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Development of a Low Cost Bread Slicing Machine

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ABSTRACT

Bread has become a common food and a cheap source of carbohydrate to all sundry especially among Nigerians. However, the problem of how hygienic the production has become a source of concern to stakeholders. In line with this, we developed a machine that will ensure that there is little or no human contact when slicing the bread since it is the most common of the types of bread available in Nigeria. It has an efficiency of 74% and with a total cost of N45, 000 ($290) as at 2008.

Keywords: *Bread; Slicing; Machine; Nigeria.*

I. INTRODUCTION

Bread is one of the most consumed staple food in Nigeria. It has been hitherto produced from wheat flour as a major component. There has been a lot of investment in technology within the baking industry. The process of slicing breads and rolls has remained unchanged since the first inclined slicers were introduced from the baking of bread to its actual storage, different tools and equipment that deals with bread had been invented and commercialized.

One of the most important bread tool is the bread slicer, whose name alone states its function. However, slicing of bread may be an afterthought to most bakeries, but new bread type requires bakers to reexamine their slicing process and make necessary slicer modification. A growing trend in various type of bread such as premium, thick crust, raising and soft white bread, called for advancement in equipment flexibility.

The world's first mechanical sliced bread was produced in 1928, it was during that year that presliced bread were sold in bakeries. Nowadays, no bakery exists without some type of Bread slicing machine (BSM), some bread slicer are more conventional than ordinary methods of slicing bread, while some are designed to be more specialized and advanced for more unique slices.

Considering the challenges and need for an effective method of slicing and the economic and commercial importance and nutritional values, the bread slicers will be of great importance, since the traditional method of slicing gives a non-uniform thickness of bread slices and for commercial purposes, this method will be tedious, laborious, time consuming and unhygienic with the risk of injury, thus, the need for an efficient and effective Bread Slicing Machine.

Frederick Rohwedder of Davenport invented the first loaf-at-time bread slicing machine. A prototype he built in 1917 was destroyed in a fire and it was not until 1928 that Rohwedder had a fully working machine ready. The first commercial use of the machine was by Chillicothe Baking Company of Chillicothe, Missouri, which produced first slices on July 7, 1928. Their product 'kleen made sliced bread' proved a success. Battle Creek Michigan has a competing claim as the first city to sell bread, presliced by Rohwedder's machine; historians have produced no documentation backing up Battle Creek's claim. The bread was advertised as "the greatest forward step in baking industry since bread was wrapped".

St. Louis Baker Gustav papendick bought Rohwedder's seasoned bread slicing machine and set out to improve it by devising a way to keep the bread slices together at least long enough to allow the loaves to be wrapped. After failures trying rubber bands and metal pins, he settled on placing the slices into a cardboard tray. The tray aligned the slices, allowing mechanized wrapping machine function. W. E. Lonb who promoted Holsum Bread Brand, used by various independent bakeries around the country, pioneered and promoted the packaging of sliced bread beginning in1928 and in 1930, Wonder bread first started marketing sliced bread nationwide.

On March 26th 1943, the ban was rescinded. Wickard stated that "our experience with the order, however, led us to the believe that the savings are not as much as we expected, and the War Production Board tells us that that sufficient wax paper to wrap sliced bread for four months is in the hands of paper processor and the baking industry" (Wenske, 2006).
Aim: the aim of this work is to make available an easy to use and maintain bread slicing machine at an affordable amount.
Bread is one of the most consumed staple food in Nigeria. It has been hitherto produced from wheat flour as a major component. There has been a lot of investment in technology within the baking industry. The process of slicing breads and rolls has remained unchanged since the first inclined slicers were introduced from the baking of bread to its actual storage, different tools and equipment that deals with bread had been invented and commercialized.

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Aim: the aim of this work is to make available an easy to use and maintain bread slicing machine at an affordable amount.

II. MATERIALS AND METHODS

Design Analysis and Material Selection

The Bread Slicing Machine consists essentially of the following components:

i. Prime Mover (also called Electric Motor) which supplies the power required to drive the pulley and belt system.

ii. Belt Drive (Belt and Pulley) which transmits power from the electric motor to the shaft that rotates the pulley.

iii. Bearing which support and hold the shaft axis line, reduce force dissipation on the shaft due to their low friction coefficient and prevent radial movement of shaft.

iv. Link that transmits rotational motion of the shaft into reciprocating motion of the slider.

III. DESIGN ANALYSIS

The following mechanism of the machine were considered and designed:

Drive Mechanism

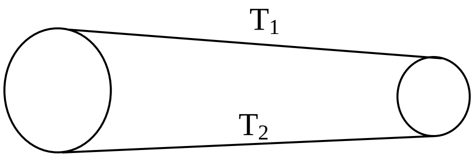
The design of the drive mechanism includes the belt pulley analysis, main shaft analysis, bearing and link mechanisms.

Belt Pulley Analysis

Generally pulleys are made of cast iron, steel fiber or various types of wood. In the selection of material for the pulley, some factors such as weight, cost, availability, machinability and durability of the material must be considered. Having considered the above, aluminum was selected for the design of a pulley for the bread slicing machine.

To design a belt drive, the speed of the driving unit, speed of driven unit, desired center distance and other operating conditions must be known.

The belt pulley diagram is shown below:



Where

T_1 = Tension of the tight side of belt

T_2 = Tension on the slack side of belt

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(a) Speed Ratio of the Belt Drive

The objective of the belt drive speed analysis is to determine the diameter of the main shaft pulley that will produce the speed required to shear the bread.

The speed ratio is determined from

Speed Ratio = $\frac{N_m}{N_s} = \frac{D_s}{D_m}$ (Khurmi and Gupta, 2006)

$$N_s = \frac{N_m \times D_m}{D_s}$$

Where
Nm = Speed of Electric Motor in Rev/Min
N_s = Speed of Main Driving Shaft in Rev/Min
D_s = Diameter of Pulley of the Main Shaft
D_m = Diameter of Motor Pulley

The following values were selected for the belt drive,

N_m = 1340rev/min N_s = ?
D_m = 70mm D_s = 120mm

$$N_s = \frac{1340 \times 70}{120}$$

$$N_s = \mathbf{781.66rev/min}$$

Hence the speed of the main shaft pulley,
N_s = 781.66rev/min.

This implies a speed reduction of 2:1

(b) Peripheral Belt Speed

This is determined from:

Belt Speed, $V = wr$ (Khurmi and Gupta, 2006)

$$V = \frac{2\pi N_s}{60} * \frac{D_s}{2}$$

Since

$$w = \frac{2\pi N_s}{60} \text{ and } r = \frac{D_s}{2}$$

Where

w = angular speed in rad/sec

r = radius of the pulley in m

$$V = \frac{2 \times 3.142 \times 781.66}{60} \times \frac{0.012}{2}$$

V = 4.911m/s

(c) Angle of Lap (Φ)

The angle of lap is determined from

$$\cos\left(\frac{\emptyset}{2}\right) = \frac{D_s - D_m}{2c}$$

Hannah and Stephens (1998)

Where

D_s = Diameter of Pulley of the Main Shaft in m
D_m = Diameter of Motor Pulley in m
C = distance between the centres of the two pulley
D_s = 120mm = 0.12m, D_m = 70mm = 0 07m
C = 300mm = 0.3m

$$= 2 \times \cos^{-1}\frac{D_s - D_m}{2c}$$

$$= 2 \times \cos^{-1}\frac{(0.12 - 0.07)}{2 \times 0.3}$$

= 170.44°

Angle of Lap, φ = 170.44° = 2.98rad

(d) (1) Tension due to centrifugal force on Belt

The centrifugal tension, T_c on the belt is determined from:

$$T_c = \frac{MV^2}{g}$$ Khurmi and Gupta (2006)

Where V = Peripheral belt speed in m/s;

M = 1.06N/M, for a belt type

Khurmi and Gupta (2006)

$$T_c = \frac{1.06 \times (4.911)^2}{9.81}$$

$$T_c = 2.606N$$

Tension due to centrifugal force on Belt, **T_c = 2.606N**

(2) Tension T_1 and T_2 of the Belt

The tension T_1 and T_2 of the belt is determined from:

Power Transmitted, $P = (T_1 - T_2) \times V$ Khurmi and Gupta (2006)

$$P = T_1\left(1 - \frac{T_2}{T_1}\right) \times V$$

But $\frac{T_1}{T_2} = e^{\mu\varphi}$ Khurmi and Gupta (2006)

T_1 = Tension of the tight side of belt

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T_2 = Tension on the slack side of belt

$$P = T_1\left(1 - \frac{1}{e^{\mu\varphi}}\right) \times V$$

μ = Coefficient of friction between and pulley groove = 0.2
φ = angle of lap = 0.2
P = 746w

$$746 = T_1\left(1 - \frac{1}{e^{0.2\times 2.7}}\right) \times 4.911$$

$$746 = T_1 \times 2.049$$

$$T_1 = \frac{746}{2.049}$$

T_1 = 364.08N

$$\frac{T_1 - T_2}{T_2 - T_c} = e^{\mu\theta cosec\beta}$$

Where β = Semi-angle of pulley groove = 16^0

T_c = 2.606N, T_1 = 364.08N

$$\frac{364 - 2.606}{T_2 - 2.606} = e^{0.2\times 2.7\times cosec16}$$

$$T_2 - 2.606 = \frac{361.394}{7.0929}$$

$$T_2 - 2.606 = 50.95$$

T_2 = 53.56N

(e) Torque on the machine pulley

$$T_t = (T_1 - T_2) \times R$$
$$= (364.08 - 53.56) \times \frac{0.12}{2}$$

T_t = 18.63Nm

For it to work, V-belt is selected because it is cannot come out of pulleys grooves, the gripping action results in a greater frictional force and lower belt tension, hence longer belt life and ability to absorb shock.

Main Shaft Analysis

The objective of main shaft analysis is to determine the minimum value of shaft diameter that will withstand the torsional and bending load exerted on it. Shaft may be classified as solid and hollow shaft. For this design project, a uniform solid shaft is used due to the following reasons:

- To increase the life span of the shaft
- To allow efficient movement of the shaft through the support bearing.

Shaft design involves determination of correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading condition.

The types of loading on the shaft are bending load, weight and reaction on the shaft, torsional load imposed from the energy input. The forces acting on the shaft when in operation are:

- Weight of Pulley
- Weight of bearing
- Torsional load from pulley

Determination of Pulley Weight

The pulley is of 120mm diameter and 25mm thickness is made of aluminum.

Weight of Pulley = Vol. of Pulley x Density of Pulley x Acceleration due to gravity

$$W = \rho V g$$

Where

D = Diameter of Pulley = 120mm = 0.12m

H = Thickness of Pulley = 0.025m

$$Volume\ of\ pulley = \frac{\pi D^2 H}{4}$$

$$V_p = \frac{\pi D^2 H}{4}$$

$$V_p = \frac{\pi \times 0.12^2 \times 0.025}{4}$$

Volume of pulley = 2.356 x $10^{-3}$$m^3$

Density of Aluminium = 2700kg/m^3

Weight of pulley = $(2.356 \times 10^{-3}) \times 2700 \times 9.81$
= 62.40N

Weight of Bearing:

Weight of each Bearing = 50N

Vertical component of load on the shaft at E = Weight of pulley

Weight of pulley = self weight of pulley = $W_{pv} = 62.40N$

Vertical component of force on the shaft due to weight of the bearing at point C and D

Weight of Bearing $W_{bv} = 50N$

Horizontal component of load on the shaft at E,

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$W_{PH} = T_1 + T_2$

= 53.56 + 364.08

W_{PH} = 417.64N

Vertical component of reaction at shaft end, A and B

$R_{AV} + R_{BV} = (50 + 50 + 62.40)$
$R_{AV} + R_{BV} = 162.40N$

Taking moment about A,

$R_{BV} \times 0.47 = (50 \times 0.29) + (62.4 \times 0.235) + (50 \times 0.18)$
$R_{BV} \times 0.47 = 38.164N$

$R_{BV} = \frac{38.164}{0.47}$

R_{BV} = 81.2N

If

$R_{AV} + R_{BV} = 162.40N$
$R_{AV} = 162.40 - R_{BV}$
$R_{AV} = 162.40 – 81.20$

R_{AV} = 81.20N

Horizontal Component of load at shaft end;

$R_{AH} + R_{BH} = 417.62+50+50$
$R_{AH} + R_{BH} = 517.62$
$R_{AH} = R_{BH}$

$$R_{AH} = \frac{517.62}{2}$$

$R_{AH} = 258.821N$
$R_{BH} = 258.81N$

Bending moment for vertical loading

At A, M = 0
At C, M = (81.2 x 0.18) = 14.616M
At D, M = (81.2 x 0.29) – (50 x 0.110) – (62.4 x 0.055) = 14.616M
At B, M = (81.2 x 0.47) – (50 x 0.29) – (62.4 x 0.235) – (50 x 0.18) = 0

Bending moment for Horizontal loading

At A_1, M =0
At C_1, M = 46.58Nm
At E, M = (258.81 x 0.235) – (50 x 0.055) = 58.07Nm
At D, M = (258.81 x 0.29) – (50 x 0.09) – (417.62 x 0.055) = 47.58Nm
At B, M = (258.81 x 0.47) – (50 x 0.29) – (417.62 x 0.235) – (50 x 0.18) = 0

The Resultant Bending Moment is obtained using

$$M = \sqrt{(M_V{}^2) + (M_H{}^2)}$$

Khurmi and Gupta, (2006)

$$At\ A, \quad M = \sqrt{(0^2 + 0^2)} \quad = 0$$

$$At\ C, \quad M = \sqrt{(14.616^2) + (46.58^2)} = 48.82Nm$$

$$At\ E, \quad M = \sqrt{(16.382^2) + (58.07^2)} = 60.323Nm$$

$$At\ B, \quad M = \sqrt{(0^2 + 0^2)} \quad = 0$$

The Maximum Resultant bending moment M is at E because it has the Maximum Resultant Bending Moment.
The shaft is subjected to Combined Bending and Tensional Stresses. The equivalent twisting moment is:

$$T_e = \sqrt{(K_m \times M)^2 + (K_e \times T)^2}$$

Khurmi and Gupta (2006)

And the equivalent bending moment is

$$M_e = \tfrac{1}{2}\left[(K_m \times M) + \left\{\sqrt{(K_m \times M)^2 + (K_e \times T)^2}\right\}\right]$$

Khurmi and Gupta (2006)

K_m = Combined Shock and fatigue factor for bending = 1.5

Khurmi and Gupta (2006)

K_e = Combined Shock and fatigue factor for torsion = 1.0

Khurmi and Gupta (2006)

T = Twisting Moment of main shaft in Nmm

$$T = (T_1 - T_2) \times \frac{D_s}{2}$$

$$T = (264.08 - 53.54) \times \frac{0.12}{2}$$

$$T = 18.63\text{Nm}$$

$$T_e = \sqrt{(K_m \times M)^2 + (K_e \times T)^2}$$

$$T_e = \sqrt{(1.5 \times 60.323)^2 + (1.0 \times 18.623)^2} = 92.38Nm$$

$$M_e = \tfrac{1}{2}\left[(K_m \times M) + \left\{\sqrt{(K_m \times M)^2 + (K_e \times T)^2}\right\}\right]$$

$$M_e = \tfrac{1}{2}[1.5 \times 60.323 + 92.38] = 84.47Nm$$

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From Torsion equation;

$$T = \frac{\pi d^3}{16} \times t \qquad \textit{Khurmi and Gupta } (2006)$$

T_e = Equivalent Twisting Moment = 92.38Nm
r = radius of the shaft = d/2
d = diameter of shaft
J = second moment of inertia

$$= \frac{\pi d^4}{32}$$

T = torsional shear stress = $42MN.M^2$

$$d = \frac{\sqrt[3]{16T}}{\pi \times t}$$

$$d = \frac{\sqrt[3]{16 \times 92.38}}{\pi \times 42 \times 10^6}$$

d = 0.02238m

d = 22.38mm

From Bending Equation,

$$M = \frac{I \times \sigma}{Y}$$

$M = Z\sigma$ Khurmi and Gupta (2006)

Where

σ (bending stress) = $56MN/M^2$

Khurmi and Gupta (2006)

M = Equivalent bending moment = 84.47

$$I = Moment\ of\ Inertia = \frac{\pi d^4}{64}$$

$$Y = distance\ from\ the\ neutral\ axis\ to\ the\ extreme\ surface = \frac{d}{2}$$

$$Z = section\ modulus = \frac{\pi d^3}{32}$$

$$M = \frac{\pi d^3 \times \sigma}{32}$$

$$d = \frac{\sqrt[3]{32 \times M}}{\pi \times \sigma}$$

$$d = \frac{\sqrt[3]{32 \times 84.47}}{\pi \times 56 \times 10^6}$$

d = 24.91mm

Deduction

From the torsional analysis, the minimum diameter required to withstand the torque loading is 22.38mm while the minimum diameter to withstand the bending stress is 24.91mm. Since the main shaft diameter is 25mm, then the main shaft will effectively withstand both torsional and bending stress.

Link Mechanism

The link mechanism diagram is shown in fig. 3.3;

Ns = Speed of Main Driving Shaft in Rev/Min
= 781.66rev/min

Tangential velocity of arm OA = Velocity of A with respect to O

$$V_{OA} = OA \times W$$

OA = 50mm

But $w = \frac{2\pi N_s}{60}$

$$V_{OA} = \frac{0.005 \times 2\pi \times 781.66}{60}$$

V_{OA} = 4.0927m/s

Considering the velocity triangle,

4.0727 = 50mm

To find the velocity of the slider, Let Length CO represents the slider speed,

CO = 70mm Khurmi and Gupta (2006)

$$V_{CO} = \frac{70 \times 4.0927}{50}$$

Speed of the slider = cutting speed of the blade = 5.729m/s

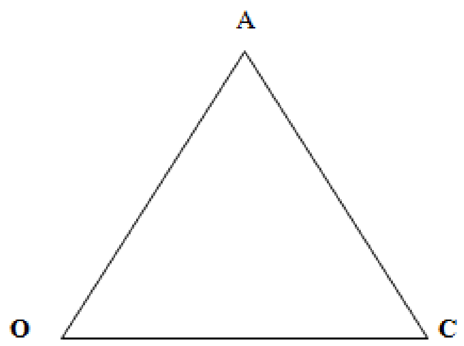

Fig 3.3: Link Mechanism

Link Design

The link connects the shaft to the slider, it is constructed from mild steel with lengths 120mm and 90mm with a width of 8mm and holes of diameter 20mm and a slot of width 12mm to accommodate a bearing and nut. The bearing was incorporated to ensure smooth running of the slider.

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Material Selection

The choice of material for the design of the Bread Slicing Machine is aimed at achieving high efficiency. This was achieved by selecting the appropriate materials with adequate working condition and stability of the component.

The specifications of the major component in the Bread Slicing Machine are described below. These components are the Electric Motor, Bearing Link and the Mounting support.

Electric Motor

The Electric Motor was selected based on the speed and power output required for the machine. The specifications of the electric motor as available on its tag are:

Table: Electric motor specification

DESCRIPTION	DATA
Power	0.75Kw
Speed	1340rev/min
Voltage	220v
Frequency	50Hz

Bearing Selection

Ball bearing was selected for the shaft in this design because it holds the shaft axis in line and thus ensure smooth and steady running of the shaft. A ball bearing of 25mm diameter has a rating of 16.8KN (Shigley and Mischike) and the bearing life of 14-20hrs service is recommended. The radial load on the bearing is far less than the load rating, hence, the bearing will not fail.

Mounting Support

The mounting support is made from an Angle plate of thickness 60mm to which the rod connecting the shaft are welded. The choice of mild steel for this support is due to its machinability, good weight ration and its availability.

Link Material

The link is made of Mild Steel. The link connects the shaft to the slider carriage. The link is perfectly shaped to ensure a balanced and smooth oscillation of the slider coupled to the link. The choice of Mild Steel for this component is due to its machinability and availability.

Fabrication

After the initial preliminary testing of the bread slicing machine, different problems were observed. the problems range from efficiency of the link mechanisms, wobbling of main shaft and faulty condition of the Electric Motor. This resulted in redesign, modification and changing of different components like:

- **Main Shaft**

  The wobbling of main shaft was due to the absence of support, for which one support was initially used. A support was fabricated from 30mm diameter pipe of length 200mm. The support was used to restrain the main shaft to ensure smooth and steady rotation.

- **Bearing Housing**

  The bearing Housing was made from mild steel pipe with diameter of 60mm and thickness of 4mm. the pipe was cut using pipe cutter to the necessary concentric, smooth and high quality surface finisher.

- **Link**

  The link material was made from mild steel pipe of length 10mm and height of 30mm, to carry 2 ball bearings of diameter 21mm, which will undergo linear movement

- **Slider**

  The slider is made of a 20mm diameter galvanized sheet metal. The slider is curved at both ends with the aid of a vice for securing the slider with the slide frame

IV. OPERATION OF THE BREAD SLICING MACHINE (BSM)

The Bread slicing Machine is easy and simple to operate. This is achieved when all the components are properly assembled.

The machine is operated electrically with the principal motion of the main shaft operated from one horse power electric motor. The speed of the electric motor, which is 1340rev/min, was stepped down with the help of a bigger pulley fitted to the main shaft. When the machine is switched on, the speed of the electric motor is transmitted to the pulley via the Vee-belt and hence to the main shaft, from the main shaft the motion is transmitted to the link machine to effect the reciprocating motion of the Slider frame carrying the blades. As the slider reciprocates the blades which is fed from a rail securing the actions of the blade, the rack ensures the breads are uniformly fed to the blades.

V. MAINTENANCE

Proper maintenance is important for the safe and reliable operation of any machine, machine maintenance and serving operation are the measures employed to keep a machine in good working condition and to correct any abnormality that could arise during operation of such machines. Considering the operation of such machine and the different components used in the Bread Slicing Machine, it is important to carry out periodic maintenance on these components to ensure proper and effective operation of the machine.

Adequate and proper maintenance of the machine will reduce the occurrence of accidents, hence ensure safety of the operator thereby extending the service life of the machine and gives a maximum return in investment.

The set of maintenance operation to be carried out includes:

a. Checking the Belt Tension and adjusting if necessary

b. Cleaning the blades

c. Greasing the moving parts before and after operation to reduce friction.

VI. COST ANALYSIS

High priority is placed on cost minimization in the course of the design and construction of the machine. The choice of locally available materials in the construction is aimed primarily at making the maintenance inexpensive and affordable for small scale baking industry. The cost analysis for the machine is **₦44500**

VII. PERFORMANCE EVALUATION

After fabrication, the machine was tested and the following observations were made:

a. Frequent breakage of the sliced bread was observed during slicing. This is as a result of the position and orientation of the blade. This necessitated the repositioning of the blade and changing the thickness to 10mm.

b. The slicing speed 11.45m/s was observed to be too high for the fragile nature of the bread. Although the electric motor does not run the power transmitting element of the successfully. The speed was too much for the bread to withstand. Efforts were made to get a variable speed motor to check] how the machine will perform if such motor is used which was achieved.

Having corrected the observations made during the test, it was observed that the machine ca slice a loaf of bread if few blades are used, with more efficient slicing at the middle of the slider blade. Comparing this result obtained with the old existing design, the machine has a higher efficiency.

VIII. CONCLUSION & RECOMMENDATION

This work has actually gone within the limits of its scope to design and construct bread slicing machine for small scale indigenous baking industry through the historical development of bread slicing machine, bread preparation processes and development of bread slicing machine. This design analysis, material selection, construction, maintenance and performance evaluation of the machine was also checked.

The objectives of this work have been considerably achieved, as we have been able to:

a. Reduce the time spent on slicing operation, hence increase the rate of production

b. Produce a machine that is easy to assemble and disassemble using a mounting support so each unit can be considered separately during maintenance.

c. Produce a machine that is safe to use by using cover and guard to guard the transmission parts, thereby, protecting the operator from hazards of unguarded rotating parts.

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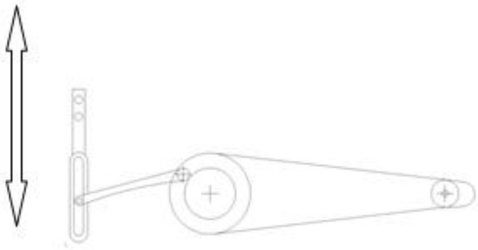
DIAGRAMS



LINK MECHANISM

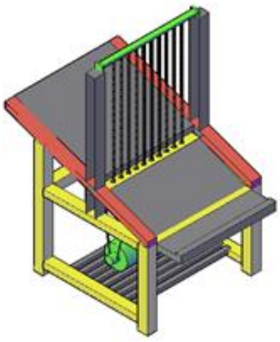


Figure 2: 3D South-West Isometric View

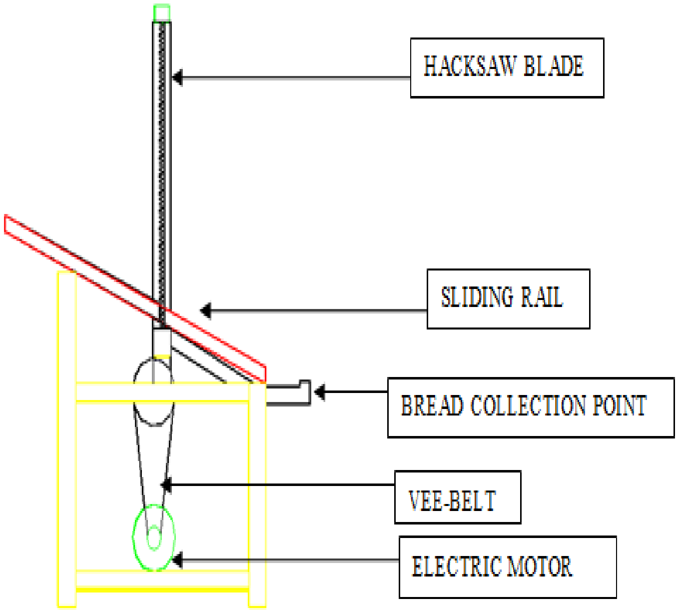


Figure 3: Side View of the Machine