Design for manufacture and assembly of an automated wood cutter: Case for developing country

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Abstract

Wood is a renewable source of energy that is used by everyone and cutting wood is a vast problem in developing countries such as Zimbabwe where manual methods are still been mostly used. Zimbabwe has been facing electricity shortages to the extent of importing 1200 megawatts of electricity from Zambia which is almost half of its peak demand. The aim of the paper is to design an automated wood cutter for cutting wood for domestic use. The objectives were to design a wood cutter which can cut wood of diameter 100mm, to design a wood cutter with an output capacity of (850-1000) kg per hour and to come up with a 3D prototype of the wood cutter. This machine will cut wood with minimum human influence. The objectives were achieved by performing an experiment to come up with the force required to cut the 100mm diameter round-wood and the torque generated was used to design and size the components of the machine. SolidWorks 2016 was used to calculate and estimate the bearing type and life, do the deflections and stress analysis to determine the weakest point on the machine. Automation was done using the SMT Version 3.3 PLC in connection with a shoe brake to protect the machine operator making the machine safer and user friendly. The fuzzy logic controller was used to monitor moisture content of inserted wood to prevent jamming of the machine. DFMA principle was also used to optimize the machine cost without reducing the product quality.

Keywords
Woodcutter, Design For Manufacture and Assembly (DFMA), Automation, Fuzzy, Programmable Logic Controller (PLC).

1. Introduction

In Zimbabwe, wood is used as fuel and cutting is done manually since the country lacks foreign currency to import wood cutters hence need for manufacturing this machine with available resources. Wood is a very important and beautiful raw material that is used by everyone in the world. In Australia, which is one of the world's most developing countries, researchers found that about one cubic meter (m^3) or one tonne of wood is used for every human being each year (Bootle, 2006) .Wood is a renewable material which comes from the trunk or the main stem of trees. Trunks of mature trees comprises of two kinds of woods that is the heartwood which forms the central part as well as the sapwood which surround the heartwood(Wallis). Trees develop an annual ring pattern in the stem as they grow with each annual ring being analogous to one year's growth. They are two main types of wood which are hardwoods and softwoods(Wallis). In developing countries, wood is mainly used as a source of fuel for domestic purposes as well as for other processing industry(D Boucher, 2011).

A wood cutter is basically known as a machine which cuts wood into pieces of desired sizes depending on the design of the machine for example a band saw which is used to cut logs across into the desired shape. In Zimbabwe**,** a country which is still developing, about six million tonnes of wood fuel are used per year for domestic, agricultural and industrial use due to the power cuts which were being experienced by the country(Mushava, 2013).The wood processing industry in Zimbabwe focuses mainly on the exotic plantation forestry which is largely based on pines and eucalyptus and the industry is mostly vertically integrated in timber production ,processing ,packaging and marketing.

The industry employs about 16000 people, contributing to about 3% to the Gross Domestic product(Department, 2014).The wood processing industry in Zimbabwe uses the wood cutter after cutting down trees for either cutting them down into pieces of smaller length(Engineering, 2013).The wood processing industries are currently using conventional methods of feeding the machine with the infeed hopper inclined at an angle such that the work is difficult to do especially when dealing with logs of larger diameters. The safety of users is also threatened during the feeding of wood as if they by mistake put their fingers at the inlet they might get wounded and this also causes malfunctioning of the machine(Engineering, 2013).

Border Timbers is one of the major wood processing companies which is still running and, their manufacturing section is divided into three major divisions. There is the Forestry division which specializes basically in planting and felling the trees and during felling, chainsaws are used which are used to fell trees whilst they will be hold from falling by the holder(Timbers, 2015). The sawmilling division is the second which basically specializes in processing which is basically cutting both the pine and the eucalyptus logs into the desired product. The third division is the Pole division which is designed for processing logs from the forestry into poles and some of their customers being ZETDC and TelOne which purchase these logs for transmission lines(Timbers, 2015).

In addition to that, during the process of felling trees, the company extract the stem leaving the upper parts of the trees lying around and now to prepare them for planting new trees, they will have to burn the left-over branches. In Zimbabwe, most of the Zimbabwean citizens are

subsistent farmers and they depend mostly on wood as a source of fuel and the situation is currently being worsened by the dwindling levels of water in Kariba dam which is the main source of hydro-energy in Zimbabwe. In accumulation to that, Zimbabwe is bringing in 1200 megawatts of electricity from Zambia which is about half of its peak demand(Kadzere, 2015). Cutting of wood for use as firewood has become a problem in since many citizens in Zimbabwe uses the conventional axes and saws which are more arduous to use as well as very unsafe due to incidents of cutting oneself especially the legs.

2. Literature Review

Wood shares common features and yet they are produced different tree species(G E. Woodson, 2000). Annual rings are a characteristic of an annual growth pattern of slow and rapid growth rates experienced by trees. Each pattern will be displaying one year's growth and by counting the number of annual rings, it is possible to find the trees age. In Zimbabwe, they there are two major companies which specialize in planting and processing trees and these are Allied Timbers and Border Timbers. Different tactics of cutting have been well thought-out in the wood products industry dependent on the use of the wood and purpose of operation. In all of these cutting tactics, the surface quality obtained as a result of the cutting process is affected by features related to the processed material such as tree species, quality of materials, moisture contents of the materials just to mention a few.

Several sources were used by the researcher to study machines which are currently used to cut wood and these includes wood crushers, lasers, hand saws, chainsaws, axes and wood chippers. Wood crushers are devices used in reducing large volume wood into smaller volume materials. This wood crushers processes different kinds of waste wood material from carpenter workshops, saw mills, after wood cut, wood cleaning, from parks, gardens, avenues in towns and communities, for disposal of waste building wood.

Wood chippers are used for chipping all sorts of wood up to sizes ranging from 20-25mm to 100-150mm and they may be electric or tractor engine powered or diesel powered for example the Laimet screw chipper. It has a conical screw blade which rotates pulling in the log and chips at the same time. The screw blade is joined to a fly wheel whereby the rotating wings flip the chips out of the chipper. It uses several types of in-feed conveyors for transporting logs into the chipper in-put opening where the screw blade grabs the log pulling it into the chipper. It doesn't use additional in-feed device and as the screw blade rotates with a speed, the chipping speed remains the same warranting standard chip length and uniform, high standard chips unlike those produced with a drum- and disc chipper.

The Branch logger cutting machine has a feed way which is oriented either horizontally or vertically or oblique. The branch logger is powered by shaft and the power is transferred with gears from the engine to the cutting device. The knives are made from tool steel and the knife is supported by a pad after each sharpening. They have a small gap of maximum 0.3 mm between knives. Knives can produce more than 1000 bags per sharpening depending on the quantity of impurities. The impurities include clay and stones.

The cutting hand saws made of metal are also used and comes in three principal types which are the reciprocating power saws, the band type saw and the circular type power saws. The band type uses the back and forth or reciprocating saws with a blade and the cutting is done on the backstroke. It has a continuous blade that moves in one direction. The circular type power saws which has a round, flat blade that rotates into the work. The blades are grouped into toothed,

friction or abrasive depending on the material and the operation(Scanner, 2015).The Fig 2.1 below shows what saw types being described.

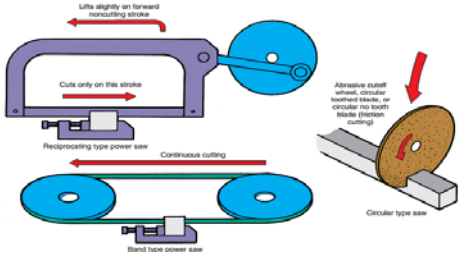

Figure 1. Saws types in use (Scanner, 2015)

Axes are also used in traditional wood harvesting especially in developing countries, for felling, debranching, cross-cutting, splitting and debarking wood. Its advantages are its simple tool outfit as well as its easy maintenance. Its disadvantages are in its heavy work and it wastes a lot of wood and causing many accidents, including very serious ones(Engineering, 2013).

Figure 2. Wood cutting axe (Gilmore, 2016)

2.1 Problems associated with the current conventional wood cutters

Axes mostly used in Zimbabwe for cutting firewood has problems which threatens both the operator and the final user of firewood, but however the user is the one that faces a greater risk. Most axes used in Zimbabwe have a wooden handle and a metal cutter which engraves into the wood branches being cut and therefore the metal cutter has a tendency of sometimes moving out of the handle due to the effort being applied by the user and the result is the metal cutter being thrown up such that it may hit the operator. The problem faced by the user of the wood is that since when using an axe, the user has to cut the wood at an angle less than 90^0, some of the wood is wasted during the cutting process. Since of all factors, safety is of supreme importance, there is need for machine which can cut wood smartly without any wood waste as well as menacing the axe operator.

Looking again into the wood cutting industry in Zimbabwe, for example at Erin sawmills which is a sub-plant of Allied Timbers, the branches which are left after the extraction of the saw logs are burnt can be harnessed for use as a fuel and instead of burning, the machine to be designed can be used to smartly cut these branches into smaller pieces which can be packaged and be sold to other citizens of Zimbabwe in need of wood for domestic use such as heating and cooking. By practicing this, it would imply that the problems associated with burning such as disruption of the ecosystem would have been avoided and also the company would gain income from these waste wood.

2.2 Cutting power requirements

Power demand is directly proportionate to the wood cutting forces. The forces invested by the tool are directly affected by factors connected to feeding process, the cutting tool, and the workpiece (P.Koch, 2000). Wood features for instance species, basic density, sizes, direction of grain with respect to the tool edge, and the presence of knots or decay also affect the wood mechanical properties which consequently affects the cutting force requirements. In Northern countries, the temperature of logs becomes critical during the winter. Mechanical strength of wood is greater at temperatures below zero especially in greater Moisture Content conditions(A. Mushiro, 2006)**.**The geometry of the cutting tool has an effect on the forces made in the process of machining wood, for example, forces increase as the rake angle decreases in the process of cutting orthogonally(G E. Woodson, 2000); (P.Koch, 2000).

3. Methodology

The designer studied and researched on the available cutter machines and the problems faced by the operators. The study was carried for case for Zimbabwe. The designer made use of Concepts from Engineering Design, Solid Mechanics and Control Systems, visits to wood processing industries, university library journals, research on the available wood cutters used in Zimbabwe was performed, concepts from Engineering Design and Solid Mechanics were used to design the size of the required motor and other several parts of the machine. Concepts from Control Systems were used in the automation of the wood cutter.

Automation was accomplished on the machine through the use of the PLC and Fuzzy controller to upsurge safety of the machine as well as solving the problem of jamming of knives respectively. Design for manufacture and assembly was carried out on the machine in-order to come out with a cost-effective machine without changing the performance or lowering the quality of product. The machine was modified such that it could be manufactured with the available resources in Zimbabwe which is a developing country. The researcher finally came out with a 3D printed model of the wood cutter.

4. Automation

The Charpy impact toughness test equipment was performed on the 11mm samples of softwood from pine trees with moisture content values in the range of 8%-11% and each of the samples were cut on the marked points. After being struck with a pendulum hammer and the energy absorbed to fracture the material was found and the value was used to estimate the value of the energy required to fracture 100mm wood which was used to find the torque required from the motor.

Figure 3. Charpy Impact testing equipment (UZ Mechanical Engineering Laboratory)

Using the above force, the motor and several parts of the machine were sized. The torque required was found and it was then used to design the driver shafts, spur gears, the belt drive, keys and the bearing. The deflection of the driver shaft, maximum bending moment and the maximum stress were calculated theoretically and a von-misses analysis was performed on the same shaft and the theoretical values were compared and confirmed with the von-misses analysis. Stress analysis was also performed on the knives as it will be cutting wood to check on the maximum stresses and ensuring safety during design of the shaft.

Automation was achieved using the Programmable Logic Controller (PLC). An infrared sensor which will be continuously producing infrared radiation will detect the presence of the hand in the proximity of up-to 300mm.The presence of a hand will cause IR to be deflected and then it will be detected by the detector. In positioning the sensor, the emitter and the detector was placed side by side such that in the presence of a hand in white gloves, IR light will be reflected back to the detector and then current will flow in the sensor circuit activating the sensor. The PLC sensing an input on the sensor will activate the shoe brake to stop the rotation of the driver shaft. The Ladder program was used to set the program and is as shown below:

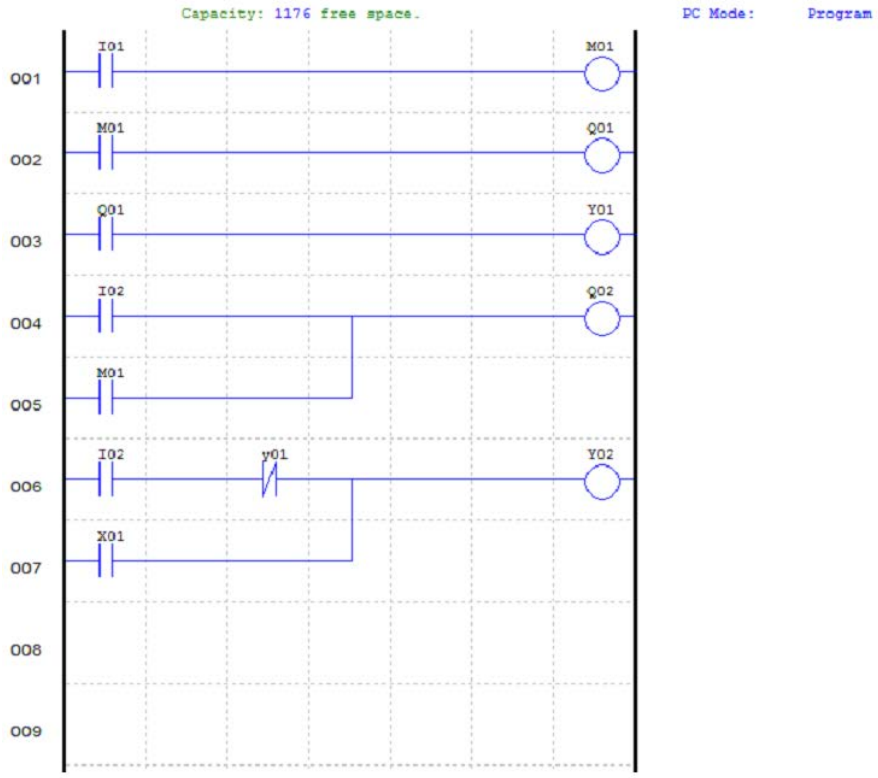

Figure 4. Ladder logic program

A Fuzzy controller was also incorporated on-order to controller the moisture content of the wood as too much little of water content of wood being cut may cause jamming of the blades in the wood. The fuzzy program was set-up in such a way that only wood of moisture content in the range 12%-50% is cut. If wood detected will be out of range, the wood will be reject with a sound on the alarm.

5. Design for Manufacture and Assembly (DFMA)

DFMA was done with the aim of evaluating and assessing the wood cutter for coming out with a machine with a reduced cost. This was achieved by basically improving both the assembly and the manufacturing processes making sure that the performance of the machine remain unchanged. The frame support was reduced by 5mm, the knife holder material had its material reduced also by 5mm and the net number of components were reduced by removal of the flexible belt assembly which did not also affected the net torque or power transmitted. The belt assembly also made the net maintenance costs of the belt to be cut making also the whole machine to be easy to assemble. The cost of the machine was finally reduced by **US$107.80.**The final diagram of the machine is as shown in the figure below

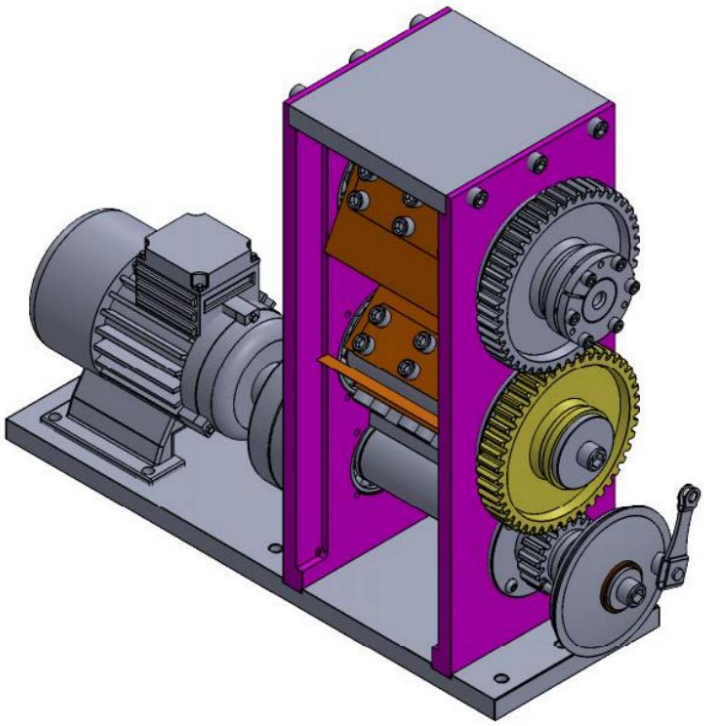

Figure 5. Drawn assembled wood cutter

6. Results and Discussion

The researchers looked into the literature that was required to partake the project which included the wood anatomy, sawmilling in developing countries as well as in first world countries, the current machines being used, the problems faced with these machines and how the industry has tried to reduce them. This helped the researcher to come up with solutions to achieve the objectives stated in chapter 1 as well as to come up other methods which could be used to protect the machine users from being injured by the blades. The researcher came up with possible solutions and used the Binary Dominance Matrix Method to come.

The researcher worked on designing for cost effective manufacturing of the wood cutter by analyzing the cost involved and how best these costs can be reduced without reducing but rather improving the overall machine performance. Design for ease of assembly was also performed in this write-up by reducing the overall machine assemblies of the machine. Cost analysis was performed, DFMA reduced the overall cost of the machine as well as making it easier to sustain by an amount of by **US$107.80** which is reasonable.

7. Recommendations and Conclusion

The researcher acclaims that in the process of feeding wood, care should be taken before switching the machine on to check if it is in a good condition to function and the users are recommended to wear eye protection googles to protect themselves in the case of flying cuts. In sustaining the machine, the bearings should be greased after approximately every 5000Hrs of service and after use, the machine should be shut down, cleaned and covered to prevent dust from accumulating which may end up hindering the sight of the user which is un-safe. The researcher also recommends the exchange of the cutter knives after sharpening to a maximum of

4mm from the cutting edge. The gears should consistently be lubricated with a thicker lubricant to reduce gear failure probabilities. The researcher also recommends the mounting of a horizontal based hopper for easy feeding of the stock into the machine for cutting and the use of rollers to pull the wood into the machine which is safer to the user as well as user friendly.

In conclusion of the whole write-up, the main aims of the project which are to design an automated wood cutter for cutting wood in the wood industry as well as for domestic use were achieved. The safety of the machine was also improved through the introduction of a PLC. The objectives of the write-up were also met through designing the machine for maximum force required to cut wood of diameter 100mm.

References

A. MUSHIRO, I. A. 2006. *Mechanical properties of wood at low temperatures*.

BOOTLE, K. R. 2006. *Wood in Australia*, Sydney, McGraw-Hill Book Company.

D BOUCHER, C. M.-T., K LININGER AND S ROQUEMORE 2011. The Root the Problem. *The Root the Problem***,** 3-7.

DEPARTMENT, F. 2014. *Country Report Zimbabwe* [Online]. Available: http://www.fao.org/docrep/004/AC429E/AC429E04.htm.

ENGINEERING, K. 2013. *Henan Kingman M&E* [Online]. Available: http://www.woodbriquetteplant.com/briquette-machine/wood-crusher.html [Accessed 16 2016].

G E. WOODSON, P. K. 2000. Tool Forces and Chip Formation In Orthogonal Cutting Of Loblolly Pine. *Forest Service Research Paper SO-52*.

GILMORE, R. 2016. Wood trekker.

KADZERE, M. 2015. ZESA to import Zambian power. *The Herald*, p.1.

MUSHAVA, E. 2013. Zimbos use 6m tonnes of wood fuel per year. *News Day*, 22.

P.KOCH 2000. Utilisation of hardwoods growing on Southern pine sites. *Elservier,* 2**,** 1123.

SCANNER 2015. Sawing and Cuttoff Machines. 5.

TIMBERS, B. 2015. Annual Report. 78.

WALLIS, N. About Wood. *Primefacts***,** 1-3.

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Dr. Tawanda Mushiri received his Bachelor of Science Honors Degree in Mechanical Engineering (2004-2008) and a Masters (2011-2012) from the University of Zimbabwe, Harare, and a Ph.D. from the University of Johannesburg, South Africa (2013-2017). He also obtained a Certificate with Siemens in Programmable Logic Controllers in the year 2013 where he worked with SCADA and Link Programming. His doctorate involved fuzzy logic and automated machinery monitoring and control. Currently, he is a lecturer and Senior Research Associate at the university of Zimbabwe and University of Johannesburg, respectively. In the past (2012-2013), he has also lectured at the Chinhoyi University of Technology, Zimbabwe, lecturing mechatronics courses. He has also been an assistant lecturer for undergraduate students at Chinhoyi University of Technology, tutoring advanced manufacturing technology and machine mechanisms.

 **Professor Charles Mbohwa** is an NRF-rated established researcher and professor in the field of sustainability engineering and energy focusing on green technology, energy and systems. In January 2012 he was confirmed as an established researcher making significant contribution to the developing fields of sustainability and life cycle assessment. He has contributed a chapter to a state-of-the-art book by experts in energy efficiency. In addition he has produced high quality body of research work on Southern Africa. Since 2012 he has worked on sustainability engineering with emphasis on integration of other soft aspects like humanitarian logistics and health care systems. The work also encompasses and integrates energy systems, life cycle assessment and bio-energy/fuel feasibility and renewable energy.