Materials and Methods

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the determination of various engineering properties such as physical and frictional properties of dehusked coconut as well as the procedure followed for design, fabrication and performance evaluation of dehusked coconut grader.

3.1. Plant Material

In the present investigation, coconut variety of *West Coast Tall* was obtained from Sungaramudaku village, near Pollachi, Coimbatore, Tamil Nadu. Coconuts were harvested from trees bearing 12-13 months old fruits. In order to determine the physical properties of coconut randomly 100 nuts were taken (Appendix 1). The fruits contain the nut enclosed by the husk of fibrous layers. The outer husk was removed and properties were estimated.

3.2. Fruit Characteristics

For each fruit, principle dimensions, such as length, major diameter (width) and minor diameter (thickness) were measured using a digital vernier caliper (Plate 3.1). The least count and accuracy of the Vernier caliper used for measurement was 0.01mm and ±0.05mm, respectively. The width and thickness of the coconut measured are perpendicular to each other. To obtain the mass, each fruit was weighed (w_1) with an electronic balance of ±0.01g accuracy.

Fruits were carefully opened to avoid damage of the kernel and shell (Plate 3.2). The coconut water was drained off and again the weight was measured (w_2). Thickness of both the kernel along with shell was measured using screw gauge (least count 0.01mm) (t_1). By subtracting w_1 and w_2 the amount of coconut water (w_3) present in each fruit was calculated. The wet flesh of coconut was sun dried to determine the weight of copra (w_4) (Plate 3.3 and 3.4). Coconuts were sun dried to attain a moisture content of 8% (w.b) and then shell was removed. The weight of shell of each fruit was measured (w_5). Weight of kernel (w_6) was calculated by subtracting w_2 and w_5. Thickness of the shell (t_2) was also determined using screw gauge. By subtracting the t_1 and t_2 thickness of the kernel was determined. The percentage of shell weight, wet and dry flesh weight was also calculated.

3.3. Physical Properties

The knowledge of physical properties such as size, shape, bulk density, true density and surface area helps to analyse the behaviour of dehusked coconut during handling and also for designing of grader. The methods adopted to estimate these engineering parameters are as follows.

3.3.1. Geometric mean diameter, sphericity and surface area

Geometric mean diameter (D_g), sphericity (Φ) and surface area (S) were calculated by using the following equations (Jahromi *et al.,* 2008).

$$Dg = (LWT)^{1/3} \tag{3. 1}$$

$$\Phi = D_g/L \tag{3. 2}$$

$$S = \pi D_g^2 \tag{3. 3}$$

where,

L = length of the whole fruit, mm

W = width of the whole fruit, mm

T = thickness of the whole fruit, mm

3.3.2. True density

True density of dehusked coconut was determined by water displacement method (Mohsenin, 1986) in a graduated cylinder.

$$True\,volume = \frac{Mass\ of\ displaced\ water\,(kg)}{Density\ of\ water\,(kg/m^3)} \tag{3.4}$$

By knowing the mass of dehusked coconut and the true volume, the true density was obtained as follows:

$$\rho_t = \frac{W_a}{V_a} \tag{3.5}$$

where

ρ_t = true density of dehusked coconut, kg/m^3

W_a = mass of dehusked coconut, kg

V_a = true volume of dehusked coconut, m^3

3.3.3. Bulk density

The bulk density was determined using the relationship between mass and volume (Mohsenin, 1986) by filling an empty container of predetermined volume with coconuts. Bulk density was calculated using the following equation

$$\rho_b = \frac{M}{V} \quad (3.6)$$

where,

ρ_b = bulk density, kg/m^3

M = Mass of the sample, kg

V = volume of the container, m^3

3.4. Frictional Properties

Frictional properties such as angle of repose and coefficient of friction were studied to understand how smooth the dehusked coconut moves over selected surfaces**.**

3.4.1. Coefficient of friction

The experimental apparatus used for the friction studies was similar to that reported by Kaleemullah and Kailappan (2003) for chillies. The apparatus consisted of a frictionless pulley fitted on a frame, a cylinder open on both sides of dimension 150mm x 190mm, loading pan and test surfaces. The cylinder was connected by means of a string, parallel to the surface of the material and passed over a frictionless pulley with a pan hanging from it. The cylinder placed on the test surface was filled with a dehusked coconut and weights were added to the loading pan until the cylinder began to slide. The mass of dehusked coconut and the added weight represents the normal force and frictional force, respectively. The co-efficient of static friction was calculated as the ratio of frictional force to the normal force given as,

$$\mu = \frac{F}{N_f} \tag{3. 7}$$

Where,

μ = co-efficient of friction

F = frictional force, kg

N_f = normal force, kg

The experiment was performed using test surfaces of cardboard, galvanized iron, aluminium and stainless steel sheets. Experiments were repeated three times by emptying and refilling with 10 different coconuts in the container every time and the average value was reported.

3.5. Analysis of Data

To calculate the analysis of variance between the different grades of dehusked coconut, , were taken. To achieve this SPSS-15 software was used.

3.5.1. Principal component analysis (PCA)

The major concern to use PCA is to reduce dimensionality and to achieve the least possible number of components which governs original variation of multivariate data. Among the dependent variables PCA identifies the pattern of correlations, then it substitute a new variable called as ‘factor’ for group of correlated original characteristics. Based on the residual variance, the second and third group are identified with derivation of factors. To carry out principal component analysis Minitab 17 software was used.

3.6. Grading of Coconuts

Correlation between the different attributes of dehusked coconut were evaluated using principal component analysis (as shown is section 4.5) and based on the studies conducted, the dehusked coconut can be graded according to its size as well as weight. Hence it was decided to fabricate a lab scale grading machine for dehusked coconut based on size (size grader) and from each outlets of size grader the nuts has to be graded according to its weight (weight grader).

Generally coconuts meant for copra making which are sold in local markets are fully husked and coconuts meant for distant market places are left with some fibres covering the eyes or on all around nuts (semi dehusked). Therefore, bearing in mind the need of local and distant market, the grading machine has to be developed considering both semi dehusked and fully dehusked coconuts.

The following parameters were considered to design and develop the coconut grader based on the size: 1) Major diameter of the dehusked coconut 2) grading mechanism had to convey the fruit steadily to the sizing board and uniformly release the graded fruit in the proper receiving tray 3) the machine should be simple, compact and transportable. After a detailed review of literatures, it was found that the belt conveyor system consist of tapered bed suits best for grading dehusked coconuts because each fruit is brought into contact with belt and a grading board though gravitational and tangential force. Fig. 3.1 shows the side view of the tapered bed type belt conveyor system.

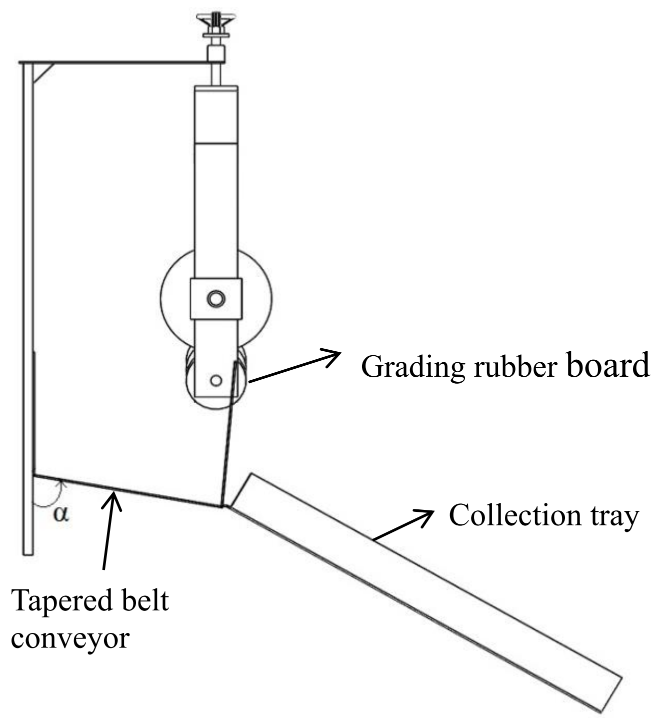


Fig. 3.1. Design concept of the dehusked coconut grading machine showing the inclination angle and the side view of the grading configuration

3.7. Description of an Existing Grading Machine

The existing grading machine consists of the following components: 1. Step metering aperture 1.a) cylindrical rubber board 1.b) connecting rods 1.c) rubber roller 1.d) helical compression spring 2. Belt conveyor system 3. Belt guide plates.

3.7.1. Step metering aperture

Connecting rods of length 150 mm was connected on both sides of the cylindrical rubber board of 500 mm length and 60 mm diameter. Helical compression spring of pitch 5.5 mm was fixed in the connecting rod with the main frame which helps to adjust the metering aperture.

There are four rubber rollers of each 75 mm length and the diameter of 100 mm, 90 mm, 80 mm and 70 mm were fixed on a one inch rod of 3000 mm length at the interval of 500 mm. It was then fixed to the main frame with connecting rods of length 150 mm such a way that it rest at the center of the cylindrical rubber board. The step metering gap is characterised by increasing aperture of 10 mm, to maximum diameter of the dehusked coconut. The opening of first collection unit was 80 mm by 500 mm, second unit was 90 mm by 500 mm and so on. The aperture profile of belt is shown in Fig 3.2. The chain drive was used for power transmission from the motor to the step metering aperture. The rubber roller acts as a drive pulley which enables to rotate cylindrical rubber board.

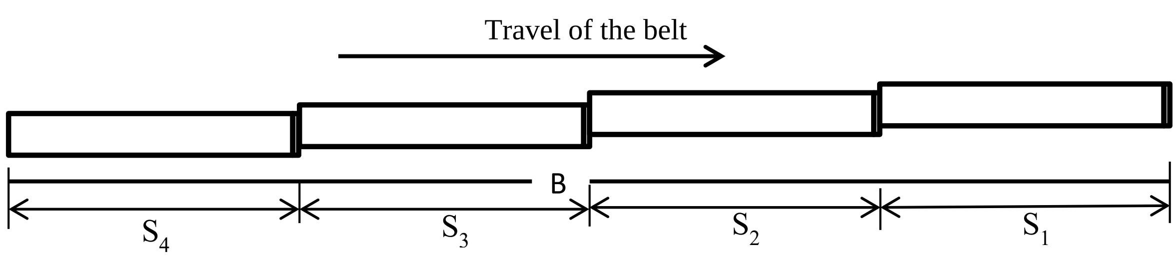


Fig. 3.2. Aperture profile of the belt (S_1 = grading length of first grade, S_2 = grading length of second grade, S_3 = grading length of third grade, S_4 = grading length of fourth grade, B_L = belt length

3.7.2. Belt conveyor

The belt width of 125 mm was used to convey each fruit in to the grading aperture. The belt was mounted on a tapered stainless sheet fixed on the main frame.

3.7.3. Belt guide plates

The belt has to be moved throughout the length of the conveyor without any change in the alignment. Moreover, to avoid any jump, guide plates were given at the bottom of the tight side of belt. The guide plate was made of steel rods.

3.7.4. Length of the conveying section

The total length of the conveying section was calculated based on the feeding section, grading section and length of rollers.

$$L_c = L_F + L_G + L_R + allowance \qquad (3.8)$$

Where L denotes length and the subscript C: conveying section, F: feeding section, G: grading section, R: length of rollers.

The length of feeding section was fixed as 600 mm to ensure that each fruit comes in contact with the metering aperture. In the grading section, five numbers of outlets were given in order to separate the dehusked coconut into five different grades. The width of the each metering aperture was 500 mm and clearance was fixed as100 mm. The total length of the separation section was 2600 mm and the length of the rollers was 440 mm.

$$L_C = 600 + 2600 + (2 * 440)$$

$$= 4080\ mm$$

3.8. Design of Various Components of Size Grading Machine

3.8.1. Design of shaft

Diameter of the shaft was determined by estimating bending moment of the shaft.

3.8.1.1. Bending Moment on the Shaft

Total weight of the dehusked coconut present in the conveying section at any point of time during operation was determined and found to be 5.028 kg (10 nuts).

Assume the fore mentioned load is acting on a shaft of the conveying section as uniformly distributed load. Assume factor of safety value as 2 to overcome any unexpected overfeeding into the unit, *i.e* 5.028 x 2 = 10.056 kg. Therefore, maximum weight of conveyor section at any point is

= Total weight of dehusked coconut + weight of roller

= 10.056 + 4

= 14.056 kg

The maximum bending moment is acting in the shaft and was calculated by the formula given by Khurmi and Gupta (2010).

$$M_{max} = \frac{WL}{8} \tag{3.9}$$

W = weight on unit length of the shaft, roller and belt, kg

L = length of the shaft, cm

Maximum bending moment $= \frac{30 \times 20}{8}$

$$M_{max} = 600 \text{ kg.cm}$$

We know that

$$\frac{M}{I} = \frac{\sigma_b}{y} \tag{3.10}$$

where,

M = Maximum bending moment, kg-cm

I = moment of inertia, $\pi d^4/64$

σ_b =permissible bending stress on MS shaft, 1150 kg/cm^2

y = Distance between the outer most layer and neutral axis, cm

$$\frac{600}{3.14 \times \frac{d^4}{64}} = \frac{1150}{d/2}$$

$$d = 1.75 \ cm$$

Therefore considering the above design, standard shaft size of 2.54 cm which is available in the market was used for fabrication.

3.8.1.2. Torque Transmitted to the Roller

The torque transmitted to the major roller by belt- pulley drive was calculated by the following formula (Khurmi and Gupta, 2010) as

$$T_{tt} = (T_1 - T_2)R \tag{3.11}$$

where,

T_{tt} = torque transmitted, Nm

T_1 = tension in the tight side of the belt, N

T_2 = tension in the slack side of the belt, N

R = radius of the test pulley, m

The tension act on the tight side of the belt can be calculated by,

$$T_1 = T - T_c \tag{3.12}$$

where,

T = maximum tension in the belt, N

T_C = centrifugal tension in the belt, N

and maximum tension in the belt can be found by the formula,

$$T = \sigma \times a \tag{3.13}$$

where,

σ = permissible shear stress of the belt material, 2.5 MPa = 2.5 x 10^6 N/m^2

a = cross sectional area of the belt,

$$a = b.t \tag{3.14}$$

where,

b = width of the belt (125mm)

t = thickness of the belt (2mm)

Hence, a = 0.00025 m^2

We know that mass the of belt per meter length,

$$m = a \times l \times \rho \qquad (3.15)$$

where,

a = cross sectional area of the belt, m^2

l = unit length of belt, m

ρ = density of belt material, kg/m^3= 1140 kg/m^3 (Khurmi and Gupta, 2010)

Therefore $m = 0.00025\ x\ 1\ x\ 1140$

$= 0.285\ kg/m$

The velocity of belt can be found by using the following expression,

$$v = \frac{\pi d N}{60} \qquad (3.16)$$

where,

d = diameter of the available driving pulley, m

N = max. speed of the driving pulley, rpm = 200 rpm (output of the 1: 40 gear reduction box)

Therefore,

$$v = \frac{\pi \times 0.162\ \times 200}{60} = 1.69\ \mathrm{m/s}$$

The centrifugal tension in the belt can be calculated,

$$T_c = mv^2 \qquad (3.17)$$

where

m = mass of the belt per metre length, kg/m

v = velocity of the belt, m/s

hence centrifugal tension in the belt, is

$$T_C = 0.8139\ N$$

The maximum tension in the belt can be found by the formula

$$T = 2.5 \times 10^6 \times 0.00025$$

$$= 625\ N$$

Therefore tension in the tight side of the belt is,

$$T_1 = 625 - 0.8139$$

$$= 624.1861\ N$$

The tension on the slack side of the pulley can be found by the expression 3.17, in which μ,θ and α are calculated by equation 3.18, 3.19 and 3.20, respectively

$$2.3\ log\left(\frac{T_1}{T_2}\right) = \mu.\theta \tag{3.18}$$

$$\mu = 0.54 - \frac{42.6}{152.6 + v} \tag{3.19}$$

$$\theta = (180 - \alpha)\left(\frac{\pi}{180}\right) rad \tag{3.20}$$

$$sin\ \alpha = \frac{d_1 - d_2}{2x} \tag{3.21}$$

where,

μ = co-efficient of the belt friction

α = angle of contact of belt with the pulley, degree

v = velocity of the belt, m/s

d_1, d_2 = diameter of the driving and driven pulley respectively, cm

Using the eq. 3.20, $\mu = 0.26$. The diameter of the two pulley are same. Hence $\alpha = 0$, therefore $\theta = 3.14$.

By substituting θ and μ in eq. 3.17, we get

$$2.3 \log\left(\frac{T_1}{T_2}\right) = 0.8283$$

$$T_2 = 272.451 \text{ N}$$

Hence, torque transmitted $= (T_1 - T_2)\, R$

$= 28.490$ Nm

3.8.2. Design of bearing

Let as assume the life of bearing (L_H) as 12,500 hours. Life of bearing in revolutions was calculated by the following formula given by Khurmi and Gupta (2010).

$$L = 60 \times N \times L_H \qquad (3.22)$$

where

L = Life of bearing, revolutions

N = number of revolutions of bearing

L_H = useful life of bearing, h

Therefore, $L = 60\ x\ 200\ x\ 12{,}500$

$= 1.5 \text{ x } 10^8$ revolutions

The loading ratio of bearing was calculated based on the following formula given by Khurmi and Gupta (2010)

$$\frac{C}{P} = \left(\frac{L}{10^6}\right)^{\frac{1}{K}} \qquad (3.23)$$

where

$\frac{C}{P}$	= loading ratio
C	= basic dynamic load rating, N
P	= equivalent dynamic load rating, N
L	= life of bearing in revolution per minute
K	= a constant (3 for ball bearing)

Therefore,

$$\frac{C}{P} = \left(\frac{1.5 \text{ x } 10^8}{10^6}\right)^{\frac{1}{3}} = 5.3$$

Based on the above calculations of loading ratio and shaft diameter, T 205 bearing with 25mm diameter was found suitable and was used in the machine fabrication.

3.8.3. Power requirement

The following formula was used to calculate the power required for the main shaft to rotate:

Power transmitted = $(T_1 - T_2)v$

= (624.186 – 272.451)1.69

= 594.432 W or 0.8 hp

Hence**,** in the present study, a one hp motor is used for power transmission. On one end of the main frame, motor was mounted. A gear reduction box was fixed to reduce the speed of the motor in the ratio of 1: 40.

3.9. Modified Size Grader

Size grader for dehusked coconut was developed with the working principle of gravitational and tangential forces. The front, side and isometric view of the size grader is shown in Fig. 3.3. (a), 3.3.(b) and 3.3.(c), respectevily.

3.9.1. Main frame

All the frames were made of MS square pipe (1" x 1"). The whole conveyor system was assembled in main frame. The height of the belt conveyor from the ground level was fixed as 3 feet for easy feeding of dehusked coconut. The total length of the main frame was fixed as 11 feet and width of 1.5 feet.

3.9.2. Feeding unit

The feeding unit consist of 52cm length, 45 cm width and 12cm height and made of mild steel. To allow single nut in the grading belt the feeding unit was extended for 60 cm length converging to 15cm at the slope of 10^o.

3.9.3. Fabrication of side rollers

A flat plate of 0.2cm thick, 44cm length and 18cm width was fixed with a square rod of 1cm thick. The flat plate was drilled at the center for 3cm length and width of 5cm, such that 2.5cm shaft passes through it. A T 205 bearing attached to the square rod was able to slide over, with the 6inch screw. Same way another flat plate was also constructed and both the plates were attached to a 2.5mm thick roller of length 140mm, projected edges of 5mm and fixed with 2.5cm dia shaft. The 6 inch screw attached to the bearing was able to move the shaft back and fourth. The tension ratio of the inclined grading belt which passes over the rollers can be adjusted by adjustable bearing fixed with screw. The schematic diagram of side roller is given in Fig.3.4.

3.9.4. Grading gap width

To estimate the diameter of separation between dehusked coconut of adjacent grades from the mean and the standard deviation of each adjacent grade was suggested by Peleg, 1985 and was used, as given below.

$$X_{12} = \left[\frac{\mu_2\sigma_1^2 - \mu_1\sigma_2^2}{\sigma_1^2 - \sigma_2^2}\right] \pm \left[\left(\frac{\mu_2\sigma_1^2 - \mu_1\sigma_2^2}{\sigma_1^2 - \sigma_2^2}\right)^2 - \frac{\mu_2^2\sigma_1^2 - \mu_1^2\sigma_2^2 - 2\sigma_1^2\sigma_2^2 ln\left(\frac{\sigma_1}{\sigma_2}\right)}{\sigma_1^2 - \sigma_2^2}\right]^{\frac{1}{2}} \quad (3.24)$$

where

X_{12} = grading gap width at the separation point between dehusked coconut size 1 and size 2;

μ_1 and μ_2 = mean diameter of dehusked coconut size 1 and 2;

σ_1 *and* σ_2 = standard deviation of dehusked coconut size 1 and 2.

3.9.4.1. Supporting Sheet and Step Metering Aperture

During preliminary experiments, it was found that fully dehusked coconut passes through the aperture easily whereas semi dehusked coconut got struck in between the metering aperture and the supporting sheet. It was noted that the rotating cylindrical rubber roller draws the semi dehusked nut towards the aperture and get struck. Further it was found that the supporting sheet of belt conveyor was a hindrance for the easy discharge of semi dehusked coconut. To overcome these problems, it was decided to stop drive given to cylindrical rubber roller and keep it as idle and also the width of the supporting sheet was reduced to 13cm. This helped semi dehusked coconut to go through the aperture easily and thereby improved the separation efficiency.

3.10. Development of Size Grader for Dehusked Coconut

The fruit grader was modified and developed as per the design discussed and the front view of the developed size grader is shown in Plate 3.5.

3.10.1. Principle of operation of the machine

The basis of design is characterized by a tapered belt conveyor and grading board with openings of increasing size arranged along the periphery of the belt conveyor. Dehusked coconuts are fed onto the tapered belt conveyor where the gravitational force moves the fruit towards the periphery until it comes in contact with grading board. Due to the tangential force, the fruit reels along the grading board, where they are sized and allowed to drop through aperture according to their dimensions.

3.10.2. Factors affecting the grading efficiency of the machine

A proper interaction of dehusked coconut with the sizing board is required for achieving maximum grading efficiency. Hence certain essential parameters were considered for optimization in order to get maximum efficiency.

The inclination angle causes two point contacts, for every dehusked coconut with the sizing board. Thus every fruit is measured at its major diameter. When the inclination angle (α) is too large the dehusked coconut falls and does not symmetrically lie on the belt and therefore the major diameter is not measured. If α is too small, the major diameter of the coconut might stay at the rim of sizing board, and diameter measurement does not occur. Hence, it was decided to test the performance of the sizing machine based on its grading efficiency with small deviation in inclination angle of the belt along the length viz., 10^o, 15^o and 20^o.

Based on the preliminary study, it was decided to operate the belt speed in the range of 1.3 rpm to 2.1 rpm. Hence, five different belt speed of 1.3, 1.5, 1.7, 1.9 and 2.1 m/s were selected in combination with inclination angle of the belt.

Totally, 15 treatments were formulated and their performances were statistically analysed for determining the influence of factors on the grading efficiency.

3.10.3. Experimental design

A two factorial completely randomized block design was adopted to conduct performance tests and three replications were made on each treatment.

S.No.	Independent variables	Levels
1.	Belt speed (m/s)	1.3, 1.5, 1.7, 1.9 and 2.1
2.	Inclination angle of the belt (degree)	10^o,15^o and 20^o

Dependent variables

1. Mean contamination ratio or error ($\bar{C}_R$),
2. Grading efficiency (E_W)
3. Throughput capacity (Q)

3.10.4. Performance test

For the determination of optimum working conditions, coconuts of 12-13 months old were harvested with the help of experienced farmers and the outer husk was removed.

Damage free dehusked coconut was selected using an iron rings made of different diameter as shown in the Plate 3.6. There were twenty sample fruits of partially and fully dehusked coconuts of each size (five sizes: very small, small, medium, large and extra-large) were collected. The Plate 3.7 shows the view of semi and fully dehusked coconut used in the analysis. The maximum diameter of each sample is measured with a vernier calliper to determine the performance of grading machine.

3.10.5. Determination of mean contamination ratio or error, grading efficiency and throughput capacity

The following equations suggested by Peleg (1985) was used to determine mean contamination ratio, grading efficiency and throughput capacity of the developed machine.

$$\bar{C}_R = \frac{\sum N_{ij}}{\sum N_i} \tag{3.25}$$

$$E_W = \sum \frac{\left(P_{gi} W_i G_i\right)}{(Q P_i)} \tag{3.26}$$

$$Q = \frac{w_t}{t} \tag{3.27}$$

Where

$$P_{gi} = \frac{N_{gi}}{N_{ti}}$$

$$W_i = \frac{K_i P_i}{\sum K_i P_i}$$

$$G_i = \frac{w_i}{t}$$

$$P_i = \frac{N_i}{\sum N_i}$$

$$N_{ti} = N_{gi} + N_{ij}$$

in which

E_W = grading efficiency (%)

Q = inflow rate of dehusked coconut (kg/h)

N_{ij} = number of size i dropping into receiving tray size *j*

Ni = number of dehusked coconut size *i* inputing to the grading machine

$\sum N_i$ = total number of dehusked coconut inputing to the grading machine

P_{gi} = fraction of fruit size i to total fruit dropping into receiving tray size *i*

N_{gi} = number of size i dropping correctly into receiving tray size *i*

N_{ti} = total number of fruit dropping into receiving tray size *i*

W_i = weighted function

K_i = relative value fraction of grade i

P_i = fraction of size *i* to total fruit at the beginning of grading

G_i = outflow rate of dehusked coconut size *i* (kg/h)

w_i = total weight of dehusked coconut fruit in receiving tray size i

w_t = total weight of dehusked coconut corresponding to $\sum N_i$ and

t = grading time.

3.11. Design of Major Components of Weight Grader

3.11.1. Design of shaft

Diameter of the shaft was determined as detailed below

3.11.1.1. Bending Moment on the Shaft

Total weight of the dehusked coconut present in the carrier cups at any point of time was determined and found to be 3.6 kg (Assume average weight of dehusked coconut as 500 g in each carrier cup). Let us assume a factor of safety value of 2 to overcome any unexpected overfeeding into the unit, then 3.6 x 2 = 7.2 kg. Therefore, maximum weight in the carrier cup unit mechanism at any point of time is

= Total weight of dehusked coconut + weight of six carrier cups + weight of rotating frame

= 7.2 + 20 + 6 = 27.2 kg

~ 35 kg

∴ total vertical load acting on the shaft, W = 35 kg

Let us assume that this load is acting over a span length of 100 cm shaft as uniformly distributed load. Since the pulley is mounted at the middle of the shaft, the maximum bending moment occurs at the center of the shaft and was calculated as (Khurmi and Gupta, 2010)

$$M_{max} = \frac{WL}{4} \tag{3.28}$$

$$M_{max} = \frac{35 \times 100}{4} = 875 \text{ kg} - \text{cm}$$

We know that

$$\frac{M}{I} = \frac{\sigma_b}{y} \tag{3.29}$$

where,

M = Maximum bending moment, kg-cm

I = moment of inertia,

$$I = \frac{\pi}{64}[(d_o)^4 - (d_i)^4]$$

$$I = \frac{\pi}{64}(d_o)^4(1 - k^4) \quad \text{(Assume k = 0.8)} \tag{3.30}$$

k = Ratio of inner diameter to outer diameter

$$k = \frac{d_i}{d_o} \tag{3.31}$$

(where d_i = inner diameter, d_o = outer diameter)

σ_b = permissible bending moment on MS shaft, 1150 kg/cm^2

y = Distance between the outer most layer and neutral axis, cm, $\frac{d_o}{2}$

$$\frac{875}{\frac{\pi}{64}(d_o)^4(1 - 0.8^4)} = \frac{1150}{d_o/2}$$

$$d_o = 2.5 \text{ cm}$$

Substituting k in Eq. 3.31 we get

$$d_i = 2 \text{ cm}$$

In the present design, standard shaft with outer diameter of 5 cm and inner diameter of 4 cm is used and is safe as for as maximum bending moment is concerned.

3.11.1.2. Torsional Moment of the Shaft

Torque required to rotate the base attachment of carrier cup mechanism, while carrying the dehusked coconuts is.

$$T = W \times R \qquad (3.31)$$

where,

T = Torque required to rotate the carrier cups, kg.cm

W = weight added to the loading pan during torque testing, kg

R = radius of the pulley

$$T = 30 \text{ x } 7.62 = 228.6 \text{ kg.cm}$$

As per the torque equation, (Khurmi, 2010)

$$\frac{\tau}{r} = \frac{T}{J} \qquad (3.32)$$

where,

τ = maximum permissible shear stress in the shaft, 428 kg/cm^2

r = radius of the shaft, ${d_o}/{2}$

T = twisting moment

J = polar moment of inertia, $J = \frac{\pi}{32}(d_o)^4(1 - k^4)$

Substituting the values we get,

$$T = \frac{\pi}{16} \times \tau(d_o^3)(1 - k^4)$$

$$228 = \frac{3.14}{16} \times 428(d_o^3)(1 - (0.5)^4)$$

$d_o = 1.42$cm $\sim 1.5cm$ i.e. outer diameter of the shaft

In the design of shaft outer diameter of 50mm was adopted, which will be safe as for as twisting moment is concerned. From the above calculations, it is clear that the shaft of outer diameter 50mm and inner diameter 40mm is safe while considering both bending and twisting moment induced in the unit during operation.

3.11.2. Design of bearing

Useful life of bearing (L_H) was assumed as 12,500 hrs and life of the bearing in revolution was calculated by the following formula given by Khurmi and Gupta (2010).

$$L = 60 \times N \times L_H \tag{3.33}$$

where,

L = life of bearing , revolutions

N = number of revolutions of bearing

L_H = useful life of bearing, h

$$\therefore L = 60 \times 10 \times 12{,}500$$

$$= 7.5\ x\ 10^6\ revolution$$

The loading ratio of bearing was calculated as mentioned by Khurmi and Gupta (2010).

$$\frac{C}{P} = \left(\frac{L}{10^6}\right)^{\frac{1}{K}} \tag{3.34}$$

where

$\frac{\mathrm{C}}{\mathrm{P}}$ = loading ratio

C = basic dynamic load rating, N

P = equivalent dynamic load rating, N

L = life of bearing in revolution per minute

K = constant (3 for ball bearing)

$$\therefore \frac{C}{P} = \left(\frac{7.5 \times 10^6}{10^6}\right)^{\frac{1}{3}}$$

$$\frac{C}{P} = 1.95$$

3.11.3. Carrier cup mechanism

The carrier cup mechanism is the important feature, for the successful operation of the weight grader and it consist of a base, weight balance, balancing plate. The main parts of carrier cup mechanism are shown in Fig. 3.5.

3.11.3.1. Base

The base was made of 5 mm thick mild steel flat plate. The total height of the base was 160 mm (Fig. 3.5 (a)). Over the length of the base 160 mm length and 60mm height MS flat plate was welded horizontally at the center. A tongue like structure with 60 mm length and 60 mm height was attached to the centre of the base to tilt the carrier cup. Beneath the tongue like structure a projection is given to connect balancing plate with link.

3.11.3.2. Weight Balance

The MS flat plate was cut into 110 mm x 100 mm square plate. One end of the plate was fixed with a 25 mm length flat to which a known weight is added. The total weight of carrier cup mechanism was found to be 1500 g therefore a known weight of 1500 g was added to balance the weight on both sides (Fig. 3.5.(b)). This helps to bring back the carrier cup to the original position after it discharged the dehusked coconut in the particular grade. The other end of the plate was connected with the balancing plate.

3.11.3.3. Balancing Plate

A flat plate of 3 mm thick was made into 100 x 130 mm^2 rectangle plate. The carrier cup was attached at the top edge of the plate with steel rods. At the bottom of the plate, a projection of 15 x 10 mm was provided to attach the 4^{th} link of the parallel linkage mechanism with the base. At the edge of the flat plate (pointer) of 80 mm length was attached. This pointer is supported on the guide rail Fig.3.5. (c).

3.11.3.4. Carrier Cup

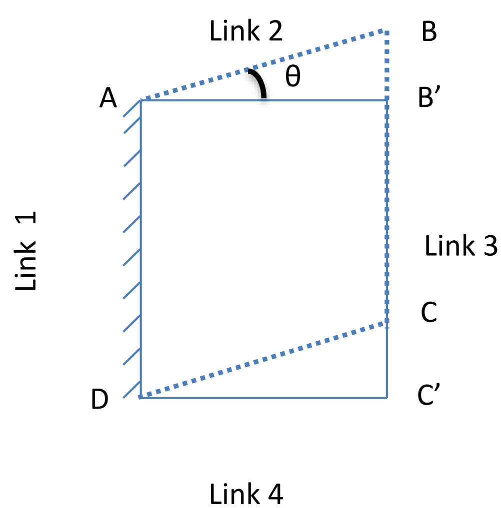
The cups to carry the dehusked coconut to be graded were selected based on the dimensions of coconut. Two different types of cups were selected for the study. The selected carrier cups were fitted on the iron steel rods of the balancing rod such a way that when the cup is poked at the bottom it tilts freely.

3.11.3.5. Kinematic Links

The binary joints in this mechanism are shown in Fig. 3.6; A. top of the base with the weight balance constitute one link; B. weight balance with balancing rod constitute second link; C. balancing rod with connecting rod constitute third link D. balancing rod with the bottom of the base constitute the fourth link.

3.11.3.6. Four Bar Linkage

The initial position of the mechanism is shown in Fig. 3.6 by dotted lines whereas the full lines shows the position of mechanism when the cup is tilted.



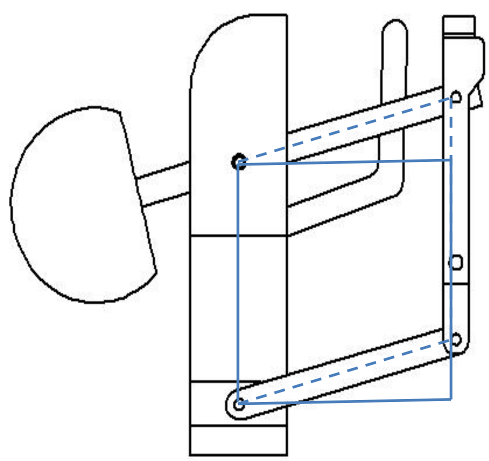


Fig. 3.6 Arrangement of four links

In the design, one of the most important concern is that the number of degrees of freedom (also called movability) of the mechanism. It is defined as the number of input parameters (usually pair variables) which must be independently controlled in order to bring the mechanism into a useful engineering purpose.

The number of degrees of freedom of a mechanism is given by (Khurmi and Gupta, 2005)

$$n = 3(l - 1) - 2j \tag{3.34}$$

where

l = number of links

j = number of binary joints

Therefore $n = 3(4 - 1) - 2(4)$

$n = 1$

∴ Degree of freedom for this mechanism is one, *ie* by independently controlling any one parameter in this mechanism desired output can be achieved.

3.11.3.7. Parallel Linkage Mechanism

When the opposite links are at same length, a parallel linkage formed, and it is a special case of Grashof's critera, for parallel linkage mechanism given as follows (Khurmi and Gupta, 2005)

$$s + l = p + q$$

where,

s = length of shortest link

l = length of longest link

p = length of one remaining link

q = length of other remaining link

Therefore in this study the following length of links were used

s =100 mm, l =110 mm, p = 100 mm and q =110 mm

∴ 21 = 21 ;

Thus satisfies the Grashof's condition for parallel linkage mechanism. This linkage can be rotated through 360^{o}. However the desired output is the angle required to tilt the carrier cup. Therefore it is necessary to find the optimum tilt angle of the linkage to get desired output.

3.11.3.8. Studying Tilting Angles of Carrier Cups

Carrier cup tilting is an important mechanism involved in the design of weight grader. In order to deliver the dehusked coconut instantaneously at the exact grade, appropriate tilting angle should be fixed and also after the discharge of coconut the carrier cup should return back to its original position. Hence an experiment was conducted to fix the tilting angle of the carrier cup. The base of the carrier cup was fixed in a bench vice as shown in the Plate 3.8. Using the protractor the selected angles were marked and manually the carrier cup was operated for each angle and observed the free falling behaviour and return back position of carrier cup of the coconut.

Hence, three tilting angles of linkage were chosen viz. 5^{o}, 10^{o} and 15^{o} and the free falling behaviour of the dehusked coconut and return back position of carrier cup was investigated. At each tilt angle two different carrier cups (C1- Plastic and C2- Mild Steel) were used and is shown in Plate 3.9. Plastic and Mild steel was selected for the present study because of availability and low cost when compared to aluminium with lowest coefficient of friction. Each treatment was replicated three times.

S. No.	Independent variables	Levels
1.	Tilting angle	5^{o},10^{o} and 15^{o}
2.	Carrier cup	1. C1 2. C2

3.12. Development of Weight Grader

The developed weight grader consists of the following components: 1. Feed hopper 2. Main frame 3. Rotor shaft 4. Rotating frame 5. Carrier cup mechanism 6. Guiding rail 7. Electronic weighing assembly 8. Proximity sensor 9. Drive transmission mechanism.

3.12.1. Feed hopper

Figure 3.7 shows the schematic diagram of the feed hopper. Feed hopper was provided above the main assembly to facilitate feeding of coconut in the cup. It was made up of MS sheet of 1.5 mm thickness. The hopper dimension was 520 mm x 500 mm x 120mm. The hopper was extended to 600 mm length with the opening of 150 mm diameter at the periphery. The MS sheet was rolled to form a cylinder of 150 mm diameter was attached with the extended piece of hopper. The height of the feed hopper was 1500 mm.

3.12.2. Main frame

Main frame is the basic structure on which whole grading assembly was mounted (Figure 3.8). It is fabricated with 50 mm MS pipes of 1028.7 mm height and 787 mm diameter. The height of the frame from the ground level is fixed as 1000 mm. The sufficient supports were provided on the main frame for the pneumatic cylinders and load cell. Also, main frame supports electronic weighing assembly, guiding rail, pneumatic cylinder, carrier cup mechanism and fruit dropping assembly.

3.12.3. Central rotor shaft

The base plates were attached on the top and bottom of the main frame to fix the bearing with the centre rotor hollow shaft. It was made of MS with the pipe inner diameter of 40 mm and outer diameter of 50 mm. The total length of the shaft was 1270 mm. It was fixed at the top and bottom of the main frame with the help of bearing. The distance between the two bearings was kept as 1000 mm.

3.12.4. Rotating frame to support carrier cup mechanism

The rotating frame comprised of a rim, arms and a hub. The rim was made of MS sheet with 3 mm thickness and 150 mm width. It was bended, to form a circle of 80 cm diameter. This rim was connected to the hub by the means of 8 supporting arms. The arms are made of square pipe of 1.5 x 15 cm. The hub acts as a sleeve and is connected with central rotor shaft. The inner diameter of the hub was equal to the outer diameter of the central rotor shaft. The length of the hub was equal to the width of the rim. The rotating frame was assembled on the main frame with 5 cm clearance.

3.12.5. Assemblage of carrier cup mechanism

The developed carrier cup mechanism is shown in Fig.3.9. After the development of the carrier cup mechanism six carrier cups were fabricated. The base of the carrier cup was welded with rotating frame attached on the central shaft. In the circumference of rotating frame, at the interval of 60 degree the carrier cups were fixed. It was fixed in such a way that pointer on the carrier cup rest freely on the guiding rail.

3.12.6. Guiding rail

Guiding rail is made up of a hollow stainless steel tube diameter of 20 mm and thickness of 2 mm, was bend to form a circle of 1200 mm diameter. With six supporting legs, it was fixed on the main frame. The guiding rail helps the pointer, placed in carrier cup mechanism to slide over it.

3.12.7. Electronic weighing assembly

The electronic weighing assembly consist of beam type load cell of 20 kg capacity (Plate 3.10) with a resolution of 1 g. The specification details of the load cell used are given in Appendix IIQ. The Wheatstone bridge of each load cell has a single shielded cable that enclosed four individually insulated signal cables, colour coded to represent excitation voltage (red for +ve and black for -ve voltage) and signal voltage (green for +ve and white for -ve voltage). The driver circuit of the load cell was connected to the microcontroller.

The load cell comprised of four cylindrical holes for mounting: one pair of holes at the bottom and the other pair on the top of opposite ends of load cell. The holes at the bottom of the load cell were used to mount the load cell on the provision given in the main frame of the grader. A piece of 150 mm length was cut from the guiding rail and fixed to the top of load cell through the holes on the top. It should be placed in such a way that it do not touch with the end-to-end of guide rail. This arrangement would helps the load cell to sense the individual weight of cups passing on it. For accurate weighing, care is taken so that the load cell alone supports all the weight being measured.

3.12.8. Proximity sensor assembly

The photograph presented in Plate 3.11 shows the proximity sensor used in the grader. The Proximity sensing assembly consist of proximity sensor and Printed Circuit Board in which both are connected with necessary wiring.

The proximity sensor used can detect only the metals that are at the distance of 5 mm. It was fitted over mainframe across the weighing scale assembly in such a way that, when each cup passes over the sensor it detects the cup and send control signal to a microcontroller. The microcontroller will then start measuring the weight of the samples on the cup.

3.12.10. Positioning of coconut dropping point

A supporting frame of height 76 mm and length 216 mm were welded with guiding rail in three positions at 60^o interval. The guiding rail at these three positions were cut and connected with pneumatic cylinder in such a way that it pulls the guiding rail when it gets command from microcontrollers through DCV (Fig.3.10).

3.12.11. Direction control value (DCV)

The main function of direction control valve is to control the direction of flow in pneumatic or hydraulic system. It receives an electrical signal to release, stop or redirect the fluid that flows through it. It does this by changing the position of internal movable parts. Plate 3.12 shows the picture of the directional control valve and it consists of a valve mechanism and a valve body usually mounted on a sub-plate. The ports of a sub-plate are threaded to hold the tube fittings which connect the valve to the compressor. The valve mechanism guides the fluid to selected output ports or pauses the fluid from passing through the valve.

Three direction control valve was fitted in the main frame near the pneumatic cylinder. The inlet and outlet valve of DCV were connected with pneumatic cylinders by reversing its ports so that the piston rod extends out. A power supply of 230 V was given to the DCV.

3.12.9. Tilting mechanism

Tilting mechanism is an important component in the dehusked coconut weight grading machine which tilts the cups at appropriate position.

3.12.9.1. Pneumatic Cylinder

Pneumatic cylinder has a piston rod which gets its movement by compressed air. The displacement of the pneumatic piston will be more accurate, fast, and reliable and can be easily controlled with electric signals. Hence pneumatic cylinder shown in Plate 3.13

was selected for tilting the cups. The rod type pneumatic cylinder consists of a tube which is sealed by end caps. In one of the end a rod is attached to an internal piston and extends through a sealed opening. The cylinder is mounted with the machine and the piston rod acts upon the load. At one end of the cylinder a port supplies compressed air to the piston through one side, causing it to move. At the same time air in the opposite side of the piston escapes through the port at the other end.

Three pneumatic cylinders were fixed at the interval of 60^o in the three outlets by reversing the roles of the ports, so that the piston rod extends outside. This arrangement was made to pull the guiding rail attached to pneumatic cylinder when the microcontroller gives signal to the DCV. Therefore when the carrier cup with the particular weight of dehusked coconut reaches the appropriate outlet, DCV gets the signal from the microcontroller and operate the pneumatic cylinder. In turn the pneumatic cylinder pulls the guiding rail, which leads to tilting of carrier cup.

3.12.12. Air Compressor

Compressed air is required to operate the pneumatic cylinder connected with the developed weight grader. Therefore a compressor with the capacity of 15 kg was used in the present study.

3.12.13. Collection points

The plastic crates were placed beneath the three dropping points at a height of 600 mm in order to minimise the damage during grading.

3.12.14. Drive transmission mechanism

Single phase DC motor (24 V) operating at a maximum speed of 300 rpm was used to run the weight grading machine. The drive transmission was done in two stages. In the first stage, the drive was transmitted from the motor to the sub shaft using ‘v’ belt and pulley. In the second stage, the drive was transmitted from the sub shaft to the rotor shaft. The sub shaft was fitted with 7 inch diameter pulley and connected to ‘v’ groove of 2 inch diameter pulley on motor. Another pulley having 6 inch diameter was mounted on the centre rotor shaft and connected to the sub shaft with 2 inch diameter pulley. The transmission of power is utilized for speed reduction of the weight grader and was made to operate at 7 rpm. The speed of the grader could be changed at any stage by varying the input voltage supplied to the DC motor.

3.12.15. Development of software program

The flowchart or the algorithm for the development of software program to operate dehusked coconut grading machine is presented in Figure 3.11. It was a preliminary step in developing software for dehusked coconut grader. A required programme was written using C language in a MPLAB software package.

3.12.16. Development of electronic hardware

The important components of the Printed circuit board (PCB) include PIC 16F 877A and ADS1230.

3.12.16.1. Microcontroller

The microcontroller used for the program is PIC 16F 877A. It is a 8-bit microcontroller packed into an 40 pin package. The PIC16F877A has EEPROM with data memory of 256 bytes. It features two comparators and eight channels of 10-bit Analog-to-Digital converter. It also has two capture functions and the synchronous serial port. Microcontroller is programmed in such a way that it decides which relay is to be operated depending on the information provided by the ADS1230. The connections of microcontroller on PCB are shown in Figure. 3.12.

3.12.16.2. Pin Description

The microcontroller has total number of 40 pins. The first pin is always given 5V as it is a master clear pin. The pin 2 is used to get the input from proximity sensor and pin 3, 4, 5 and 6 are used to get analog output from load cell. Both the pin 11 and 32 are connected to 5V as it is the positive supply for the input/output pins. Pin 12 and 31 are considered as ground references for the input/output pins. A crystal resonator is connected between pin 13 and 14 to provide external clock pulse frequency to the microcontroller. The pin 30, 29, 28 and 27 are used for the LCD display. Further pin 19, 20 and 21 are used for the relay selection and pin 22 is used for motor selection. For keypad selection the pins such as 33,34,35,36 and 37 are used.

3.12.16.3. ADS1230

The ADS1230 is a 20-bit analog-to-digital converter. An onboard low noise programmable gain amplifier makes ADS1230 a front-end solution for the sensor applications. All the features of the ADS1230 are controlled by dedicated pins. It is used to get the ADC value from the load cell, as the analog value variation from the load cell is very minute.

3.12.16.4. Power Board

Power board used in Printed circuit board is shown in Fig.3.13. The power board was provided with regulator to regulate the current fluctuation which might cause damage to entire module.

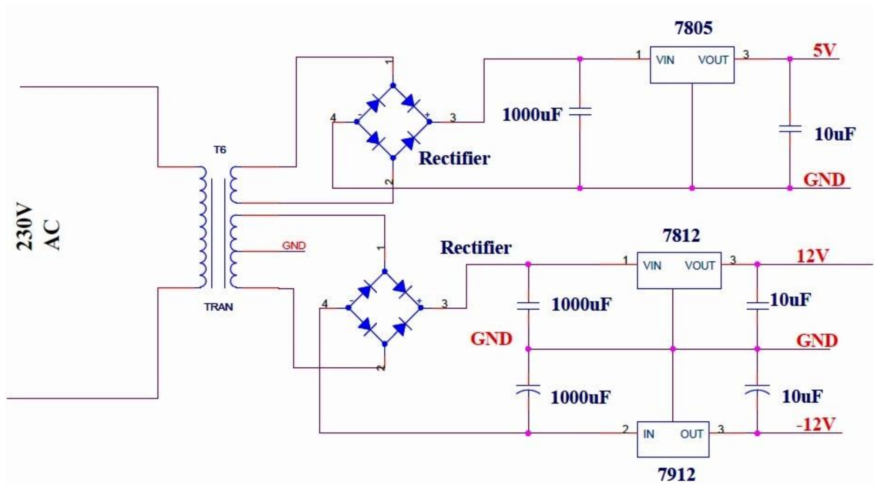


Fig. 3.13 Power supply in the developed weight grader

3.12.17. Principle of operation of the machine

The schematic diagram of developed weight grader is shown in Figure 3.14 (a) and Figure 3.14 (b), respectively. The feed hopper is used to convey dehusked coconuts one by one in the carrier cup mechanism. Initially high value and low value (weight) have to be set to grade the dehusked coconut into three grades. The proximity sensor senses the presence of each cup and sent control signals to the microcontroller. As each cup are sensed motor stops across the weighing scale assembly. Then the load cell will start measuring the weight of the carrier cup. After the settling time the motor starts again. When the carrier cup reaches its ejection point the microcontroller decides to actuate the pneumatic cylinder by sending control signals to the DCV. As the DCV gets the command from the microcontroller the pneumatic cylinder pulls the guiding rail as a result the pointer attached with the carrier cup mechanism which passes freely in guiding rail comes down, and the tongue like structure attached with the base of the carrier cup mechanism pokes the cup so that it tilts the cup and the dehusked coconut falls in appropriate box.

3.12.18. Performance of the load cell

After the development of the electronic hardware and fabrication of the weight grader experiment was conducted to examine the performance of the load cell by keeping the known weight in the carrier cup mechanism at different orientations/ positions and noted the weight displayed.

3.12.19. Evaluation of different grader variables affecting performance

The front view of the developed weight grader is shown in Plate 3.14(a) and 3.14 (b). The performance of developed weight grader was tested under different working conditions such as,

1) Settling time for the load cell
2) speed of the rotor

Collection of data from load cell requires the acceptability to maintain a consistent performance. Misra *et al.*, (2011) noted that a bridge measurement that includes switched voltage excitation, requires a settling time for the signal to reach its stable value. Keeping these points in mind, three levels of the settling time viz., 2, 3, 4 seconds and three levels of voltage viz., 6.8, 7.8 and 8.8 volts (2-4 rpm) were considered for the experiment.

3.12.19.1. Settling Time Settings

When the grading machine is turned ON, the select key has to be pressed. It asks for the high and the low value of weight which is to be graded. The desired weight at each grade is set afterwards settling time has to be set. The levels of settling time can be set and the ENTER key is pressed. Once the ENTER key pressed the machine starts to run.

3.12.19.2. Variation of Speed in Coconut Grading Machine

Regulated Power Supply (RPS) was used to vary the input voltage given to DC motor. The minimum voltage required for the DC motor to operate the grading machine was 4 V. Therefore three different levels of voltage viz., 6.8, 7.8 and 8.8 V were selected. To find the angular velocity, initially the number of rotations for 1 minute (rpm) was noted in stop watch by varying the voltages 6.8, 7.8 and 8.8 V. From the measured rpm, the angular velocity was calculated. The corresponding angular speed of the rotor was 12, 14 and 16 rad/min. The distance of 150 mm was provided for weighing each cups as already mentioned in the section 3.12.8. However when the voltage is given beyond 8.8 V, the carrier cup crossed the electronic weighing assembly and therefore the weight measurement was not done.

3.12.19.3. Experimental Design

The observations were statistically analysed using factorial completely randomized design (FCRD) to optimise the parameters and three replications were made on each treatment.

S. No.	Independent variables	Levels
1.	Settling time (s)	2, 3 and 4
2.	Angular velocity of the rotor (rad/min)	12,14 and 16

Dependent variables

1. Mean contamination ratio or error ($\bar{C}_R$),
2. Grading efficiency (E_W)
3. Throughput capacity (Q)

As explained in the section 3.10.5. The dependent variables were calculated.

3.12.20. Performance test

For the determination of optimum working conditions, well matured coconuts of weight ranging from <300, 301-500 and >500g was selected. There were twenty samples of partially dehusked coconut of each weight. The weight of each coconut was measured manually to determine the performance of grading machine. The dehusked coconut was then manually continuously fed into the feeding unit by an operator in such a way that only single coconut passes through opening. The experiment was conducted with different angular speed and settling time. The correctly and incorrectly sorted fruit at each outlet were noted. All the data including the time taken and the power consumption was noted. The experiment was repeated three times at each treatment.

3.12.21. Data analysis

The data were analysed using the statistical package SPSS 15 by the factorial analysis and the analysis of variance were obtained. The individual and interaction effect of the independent variables on dependent variables were analysed.

3.12.22. Cost economics

Based on the material cost and cost of fabrication, the total cost of the machine was worked out. Using the standard procedures (Palanisami *et al*., 1997 and Kaleemullah, 2002), operational cost of weight grader was worked out.