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Research Article

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Design, Fabrication and Performance Analysis of a Tabular Wood Sawing Machine

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Abstract Timber is a construction material which has been used for both structural and ornamental purposes. Inadequate planning and machinery layout in woodwork shops makes wood cutting inefficient, tedious and time consuming. It also constitutes occupational hazard to workers in form of injuries, noise pollution and inhalation of wood dust particles. A tabular wood sawing machine was designed and fabricated for efficient and safe sawing of wood in Lagos State University workshop. It consists of a circular saw blade, mounted on an arbour, that is driven by an electric motor. The drive power from motor is passed to the blade either directly or by belt. The machine runs on a one and half horse power electric motor of 1000r.p.m. The performance analysis result shows the cutting speed of the fabricated tabular sawing machine is 56.25m/s and also very safe to operate. The cost valued at $175. It is affordable and economical for small scale business.

Keywords Cutting speed, Cross cutting, Design, efficiency, fabrication, small scale business, tabular saw

1. Introduction

Timber is a construction material which has been used for both structural and ornamental purposes. It is used throughout the world for many tasks, from simple structural application to highly finished and ornate decoration and it is the dominant industrial material in Nigeria [1]. Nigerian forests are naturally endowed with plant, species and for this reason it has been protected for timber production. There are several softwood species in Nigeria, of the total number; only 2,300 tree species are commercially important [2]. Timber has been used as a building material for over 400, 000 years and it is very common and best-known material for house construction including framing of floors, walls and roofs. Timber accounts for about half of worldwide wood consumption [3]. The processing of timber involves the primary and secondary conversions. Primary wood conversion embodies the set of operations performed on trees hence they are cut and transported out of the forest. It comprises the activities of sawing and wood planning, unrolling and trenching, drying, and finally wood impregnation. Secondary conversion involves sawing and ripping into standardized dimensions carried out in woodwork shops. Economic wood processing requires the use of machines and power tools for increased productivity, reduced processing time and human efforts

A tabular sawing machine is a woodworking tool consisting of a circular saw blade, mounted on an arbour, that is driven by an electric motor in turn the drive power from motor is passed to the blade either directly or by belt. The blade protrudes through the surface of a table top, which provides support for the wood being cut. In a modern tabular sawing machine, the depth of the cut is varied by moving the blade up and down: the higher the blade protrudes above the table, the deeper the cut that is made in the material. In some early table saws, the blade and arbour were fixed, and the table was moved up and down to expose more or less of the blade. The angle of cut is controlled by adjusting the angle of blade. Machines used in woodworking are dangerous, particularly when used improperly or without proper safeguards.

Ejikeme *et al*., (2016) [5] studies carried out in selected sawmills in Port Harcourt Nigeria reported that the risk of developing hearing loss after 35 years of exposure is likely to be in the order of Planning machine > Table saw >Stenner 48 bandsaw> Sharpening machine. Efforts to quiet the sources and dampen the vibrations should be made. Noise sources generally include motors, gears, belts and pulleys, points of operation where blades touch wood, and any other moving parts. Resonant transmitters generally include the equipment frames, footings, and housings.

Tool wear is used to evaluate the performance of the cutting tool, owing to its direct impact on surface quality, cutting force, power consumption, etc. Hence it is of vital importance in sawmilling and the woodworking industry [4]. During wood machining multiple wear mechanisms such as abrasion, chipping, corrosion, oxidation, fatigue, and adhesion could be present. The major wear mechanisms change depending on cutting parameters, tool geometry and workpiece properties. Various parameters have been used by researchers to evaluate tool wear and bluntness of the cutting edge, such as nose width, edge recession in rake face, edge recession in clearance face, edge radius, etc. Fig1 explains the most common parameters used to evaluate tool wear in the wood industry.

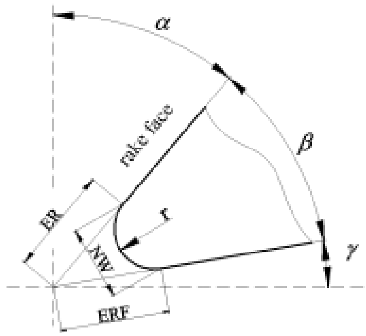


Figure 1: Parameters used to measure tool wear (α = rake angle, β = wedge angle, γ = clearance angle, ER = edge recession in rake face, ERF = edge recession in clearance face, NW = nose width, r = edge radius) [6]

The shape of a cutting tool edge is determined by the rake angle, wedge angle and clearance angle. The optimum shape depends primarily upon the cutting direction (CD) and wood species properties. The cutting tool shape directly affects the surface quality and productivity of the machining operation. Also, the tool shape defines the magnitude and direction of the cutting force. The power consumption in wood cutting is related to the cutting force: the higher the cutting force, the greater the power consumption. Aguilera and Martin (2001) [7] predicted the power consumption of climb-sawing and counter-sawing by measuring the main cutting force, and determined power consumption from the known cutting speed. Kováč and Mikleš [8] determined the power consumption of the wood cutting process using circular saws, and studied the influence of different cutting tool geometries. Orlowski *et al* (2013) [9] compared power consumption, which was calculated based on modern fracture mechanics and specific cutting resistance. Luiz cristavao *et al* (2013) [10] predicted the total theoretical power consumption in a circular sawblade is given by:

$$P_{Total} = \frac{z.n}{360} \sum_{i=1}^{360} P_i \quad (1)$$

where z is the total number of teeth engaged and n is the number of circular sawblades in the arbour. The momentary theoretical power (P_i) required to remove a chip from a workpiece using one tooth is:

$$P_i = F_{pi} V_i + \frac{H.k.S.d.v_i^2}{2} \quad (2)$$

where F_{Pi} is the main cutting force (N), H is the depth of the cut (mm), S is the feed speed (m min^{-1}) , vi is the cutting speed (m s^{-1}), k is the saw kerf width (mm), and d is the wood density (kg m^{-3}). The first term in Equation 2 refers to the power required to cause a failure, and the second term is the power required to accelerate a chip. [11] studied the influence of some cutting parameters (geometry of cutting edge, wood species, and circular saw type) and cutting conditions on the wood crosscutting process carried out with circular saws. The research reported the cutting rake angle of a circular saw is an important factor influencing torque M_k, changing circular saw type (with the same geometry) had the biggest influence on torque M_k of all tested factors, feeding speed v_f has a significant influence on torque M_k and for deciduous wood, it is more suitable to use a higher feeding speed at positive cutting angles while for coniferous wood, it is more suitable to use slower feeding speeds due to the presence of reaction wood. The cutting speed v_c was reported to have more significant influence on torque M_k in the cutting of spruce than beech and that torque M_k decreases when cutting speed v_c increases. A tabular wood sawing machine was designed for use in Lagos state university wood workshop with efforts at optimizing the cutting speed with more concentration on feed rate ahead of blade rake angle.

2. Cutting Speed and Power Transmission

2.1.1. Pulley diameter

For the selected motor of 1.5Hp 1000 rpm, the minimum diameter of pulley 75mm according to IS: 2494-1974 is selected for the motor pulley. For a selected speed of 1000rpm on shaft or driven pulley, using standard equation, we can determine the diameter of the driven pulley as follows:

$$d_1N_1=d_2N_2 \quad (3)$$

Where d_1 is the diameter of the driver puller and equals 75 mm

d_2 is the unknown diameter of the driven pulley d_2= 75∗1000/1000=75mm

2.1.2. Belt size and grade

For the best performance of the machine, the chosen Centre distance between the pulley C was set to 360mm

The belt length can be determined using

$$L=\frac{\pi}{2}(d_1+d_2)+2c+\frac{1}{4c}(d_1+d_2)^2 \quad (4)$$

After putting the value, in equation (4) the length of belt required was 971mm.

The Inside length can be determined by subtracting 36 from the pitch length for class A belt which is equivalent to 935mm. A standard belt was then chosen as the nearest match is 942 mm which is type A37 belt.

2.1.3. Cross sectional area of belt

We determine the angle of contact (θ) for both the driver and the driven pulleys from the pulley geometry presented in section 3.7.1 using the equation below

$$sin\alpha=\frac{d_2-d_1}{2c} \quad (5)$$

Inputting the values, α=0° then angle of contact for the driver pulley will be as θ_1=180°−2α=180°

In radians $180*\frac{\pi}{180}= rad$

And to determine the angle of contact for the driven pulley θ_2=180°+2α=180°

In radians

$180*\frac{\pi}{180}=3.14\ rad$

Sin both pulleys chosen are of the same material, the selected coefficient of friction will be same and this equal 0.30.

2.1.4. Slip of belt

With the chosen belt A15, the thickness of the standard belt therefore is 8 mm and then the slip of the belt can be determined using standard speed ration relationship equations as follows

$$\frac{N_1}{N_2}=\frac{d_1}{d_2}(1-\frac{s}{100}) \quad (6)$$

The slip of belt was however determined using appropriate values and equals 12.5%.

2.1.5. Belt tension

The tension on the belt was determined using appropriate standard equations as shown below for both the driver pulley and the driven pulley.

$$(T_1/T_2)=e^{\mu\theta} \quad (7)$$

Therefore

$$2.3\log(T_1/T_2)=\mu\theta$$

Where θ stands for the corresponding angle of contact, T represents the tension.

$\mu\theta_1$=0.30∗3.14=0.942 ; $\mu\theta_2$=0.30∗3.14=0.942

Let T_1 equals the tension on the tight sight and T_2 equal the tension on the slack side

Using an electric motor which has maximum power of 1119W =1.5hp

$$V=\frac{\pi d_1 N_1}{60}=3.926m/s \quad (8)$$

$$P=(T1-T2)\,V \quad (9)$$

This gives

$T1-T2=285\ N$ (10)

Therefore, using the standard equation, we selected $\mu\theta_1$ because it is same as $\mu\theta_2$.

2.3 log(T_1/T_2) =$\mu\theta_1$ (11)

Combining the equations, (10) and (11) T_1=467.1 N and T_2=182.10 N

2.2. Shaft Design

A shaft is a rotating element which is used to transmit power from one [lace to another. The power is transmitted by some tangential force and the resultant torque (or moment) setup within the shafts permits the power to be transferred to various machine or its element linked up to the shaft. In other to transfer the power from the shaft, the various members such as pulleys, bearings, drums are mounted on it. The members along with the forces exerted upon them causes the shaft to bending. In other words, we may say the shaft is used for the transmission of torque and bending moment. The various members are mounted on the shafts by means of keys/Splines [12].

2.2.1. Determination of Torque on shaft

The torque on the shaft

$$T = \frac{60P}{2\pi N} = \frac{60\times1119}{2\pi\times1000} = 10.386\text{Nm} = 10386\text{Nmm} \quad (12)$$

2.2.2. Determination of Theoretical Cutting Speed (V_C)

For a given Torque and cutting power the cutting speed can be determined using the relationship

$$P_c = \frac{2T\times V_C}{D_b} \quad (13)$$

Where T= Torque on circular blade and shaft= 10386Nmm

D_b=Diameter of Circular blade=178m ; P= Cutting power=0.8 ×1119= 895.2 Watts

This gives a maximum theoretical cutting speed of 74.5m/s

2.2.3. Determination of Maximum bending moment and shaft diameter

Consider the space diagram of the shaft carrying the loads shown below in Fig. 2 and Fig.3

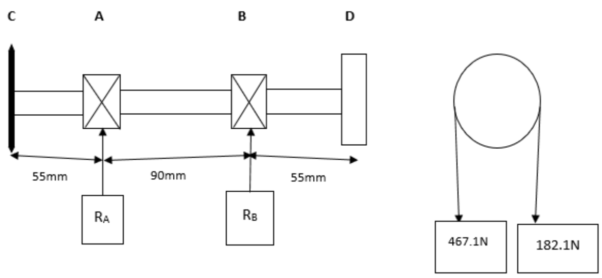


Figure 2: Shaft, blade, pulley and bearing arrangement

The weight of the pulley $W_1 = M_1g$

Where M_1= Mass of pulley in Kg =1Kg

g = acceleration due to gravity = 9.81m/s^2

W_1= 1×9.81 = 9.81N

W=Vertical downward force on shaft at D

=Weight of pulley +Belt Tension in Slack side + Belt tension in tight side

= 9.81+467.1+182.1 = 659N

Resolving the Vertical Forces (Upward direction Positive),

For equilibrium the sum of forces about any direction must be zero

$$R_A + R_B - W = 0$$

$$R_A + R_B = 659 \quad (14)$$

Taking Moment about A$-R_B \times 90 + 659 \times 145 = 0$

$90R_B = 95555$

$$R_B = 1061.7N \quad (15)$$

Substituting $R_B = 1061.7N$ in Equation (14)

$R_A + R_B = 659$N

$R_A = 659.0 - 1061.7 = -402.7$

The reaction at the bearing is upward at B and downward at A

Shear force at A = $+R_A \;\; = -402.7N$

Shear Force at B = -402.7 + R_B

$$F = -402.7 + 1061.7; F = +659N \qquad (16)$$

Shear Force at C=0

Shear force at D = + 659 – W = + 659 – 659 = 0N

Bending Moment at D=C=0

At B $M_B = -W \times 55 = -659 \times 55 = -36245$

$$\text{At A} M_A = -W \times 145 + R_B \times 90 = 659 \times 145 + 1061.7 \times 90 = 0 \qquad (17)$$

Maximum Bending Moment is at B, M = -36245Nmm

The equivalent twisting moment is given by

$$T_B = \sqrt{M^2 + T^2} \qquad (18)$$

$T_B = \sqrt{-36245^2 + 10386^2}$

$$T_B = 37703Nmm = \frac{\pi}{16} \times \tau \times d^3 \quad = \frac{\pi}{16} \times 42 \times d^3 \qquad (19)$$

$d = 16.60mm$

The nearest shaft diameter of 20mm is selected to rigid balance during operation.

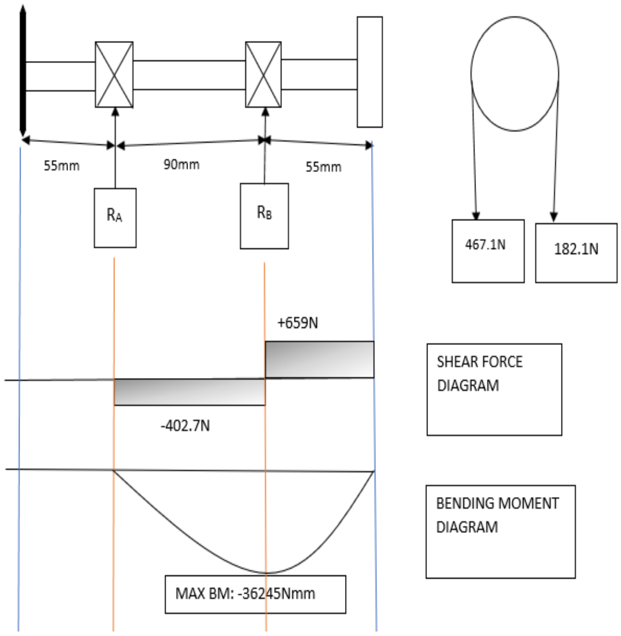
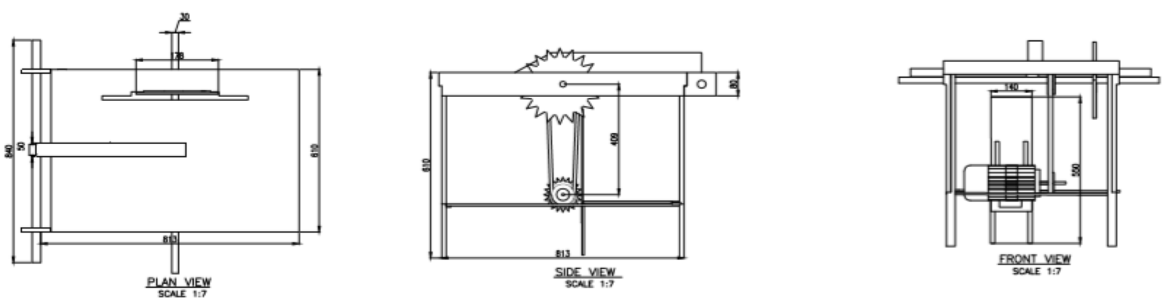


Figure 4: Shear force and Bending moment diagram



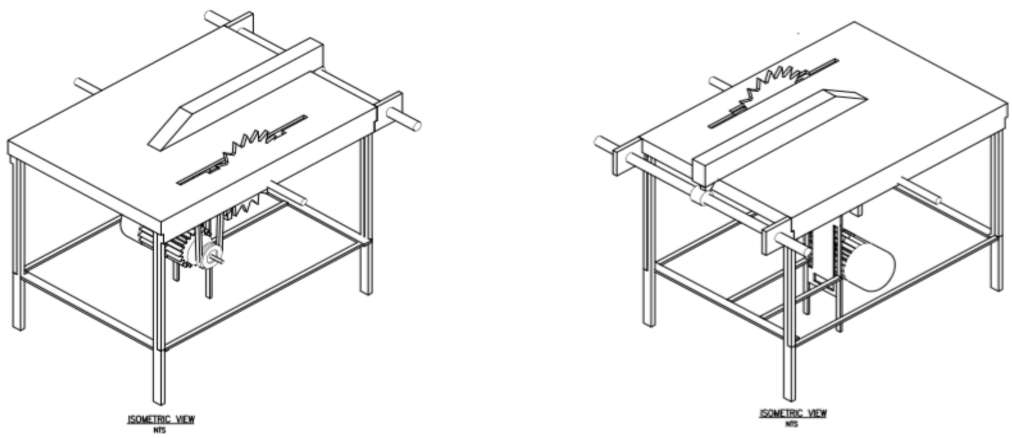


Figure 5: Detailed drawing of tabular sawing machine

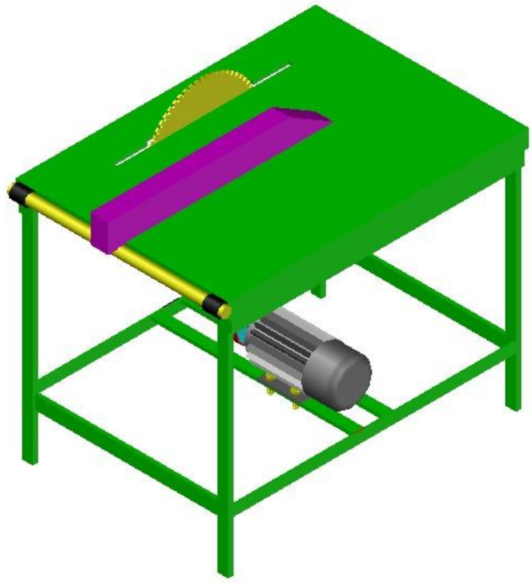


Figure 6: Isometric Drawing of tabular sawing machine

3. Performance and Cost Evaluation

The main features are a Supporting frame, electric motor, cutting blade, shaft, bearing and pulley-belt mechanism. Bearing breakage and other related problems were eliminated though proper alignment in the assembly by ensuring, the shaft drum grating was parallel between the adjacent bearings using a spirit level.

3.1. Performance Evaluation

The performance evaluation of this fabricated tabular wood machine was carried out while observing necessary safety precautions. Planks of dimension 2inches by 6inches and 8 Feet length were reduced in width with the length uncompromised. The planks were fed at different feed rate of 6m/min, 8m/min,10m/min and 12m/min respectively. A stop watch was used to take record of the time taken to complete the sawing process and the experimental cutting speed was determined for three common wood species at the different feed rates. The hardness of the wood species was determined from the Janka hardness number provided in the mechanical properties of wood.

Table 2: Hardness of wood species

WOOD SPECIES	JANKA HARDNESS (lbf)
OBECHE	408
MAHOGANY	1294
OPEPE	1724

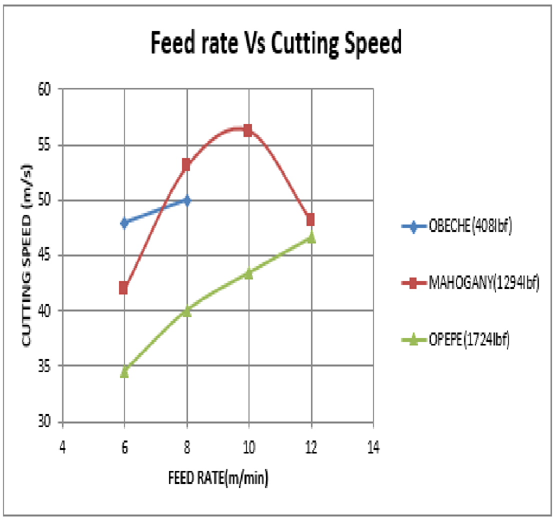


Figure 7: Feed rate Vs cutting speed for the different wood species

From Fig. 7, it is shown that the cutting speed increases as the feed rate increases from 6m/min to 8m/min for the three types of wood. The cutting speed decreases as the wood hardness increases and maximum cutting speed of 56.2m/s is observed for mahogany wood at 10m/min feed rate which drops beyond as a result of excessive pressure on the blades. Fracture is also observed for obeche wood at a feed rates above 10m/min being a soft wood. From the Janka hardness result, Opepe (1724 lbf) is the hardest and obeche (408 lbf) the softest among the three wood species considered. This suggests there a exist an inverse relationship between the cutting speed and wood hardness at constant feed rate and positive relationship between feed rate and cutting speed up to 10m/min. Also, a feed rate of 8-10m/min is recommended for the sawing machine.

3.2. Cost Analysis of Fabricated Tabular Wood Sawing Machine

The table below shows the cost of the individual components as well as Labour cost during fabrication.

Table 3: Cost Analysis of fabricated Tabular wood sawing machine

1	Angle Bar (Mild Steel)	2" by 2" and 3mm thickness	1	2,350
2	Circular Saw blade	7" diameter	1	1,400
3	Bearings	30 mm shaft fit	2	2,150
4	Belt	A37	1	750
5	Pulleys	75mm diameter,22mm hole	2	4,250
6	Metal Sheet (Mild Steel)	2mm thickness,500mm by 1000mm	4	10,000
7	Shaft	30mm diameter and 500mm length	1	1,000
8	Electric Motor	1.5Hp	1	15,000
9	Bolts and Nuts	M10, M12, M16	15	750
10	Carbon Graphite Electrodes	3mm Thickness	20	500
11	Labour Cost			25,000
12	**TOTAL**			**N63,150 ($175)**

4. Conclusion

A tabular wood sawing machine was designed, fabricated and tested. It was found to be effective, efficient and could saw wood at a speed of 52.6m/s (about 70% of the maximum theoretical cutting speed) at a feed rate of 10m/min. The performance analysis shows that the cutting speed of the fabricated tabular sawing machine is 56.25m/s and also very safe to operate. The cost valued at $175, it is affordable and economical for small scale business. Based on the construction materials selection and quality of fabrication work, the machine is durable and expected to run with proper maintenance. The efficiency, design mechanism safety at which the machine operates can be sustained. The above can be done hand in hand with addition of sensors while maintaining balance and reducing machine vibrations

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