9	200
10	150
11	120
12	200
Max	200

Table [7]: Force required for wet sheath removal

Sr. No.	Force (N)
1	100
2	160
3	130
4	150
5	50
6	30
7	40
8	200
Max	200

Table [8]: Force required for dry sheath removal

Sr. No.	Force (N)

1	170
2	85
3	140
4	80
5	70
6	60
Max	170

Appendix [2]: Observation data of gap experiment

The gap between the blades and the plate plays a very important role in quality of leaf removal and damage to stem. These two parameters are noted in one table. A quality score from 1-16 is assigned to them accordingly. The following table represents the score system.

Quality of Leaf Removal → Stem damage ↓	Very good	Good	Average	Bad
No Damage	16	12	8	4
Stem bent	15	11	7	3
inside cut on the stem	14	10	6	2
outside cut on the stem	13	9	5	1

Table [9]: Quality score for different gap sizes

Sr. No.	Gap (cm)	Score
1	1	1
2	1	1
3	1	1
4	1	9
5	1	14
6	1	16
7	1.5	1
8	1.5	12
9	1.5	12
10	1.5	13
11	1.5	16

12	2	1
13	2	1
14	2	1
15	2	1
16	2	12
17	2	12
18	2	16
19	2	16
20	2	16
21	2.5	12
22	2.5	14
23	2.5	16
24	2.5	16
25	2.5	16
26	3	12
27	3	14
28	3	15
29	3	16
30	3	16
31	3	16
32	3.5	14
33	3.5	14
34	3.5	16
35	3.5	16
36	4	14
37	4	16
38	4	16
39	4	16
40	4	16
41	4	16

Appendix [3]: Observational data of comfort to the operator experiment

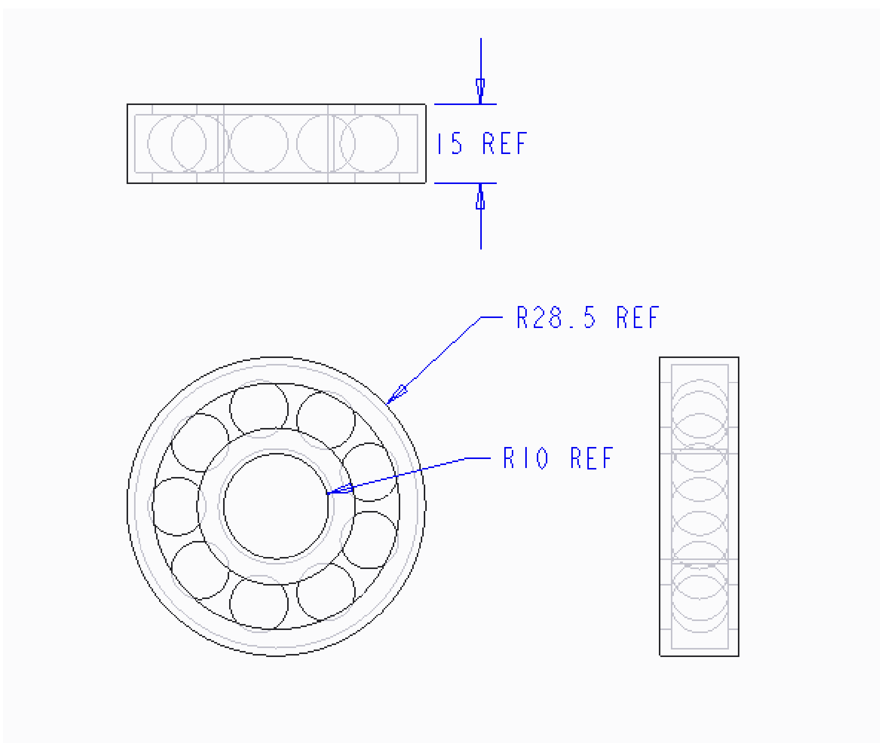
Table [10]: Effect of vibrations and pulling force experienced by the operator depending on gap size

Stem Diameter (cm)	Gap (cm)	Vibration	Pulling Force
2	2.5	L	L

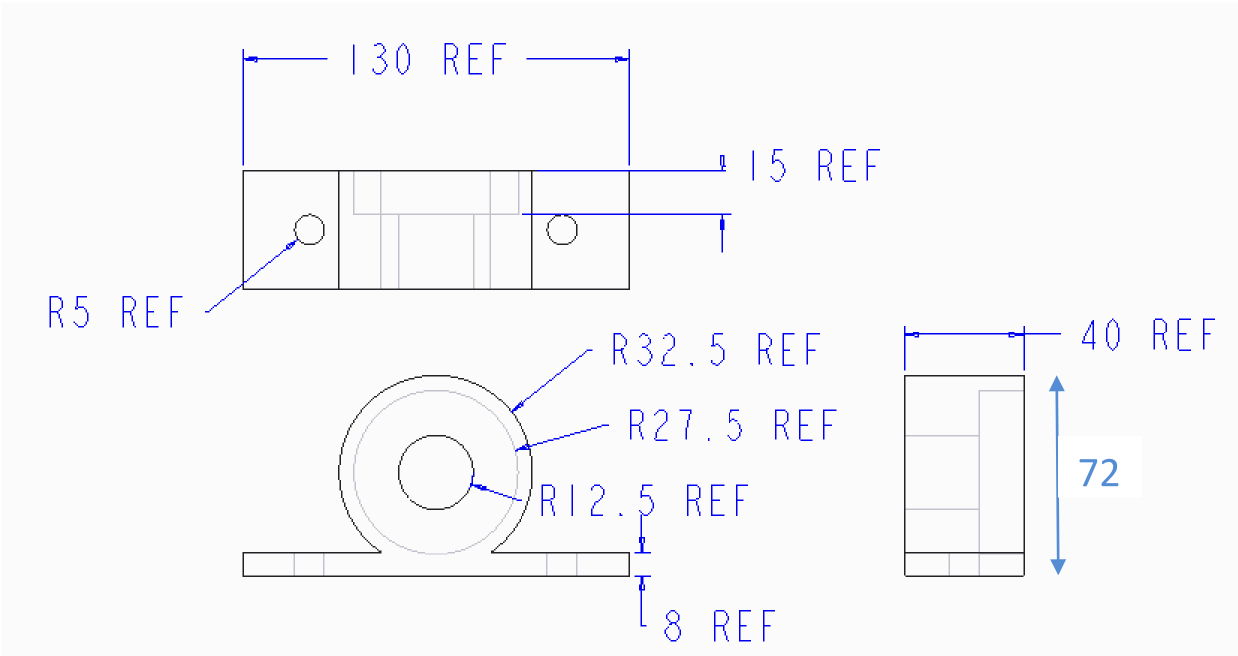
1.8	2.5	M	L
2.1*	2.5	M	H
2.5	2.5	M	M
2.6	2.5	L	L
3.1	2.5	H	H
3	2.5	H	H
2.1	3.5	L	L
2.4	3.5	L	L
2.5	3.5	L	L
2.6*	3.5	H	L
2.6	3.5	M	L
2.7*	3.5	M	L

Those mark with {*} are curved stem.

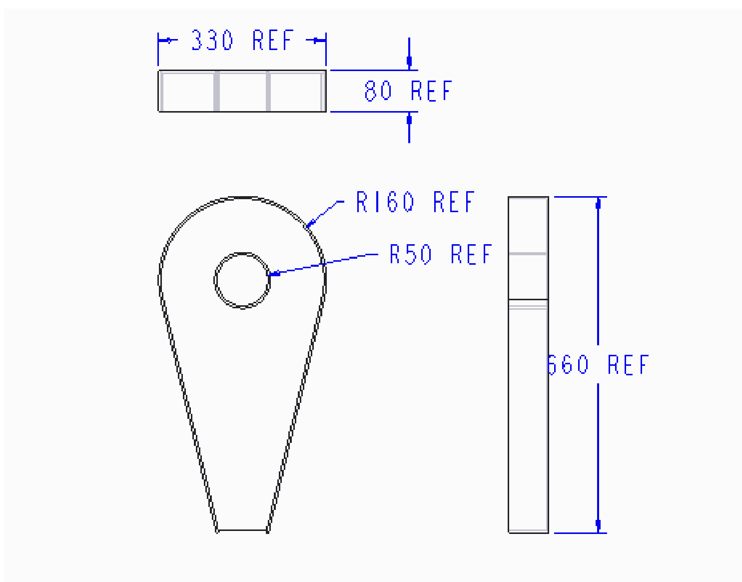
Orthogonal view of various parts-



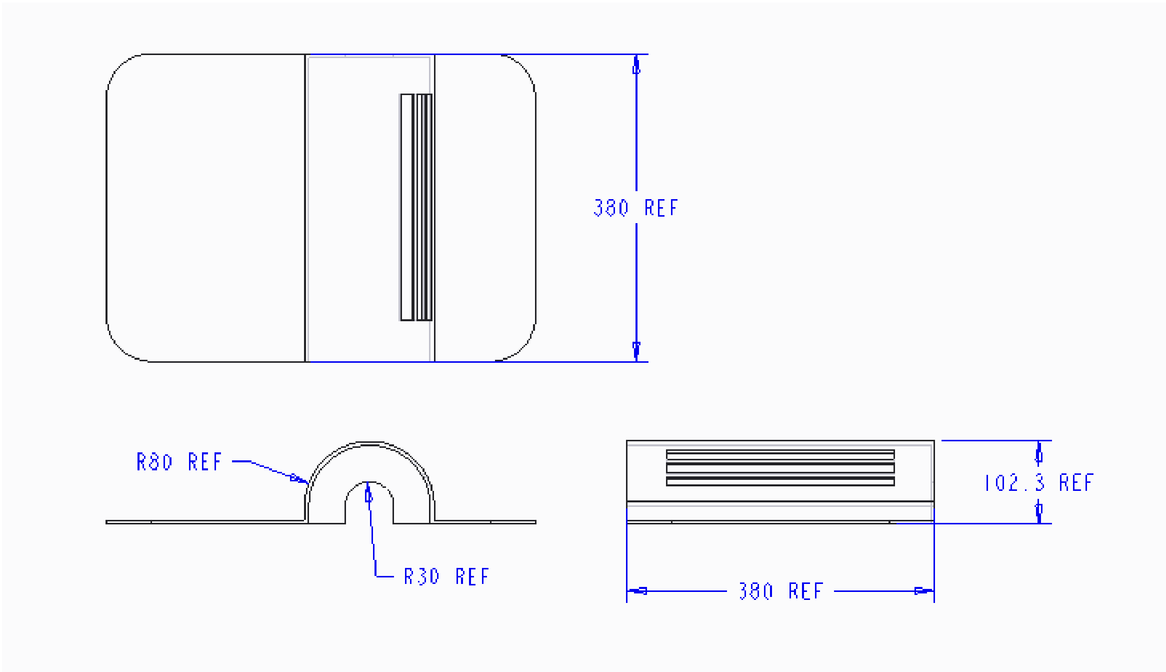
Bearing



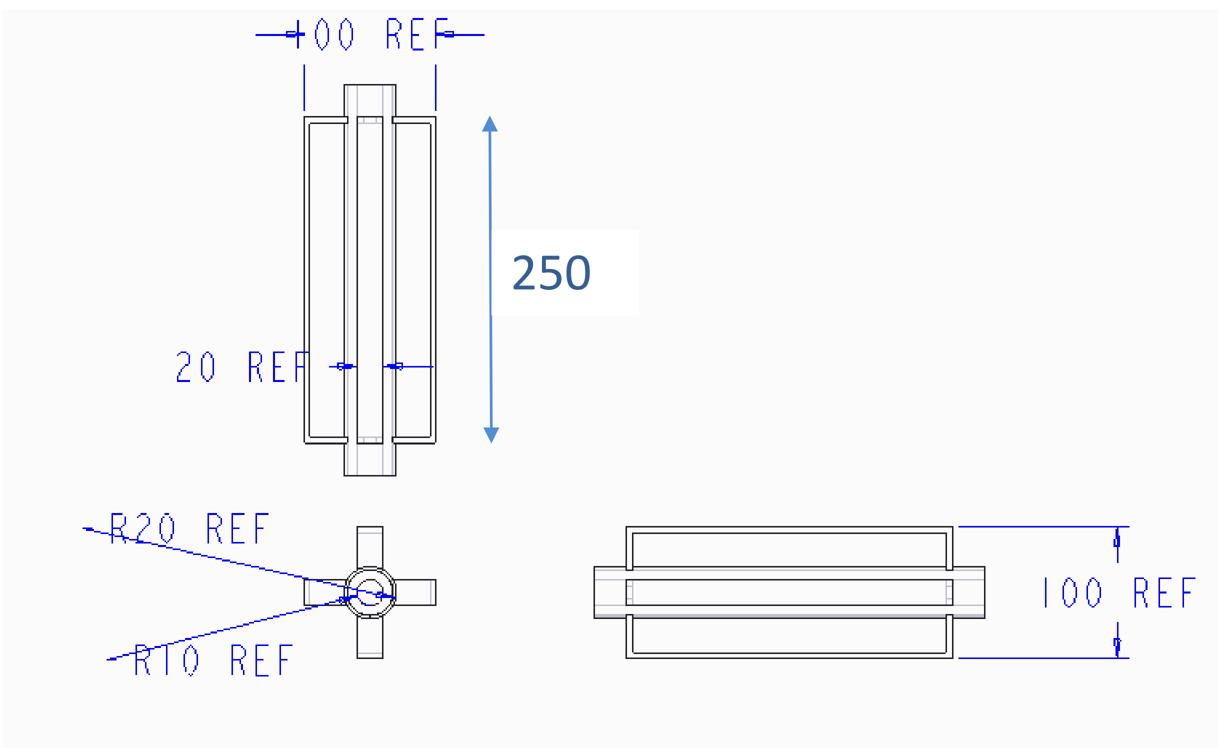
Bearing Pedal



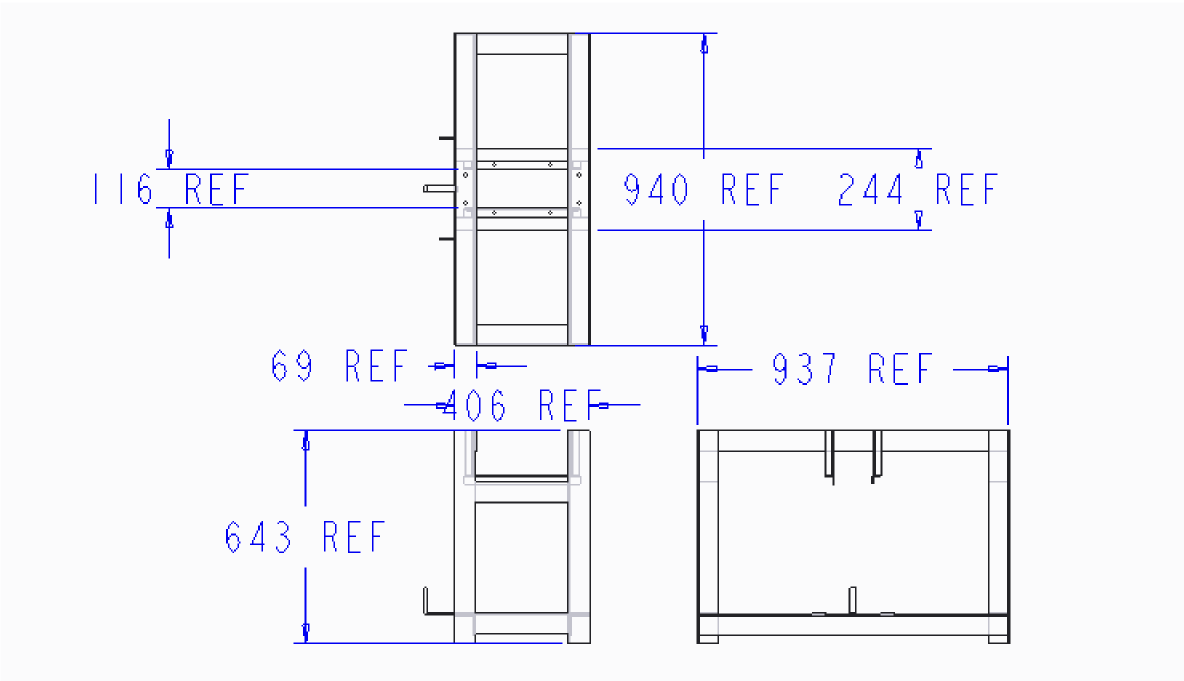
Belt covering



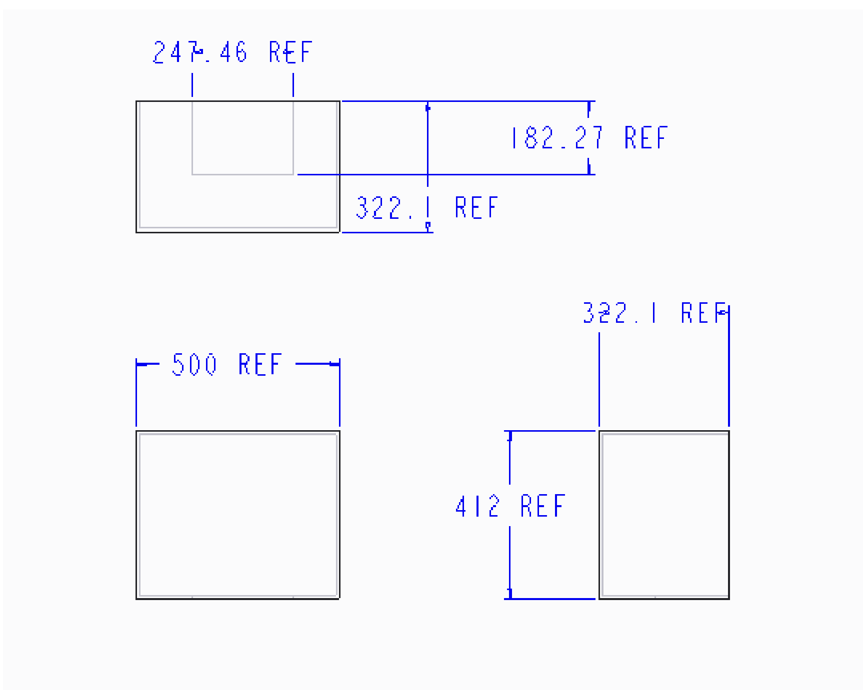
Blade coveirng



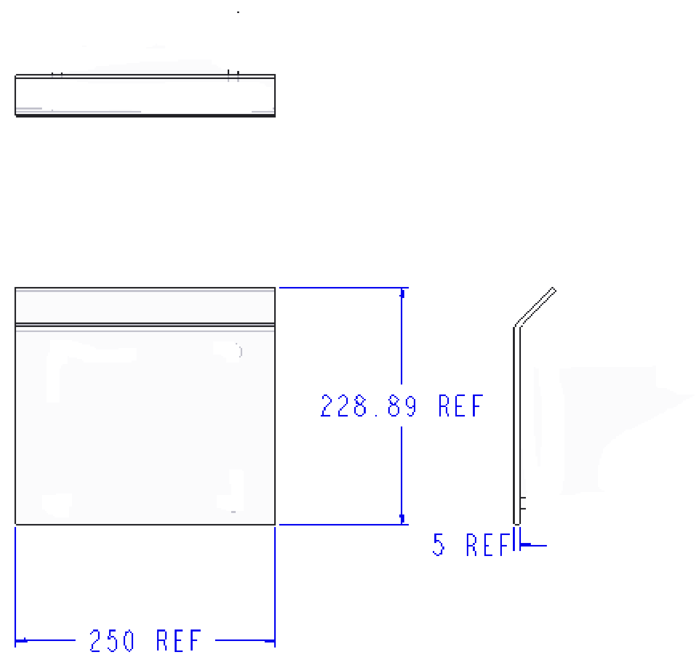
Blades



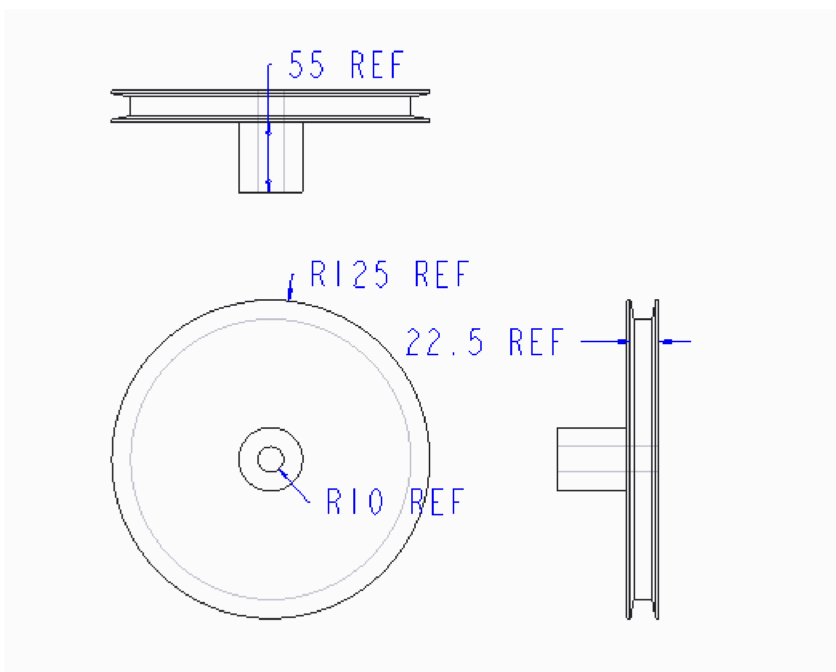
Frame



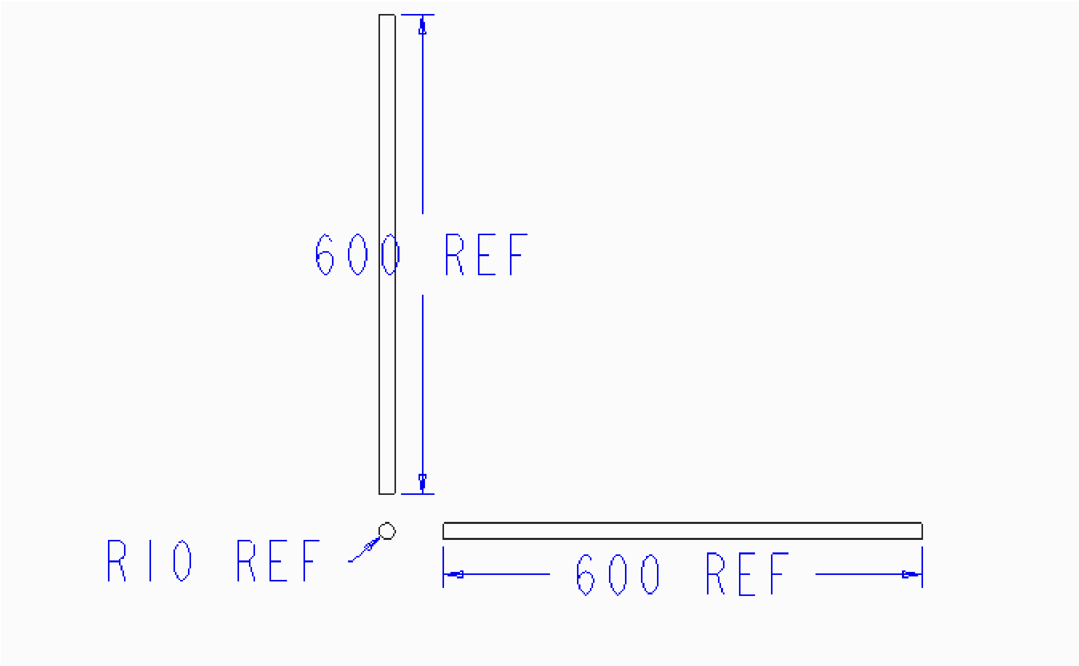
Motor covering



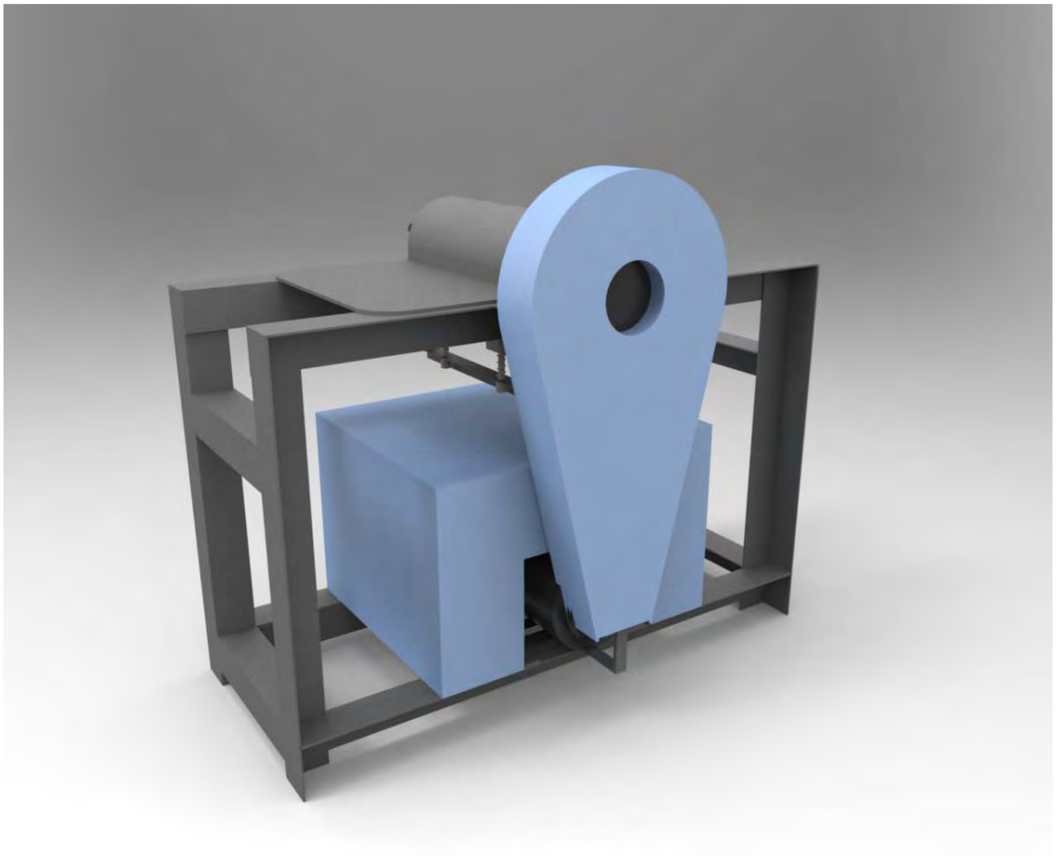
Plate



Pulley



Shaft



3d model rendered image