

Design of a bench saw cutting machine for wood with automatic braking system

Tawanda Mushiri

Department of Mechanical Engineering
University of Johannesburg
P.O Box APK 524
Johannesburg
South Africa

tawandanda.mushiri@gmail.com, tawandamushiri123@hotmail.com

Fortune Masarakufa

Department of Mechanical Engineering
University of Zimbabwe
P.O Box MP167
Mt Pleasant
Harare
Zimbabwe

masarakufafortune@gmail.com

Charles Mbohwa

Faculty of Engineering and the Built Environment
University of Johannesburg
P.O Box APK 524
Johannesburg
South Africa

cmbohwa@uj.ac.za

Abstract

This research paper explores the design of an automatic safety brake mechanism on a manual circular table saw machine which stops the blade from rotating when human flesh is detected in the blade proximity. Fatal injuries are occurring, human thumbs and entire hand cutting during operation when operator accidentally touches the spinning blade. It has become a matter of concern to develop the safety mechanism which can be retrofitted on old-model table saw machines used to train students at a university wood workshop. The researchers made use of capacitive proximity sensors to detect human flesh and then automatically activate the brake pawl to the rotating blade, D.C injection brake voltage which abruptly stop the running motor. The design procedure confirmed the quick release of the safety mechanism within 0.25 seconds as revealed from the simulation of circuits in Proteus software. With this design it is possible to stop the spinning blade in 0.25 seconds, before the operator touches the spinning blade and also the mechanism is adoptable to all circular saw machines (panel saw, bench saws), thus making a work-safe environment on the circular saws.

Keywords

Design, brake mechanism, safety, saw cutting machine, wood

1. Introduction

In changing the direction of the building sector towards a sustainable environment and satisfying the actual needs without compromising the next generations' needs, wood and their derivate products are the most suitable materials, due to renewability and it is a natural resource (Hileras, 2013).

Wood happens to be an ecological material, it brings other excellent qualities as high resistance to corrosion, durability, adaptability and versatility, these qualities make the wood products included among best references of the habitats, decoration, construction, packaging in the 21th century (Hileras, 2013).



Figure 1. Building constructed using wood in Bryno

Its works has become extremely extensive even in marine construction particularly modern ships and yachts because of low density and hygroscopic nature to adapt in marine conditions. In this regard it has taken over metals in marine and extremely cold environments possibly because of the resistivity to corrosion and embrittlement of which most steels on subjection to temperatures below the ductile brittle transition temperature (DBTT) fail in brittle fractures. (Donald R. Askeland, 2010). **DBTT** means the transition temperature demarcating ductility and brittleness, below this temperature a metal behaves as a brittle material it breaks with very minimum deformation (Chatterjee, 2015). The extensive work has been a motivation for engineers to develop modernised, digitalised and automated wood cutting, working and furnishing machines including sliding table saws, universal woodworking tools which are rather smart, efficient and reliable.

1.1 Background



Figure 2. SC25 Manually operated circular table Saw Machine.

In Zimbabwe over the past few decades' wood cutting and designing has been progressing. This is because of job opportunities are shrinking every day and night so men have chosen to sustain themselves, earning a living by making wood products for selling. The fundamental tool/machine in wood cutting and processing (mitring, cross-cutting, bevel angling) is the circular table saw machine to these above mentioned Small to Medium Enterprises (SME's). So the significance of this project focuses on the design of a simple table saw machine, concentrating on improving the safety of the fundamental machine by implementing an automatic safety brake mechanism when human flesh is detected in the rotating blade vicinity area (in the proximity of spinning blade). On a global scale, these machines have been modernised into automatic operated, Numerical Control and Computer Numerical control. The project therefore seeks to achieve the following objectives

1. To design an automatic blade stoppage within 30 milliseconds whenever operator finger or thumb accidentally enters the proximity area prior to the spinning blade.
2. The automation improvement must make the entire machine assembly cost between \$600-\$2500, affordable to local, small to medium enterprises (SME's) in Zimbabwe.

Mechanical components can always be replaced but not flesh. Safety is the key, without it can lead to injuries below.



Figure 3. Injured machine operator on a table saw



Figure 4. Injured machine operator (b)

Major accidents occurring during operation particularly cutting of finger and or even the entire hand. The reaction time for human being is quite high implying poor impulse response to instantly remove hand while the blade rotates at about 3000 rev/min, this result in cutting of the thumb or even the entire hand.

2. Literature review

A table saw 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. The first record of patent for that machine was issued in 1777 to an English man, Samuel Miller. In a modern table saw, 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.

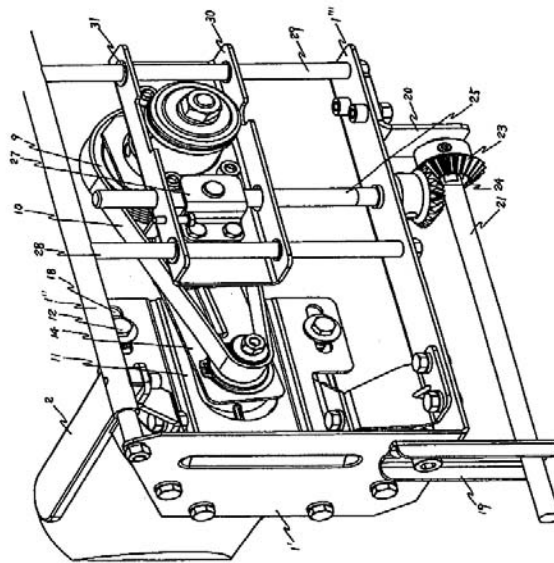


Figure 5. Blade driving mechanism for a table saw (electro-mechanical, 2006).

2.1 Safety automation in the existing circular saw machines



Figure 6. Finger and hand protection on Panel Saws (Dietmar Reinert, 2009)

The project emphasis is on preventing hand movement leading to hazards and for non-contact detection of fingers intended to permit comprehensive and economical protection on circular saws. (Dietmar Reinert, 2009). With an automatic blade guard an improved integration of the protection system can be achieved. The distinction between skin and wood or other material is achieved by a dedicated spectral analysis in the near infrared region using LED and photodiodes. With a kind of light curtain the intrusion of hands or fingers into the dangerous zone near the blade guard can be prevented and the guard will enclose the spinning blade within itself (Dietmar Reinert, 2009). The malady of the mechanism are:

- It uses spectral analysis of light is focused in the cutting area this means detection of light rays fringing on an interior or exterior defect of wood is likely to activate the safety guard hence method is not reliable and accurate.

- Both the wood and human skin/flesh are not conductive hence are more likely to give the same results which makes the method inconvenient.
- Since the guard is the one which moves to hide the spinning blade within it, it might injure the finger if they have already entered the proximity vicinity.

3. Methodology

For the technical mechanical drawings and assembling of parts the researcher used Solid Works 2015 and AutoCAD 2015. Finite element Analysis (FEA) for stress analysis of the critical components using SolidWorks 2015 software. Sensor programming to execute the individual anticipated routines, the researcher used Arduino software and for simulating the micro-controller circuit, Proteus software. The researchers also visited local machine suppliers in compilation of price of the machine assembly.

4. Results and discussion

4.1 Determination of cutting force



Figure 7. Table saw machine in the university wood workshop, used for training first year students.

The researcher did an experiment in the university wood workshop on the 24th of March 2016 to determine the cutting force and hence the choice of the motor as drive power for the saw blade. The emphasis of the experiment was to select a specific motor that could supply enough power for any type of wood therefore the hardest wood Mopane was used for the experiment. The target parameters were the cutting force and the spindle rotational speed V_c .

The cutting force, feed force and the spindle rotational speed were calculated.



Figure 8. A 350 mm diameter cross-cut saw blade

The mechanical process of cutting using saw blade is referred to as an orthogonal process (two-dimensional deformation). (Orlowiski, 2013). Using the Ernst and Marchant's force circle the forces acting during sawing can be calculated. The following parameters are key consideration in the procedure of finding the cutting force:

F_a – Active force, F_r – thrust force, F_C – Cutting Force (to be found from experimental result, with hardest wood on market), F_μ - frictional force on the rake face, F_N – Normal force to the rake face, $F_{T\theta}$ – Force required to shear the

wood along the shear plane, $F_{N\theta}$ - Normal force to the shear plane, α_r - clearance angle, θ_c - shear angle, γ_f - rake angle and β_μ - friction angle.

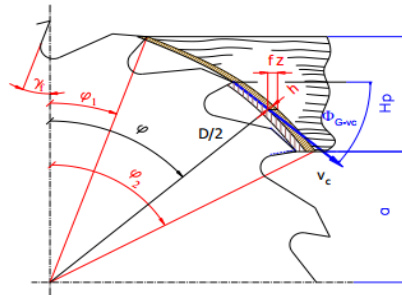


Figure 9.2 Saw blade angles illustration.

The Power required for the blade is thus calculated using the formula below

$$P_{cw} = F_c V_c = (z_a \cdot \tau_Y \cdot S_t \cdot Y \cdot V_c \cdot h) / (Q_{shear}) + (z_a \cdot R \cdot S_t \cdot V_c) / (Q_{shear}) \quad \text{where:}$$

- F_c - Cutting Force (to be found from experimental result)
- τ_Y - is the shear yield stress for the perpendicular speed direction
- Y - Is the shear strain along the shear plane given by:

$$Y = (\text{Cosine } \gamma_f) / (\text{Cosine } (\theta_c - \gamma_f) \cdot \text{Sin } \theta_c)$$
- S_t - Is the kerf (the width of the orthogonal cut)
- β_μ - Is the friction angle given by $\tan^{-1}(\mu) = \beta_\mu$.
- μ - is the coefficient of friction between the wood surface and steel blade material.
- γ_f - rake angle
- θ_c - shear angle which defines the orientation of the shear plane with respect to the cut surface
- R - Is the specific work of the surface separation/formation (fracture toughness)
- Q_{shear} - is the friction correction:

$$Q_{shear} = \frac{(1 - (\text{Sin } \beta_\mu \cdot \text{Sine } \theta_c))}{\text{Cosine } (\beta_\mu - \gamma_f) \cdot \text{Cosine } (\theta_c - \gamma_f)} \quad \text{where } Q_c = \left(\frac{\pi}{4} - \frac{1}{2}\right) \times (\beta_\mu - \gamma_f)$$

$$z_a = \frac{(\phi_2 - \phi_1)}{\phi_t} \quad \text{Is the number of teeth in the contact with the kerf}$$

- ϕ_1 - is the angle of tooth entrance given by $\phi_1 = \arccosine\left(\frac{2 \times (H_p + a)}{D_{cs}}\right)$
- ϕ_2 - is the exit angle given by $\phi_2 = \arccosine\left(\frac{2a}{D_{cs}}\right)$
- ϕ_t - Is the total of ϕ_2 and ϕ_1 .
- D_{cs} - diameter of the blade
(350 mm was used for the experiment).
- h - is the uncut chip thickness $h = f_z \cdot \text{Sine}(\phi_{average})$. $\phi_{average} = \frac{\phi_2 + \phi_1}{2}$
- H_p = Work piece height (depth of cut)
- f_z - feed per tooth (m/min)
- a - position of the work piece

The resulting plot is a demonstration of the cutting force per feed per one tooth.

Table 1. Uncut chip thickness, against obtained cutting force

uncut chip thickness/feed per tooth $\times 10^{-5}$ (m)	cutting force (N)
0	3.8424
1.1	7
2.3	10
3.2	13
4.6	18

5.6	22
7.5	26.5
9.1	32
11	36
12.5	41

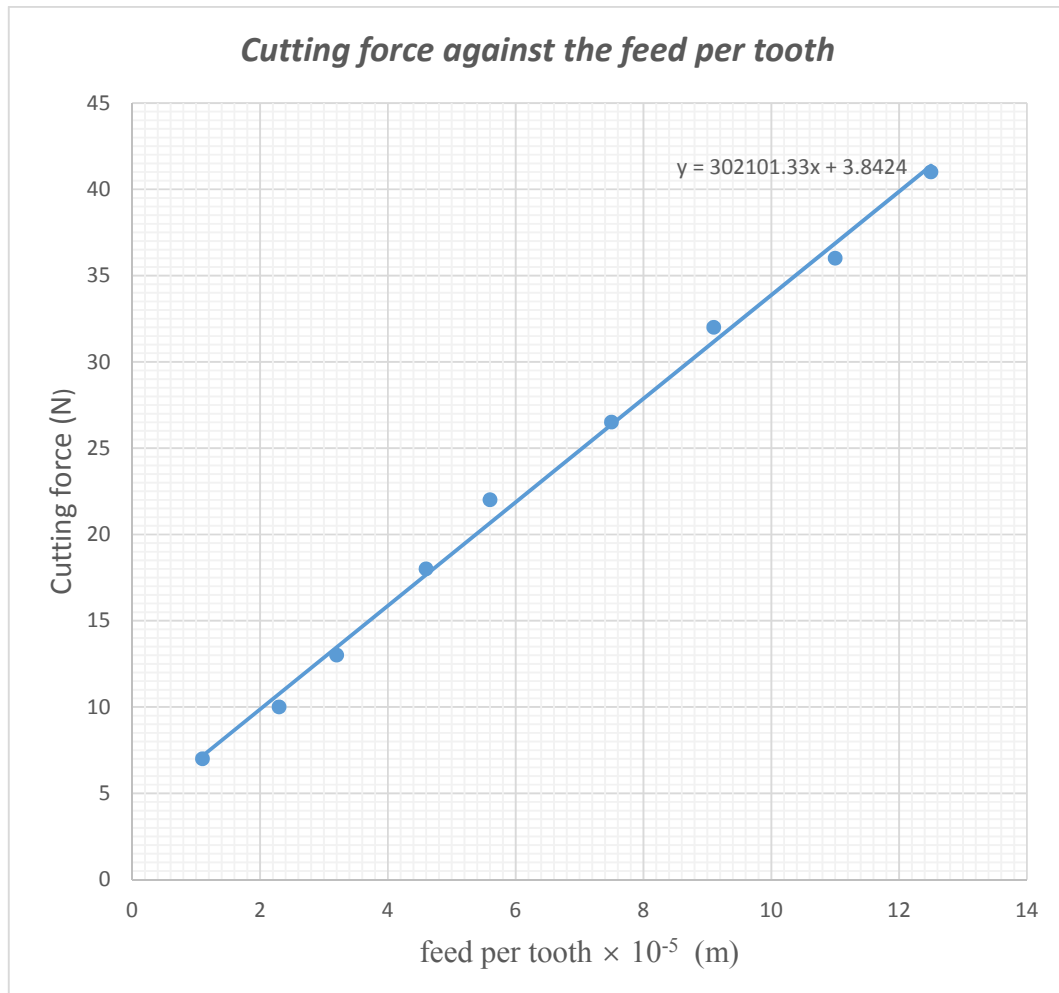


Figure 10. Cutting Force against the feed per tooth

From the graph the maximum value for *feed per tooth* was found to be 12.5×10^{-5} m.

Therefore, the Corresponding Cutting Force = $302101.33 h + 3.8424$

$$(302101.33 \times (12.5 \times 10^{-5})) + 3.8424$$

$$\text{Cutting Force (F}_c\text{)} = \mathbf{41.605 \text{ N.}}$$

The Corresponding maximum power required to perform the task is:

$$P = F_c \times V_c \quad \text{----} \quad 41.605 \times 50.488$$

$$P = 2100 \text{ W} = 2.1 \text{ KW}$$

But $0.746 \text{ Kw} = 1 \text{ horsepower}$ therefore:

$$2.1/0.746 = 2.82 \text{ horsepower}$$

Taking **3 horsepower** for a standard single phase motor.

This effectiveness factor is reasonable for the 3 horsepower will effect successful operation on any specimen and is not too much above the optimum this saves energy- lower cost monthly bill.

4.2 Design consideration

The sensor shall be embedded into the blade guard of the recommended material Thermoplastic Polyester Housing in the edge of approach. In this case the area of the table surface on which the sensor is directed to is made **from wood** and the distance between the **guard and wood work-** piece (even when no wood) is maintained constant by an adjustable guard. The sensor measures the capacitance between the attached antenna and the environment. This is done by an LMC555 timer IC. It outputs a signal with a frequency between 0 and 2 MHz, depending on the measured capacitance. The sensor is intended to be connected to a microcontroller that continuously measures the frequency and filters the resulting signal.

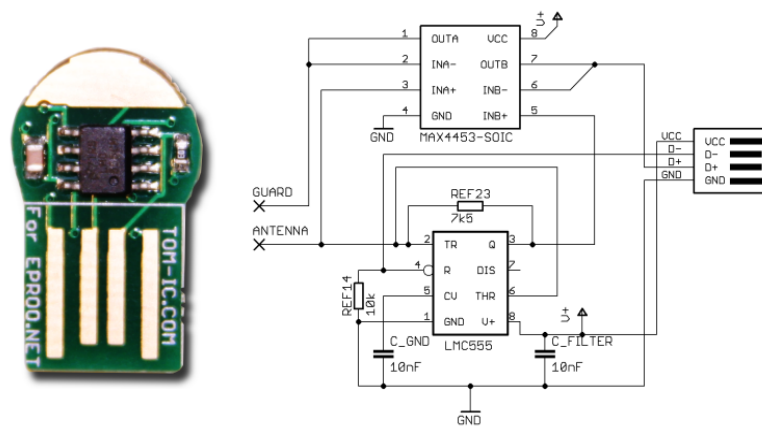


Figure 11. (a) Capacitive sensor illustration, (b) circuit

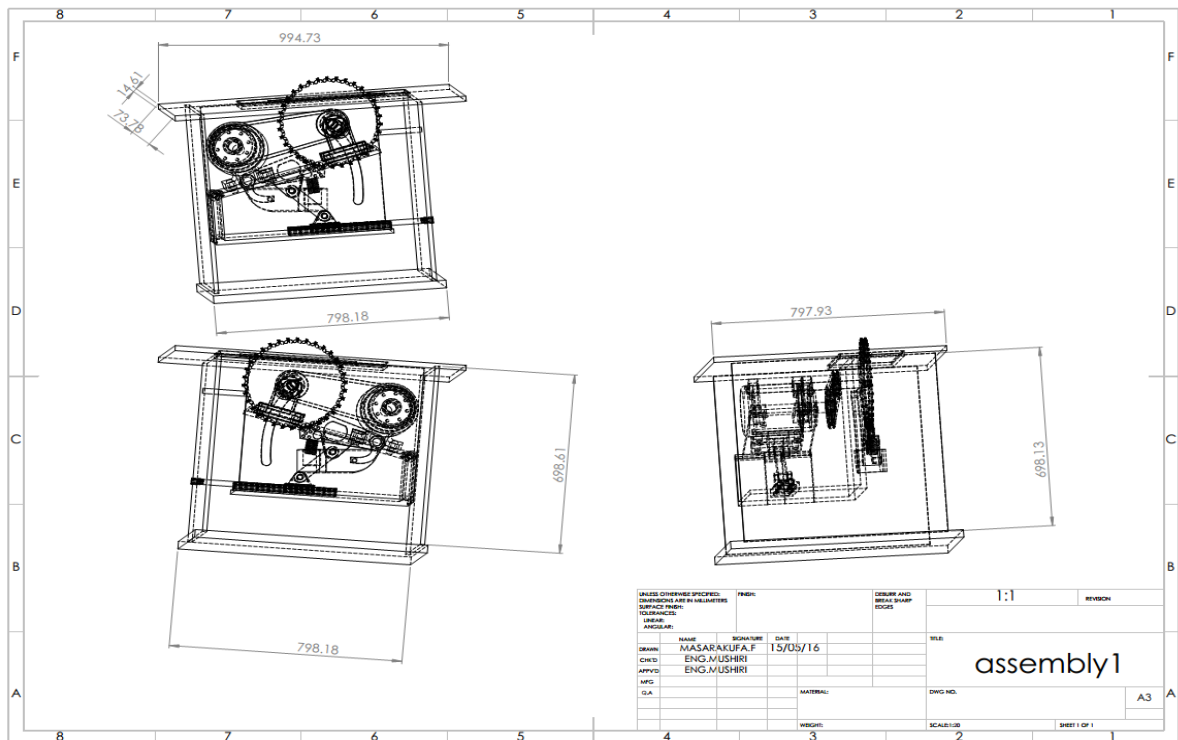


Figure 12. Assembled saw cutting machine

5. Recommendations and conclusions.

To utilize the full potential of the safety mechanism on the table saw machine the researcher found out that the following improvements can be made:

- Modify the safety mechanism without damaging the brake shoe possibly by an increased D.C voltage applied to the stator.
- This mechanism proposed in this paper damages the brake cartridge and sometimes the blade, so having a stopping mechanism which doesn't damage any of the components the design will be considerably cheap in the long run of using the machine, possibly using only the D.C injection baking
- This machine is designed not to release the safety brake when the motor is not running, but it would be more effective if the machine can be modified not to start without the safety mechanism correctly installed.
- The safety mechanism should be retrofitted to all circular saw machine (table saw, panel saw and bench saw machine)

5.1 Conclusion.

The scope of the project was to enhance safety of the table saw and making cost as low as possible, therefore with this project the researcher managed to estimate the overall cost of the project to a total of \$827.49, which falls in the range stipulated in the project objectives. Using Proteus software, for simulating the circuits used for the braking mechanism it confirms stopping within 0.25 seconds from the onset human flesh is detected in the blade proximity area, therefore with this design it can applicable for practical use to satisfy the anticipated task in improving safety. The paper is on manual table saw machine, which imply that manual machines without the safety mechanism can be retrofitted with very slight additions and alterations to fit the safety mechanism but only for those table saw machines with the blade being driven from the motor through means of belt, it does not work for direct drive (blade directly mounted to the motor rotor).

Acknowledgements

I would like to thank the university that I worked with for data gathering.

References

- Biezl, 2012. *DC injection braking*. [Online] Available at: https://en.wikipedia.org/wiki/DC_injection_braking [Accessed 17 04 2016].
- Blackman, B. R. K. H. T. R. P. Y. W. J. G., 2012. "*Tool sharpness as a factor in machining tests to determine toughness*". [Online] Available at: <http://www.10.1016/j.engfracmech.com> [Accessed 25 03 2016].
- Bosch, R., 2009. *Power Tools for Professionals*. [Online] Available at: <https://www.boschtools.com/ca/en/boschtools-ocs/table-saws-4100-30445-p/> [Accessed 15 january 2015].
- Brooks, 2003. *ABB Motor guide*. [Online] Available at: <http://www.abb.com/motors&drives> [Accessed 08 april 2016].
- brooks, 2003. *rotating a.c machines, Three phase motors*. St Thomas' Road, Huddersfield West Yorkshire: Brook Crompton.
- Carol, 2005. *OPTI_222_W10 - OPTI 222 Mechanical Design in Optical Engineering*. [Online] Available at: fp.optics.arizona.edu/optomech/references/OPTI_222/OPTI_222_W4.pd [Accessed 08 April 2016].
- Chatterjee, A., 2015. Ductile-to-brittle transition temperature (DBTT).. *Effect of deformation temperature on the ductile*, 30 April, pp. 58-70.
- Controls, C., 2002. *D.C injection braing system for an A.C Electric motors driving woodworking machines*. west yorkshire: crompton controls.
- Dietmar Reinert, N. J. F. B.-R.-S. O. S., 2009. Hand and Finger Protection for Circular Saws. *Hand and Finger Protection for Circular Saws*, 7(8), pp. 137-145.
- Dietmar Reinert, N. J. O. S., 2013. *hand and finger protection for circular saws*. [Online] Available at: http://link.springer.com/chapter/10.1007/978-3-7908-2127-7_14#page-2 [Accessed 17 december 2015].
- Donald R. Askeland, P. P. W. J., 2010. *The Science and Engineering of Materials*. Emeritus: s.n.
- Frank Bartos, P., 2010. *electrical engineering blog*. [Online] Available at: <http://electricalengineeringbasics.blogspot.com/2010/01/dc-injection-is-most-basic-and-widely.html> [Accessed 21 04 2016].
- Freescale Semiconductor, I., 2006. *freescale semi conductor*. [Online] Available at: http://www.nxp.com/files/sensors/doc/app_note/AN1985.pdf [Accessed 04 05 2016].
- Freescale Semiconductor, I., 2006. *freescale.com*. [Online] Available at: <http://www.freescale.com/support> [Accessed 10 march 2016].
- GSK, E. C., 2007. *GSK CNC*. [Online] Available at: http://www.gskcnc.com/cnc_lathe.php [Accessed 7 05 2016].
- Hearn, E., 1999. *Mechanics of materials 2*. 3 ed. London, England WIP 9HE: Butterworth-Heinemann.
- Hibbeler, R., 1997. Column Buckling: Design using Euler Theory. In: R. Hibbeler, ed. *Mechanics of Materials*. 3rd ed. Englewood Cliffs: Prentice Hall.
- Hlaskova, 2015. Wood toughness, sawing. *BioResources*, 10(3), pp. 5381-5394.

Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management Detroit, Michigan, USA, September 23-25, 2016

Hurst, K., 1999. Concept Selection. In: *Engineering Design Principles*. New York: John Wiley and Sons, pp. 53-63.

Khemani, H., 2009. *Bright Hub Engineering*. [Online]

Available at: <http://www.brighthubengineering.com/manufacturing-technology/55670-what-is-numerical-control-machine/>

Khurmi R, S. G. J., 2005. *A textbook of machine design*. NEW DELHI-110 055: RAM NAGAR.

Khurmi, R. S. a. G. J. K., 2005. *a textbook of machine design*. 14 ed. RAM NAGAR, NEW DELHI-110 055: EURASIA PUBLISHING HOUSE (PVT.) LTD..

Khurmi, R. S. G. J. K., 2005. *A textbook of machine design*. 14 ed. New Delhi: EURASIA PUBLISHING HOUSE.

Kopecky, Z. a. R. M., 2012. Impact of dorminantvibrations on noise level of dimension circular saw blades. *Wood Research*, 57(1), pp. 151-160.

Locksmith, V., 2012. *home Alarm PIR Tech*, s.l.: Steve's Lock.

Orlowiski, K. a. O. T. a. A. A. a. C. D., 2013. Application of fracture mechanics for energetic effects predictions while wood sawing. *Wood Science and Technology*, 47(5), pp. 949-963.

Orlowski, K., 2003. *Narrow-Kerf and Accurate Sawing of Wood*, Gdanski: Politechnika Gdansk.

Orlowski, K. a. A. A., 2007. Determination of the cutting power of the sawing process using both preliminary sawing data and modern fracture mechanics. *Proceedings of the third international Symposium on wood machining*.

Fracture Mechanics and Micromechanics of Wood and Wood Composites with regard to Wood Machining., 21-23 May, pp. 171-174.

Patani, S. P., 2007. *AN ATTEMPT TO IMPROVE SAFETY SYSTEM OF BENCH SAW*, Unjha: Dabhi.

Ramírez-Cadena, M., 2013. *LOW COST MACHINE TOOLS RETROFIT WITH A UNIVERSAL NUMERICAL CONTROL*. Mexico City, Tecnológico de Monterrey.

Rongmei P, L., Shimi S, L., S, D. C. & K, V., 2012. International Journal of Engineering and Innovative Technology (IJEIT). *A Novel Fast Braking System for Induction Motor*, 1(6), pp. 65-68.

Shaojuan, W. C., 2015. machine tools. *The Key Technology Research about 3D CNC Bending Machine and Experimental Verification*, Volume 73, pp. 584-588.

Sivakumar, D., 2013. MANUFACTURING industries. *International Journal of Computer Integrated Manufacturing*, 26(6), pp. 561-570.

Standards, B. o. I., 2007. *IS/IEC 60947-5-2: Low-Voltage Switchgear and Control Gear, Part 5: Control Circuit Devices and Switching Elements, Section 2: Proximity Switches*. [Online]

Available at: <https://archive.org/details/gov.in.is.iec.60947.5.2.2007>

[Accessed 19 december 2015].

Terzic, E. T. J. N. R. A. M., 2012. *Capacitive Sensing Technology*. 10 ed. s.l.:springer.

WisegEEK, 2016. *"What Is an Ultrasonic Motion Detecto*. s.l.:s.n.

WisegEEK, 2016. *Technology Comparison of Motion Detectors*. [Online] Available at:

<http://www.ecosirius.com/technology.html>. [Accessed 19 july 2014].

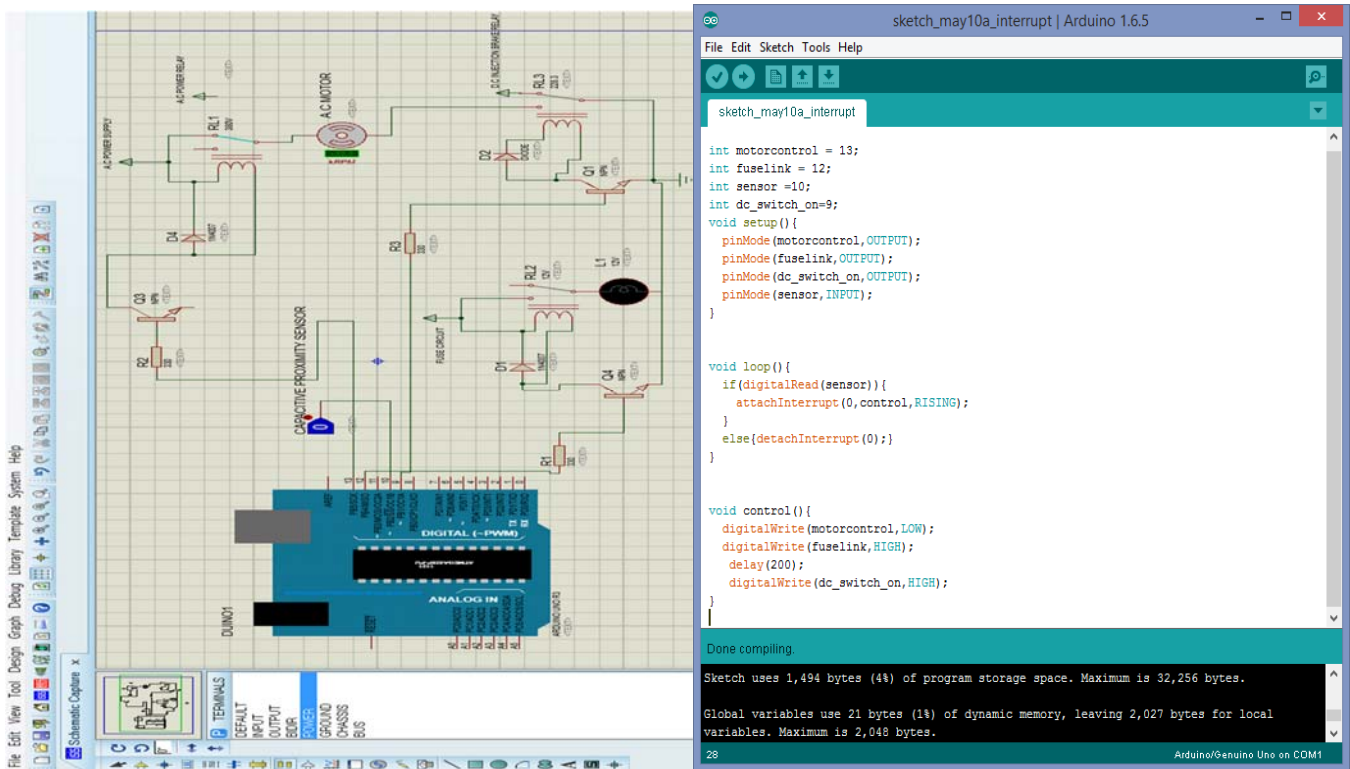
Biography

Tawanda Mushiri is a PhD student at the University of Johannesburg in the field of fuzzy logic systems and maintenance, is a Lecturer at the University of Zimbabwe teaching Machine Dynamics, Solid Mechanics and Machine Design. His research activities and interests are in Artificial intelligence, Automation, Design and Maintenance engineering Contacted at tawanda.mushiri@gmail.com / 201337963@student.uj.ac.za

Fortune Masarakufa is a Mechanical Engineering student at the University of Zimbabwe (2016). Contacted at masarakufafortune@gmail.com

Charles Mbohwa is currently a Full Professor of Sustainability Engineering and Engineering Management at the University of Johannesburg, South Africa. Contacted at cmbohwa@uj.ac.za

Appendix 1: Simulation of the micro-controller processes, Arduino simulation to perform the micro-controller tasks



The Arduino code for:

1. a. Triggering off the AC power supply to the motor
b. triggering on the fuse circuit to release the initially compressed spring hence the brake pawl.
2. Triggering on, the DC injection voltage supply to the AC motor to stop.