Design of an automated Poly-Vinyl Chloride (PVC) Pipe cutting Machine

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Abstract

The use of automated machines proves that they give a higher production rate than the manual production rate. The background of this study showed that the use of PVC pipes is very broad, varying from small scale residential use to large scale industrial use in water treatment plants. Subsequently, many ways of cutting PVC pipes are employed, with many of them being manual operations. These have proved to be laborious, time consuming and inaccurate. The designed machine to be used will ultimately reduce the total time required for the entire cutting operation and increase the production rate. The researcher and supervisor visited Pro-Plastics (a giant in the Plastics Industry in Zimbabwe) to better understand high technology PVC pipe manufacture and cutting mechanics. Three concepts were generated for the proposed solution to this project. This study was conducted with the use of SolidWorks for generating and developing the assembly of the chosen concept. SMT Client was used to automate the feeding, clamping and cutting processes according to a batch requirement. The generated model was within the required specifications for a machine to be used by small-medium scale entrepreneurs because of its size and low cost. The study showed that this machine will reduce the amount of chips formed during the process when comparing to manual methods without compromising the quality and precision of the cut. The PLC that was programmed has timers to control the feeding, clamping and cutting processes. The research was concluded with recommendations on how the safety of this machine may be increased.

Keywords
Design, PVC pipe cutter, Zimbabwe, Low cost

1 Introduction

PVC pipes are made of a thermosetting plastic called Poly Vinyl Chloride (PVC) (Allsopp, 2012). This plastic consists of long chain monomers which are linear and strong hence it can resist deterioration by the action of acids and alkalis (Schweitzer, 2000). PVC was first accepted in domestic piping and drainage in 1932 (Walker, 1990) and its use has expanded since then to make electrical cables and many other plastic items. PVC is used in its two forms which are rigid and flexible. It is employed in industrial and municipal applications in place metal pipes due to its low density, low cost and low maintenance. CPVC which is chlorinated PVC is recommended for residential water supply piping systems and electrical cabling due to its increased flexibility and ability to withstand elevated temperatures. The use of PVC pipes was introduced in 1961 in a home in Michigan (Dunlop, 2012). The use of PVC is in accordance to ASTM D1785 which is the specification for the use of PVC Plastic pipes in Schedule 40, 80 and 120 sizes. Chlorinated Poly Vinyl Chloride (CPVC) is a thermosetting plastic produced from the free radical chlorination reaction of the PVC resin (Leadbitter, 1994). It has significantly higher flexibility and heat resistance properties. It is used for hot and cold water piping, and in industrial liquid handling.

1.1 Background

Over the years, many manual ways of cutting through PVC pipes have been developed. The use of a hacksaw is the most commonly used. To cut using one, the pipe must be clamped on one end and using forward and backward action, the operator moves the blade across the pipe. The ratcheting pipe cutter uses a ratchet that repeatedly applies pressure of the blade on the plastic. This mechanism involves squeezing the handle of the ratchet then releasing it to acquire a cut. The Power Miter Saw is a handy but dangerous tool. When the switch trigger is pulled the Miter saw is brought down and the rotating blade will cut the pipe. The process is quick and large quantities can be cut. All these methods have the disadvantages, amongst many others, of inaccuracy, timeous and material is wasted.

PVC pipes are employed in residential use because they are reasonably cheap and flexible with various diverse fittings and sizes available (Massey, 2002). PVC functions admirably for home piping needs since it does not rust or and is not susceptible to corrosion after some time. This implies it will not be deposed until the point that it has been damaged and begins to leak (Gerdeen, 2011)). It is also easy to work with, as it requires no welding or metalwork, and is an inexpensive option. PVC is exceptionally solid and tough and will not succumb to bending under strain, accordingly making it the piping system of decision for high-pressure applications (Dugal, 2008).

In construction, PVC is versatile and can be used in scaffolding billboards, cable insulation and interior design articles. Due to the high chlorine content, PVC products have fire safety characteristics, which are quite favorable as these products are difficult to ignite, heat production is comparatively low and they tend to char rather than generate flaming droplets. PVC is self-quenching and if the ignition source is withdrawn it will stop burning (Dugal, 2008). PVC has been a well-received material for construction applications for decades and this is because of its physical and technical properties which provide excellent cost-performance advantages (Massey, 2002).

PVC is regularly utilized as a part of plastic pipe structures for pipelines in the water and sewer businesses in view of its cheap nature and adaptability. Pipes and fittings have the biggest volume application at 40% of the marketplace (Martins, et al., 2009). PVC is chemically safe and opposes corrosion from an extensive variety of chemicals, setting it as the material of use in numerous extreme industrial applications (Dunlop, 2012). PVC pipes have an ultra-smooth surface which makes pumping through it cost efficient, and its joints limit the loss of chemicals – which can be up to 40 per cent in some technology piping networks from the past. Unlike pipes made from traditional materials, the exceptionally smooth walls of PVC pipes make it extremely difficult for sediment to accumulate (Herren, 2014).

1.2 Objectives of the study

- To design a machine which cuts through a PVC pipe without manual labor
- To design a machine which will be used by small to medium entrepreneurs with a cost less than $5000
- To design a machine that eliminates chips formed in pipe cutting

2 Literature Survey

Poly Vinyl Chloride (PVC) is a member of a very large family of vinyl chlorides. There is a repeating monomer unit which is $(CH_2CHCl)_n$, where n takes large values (Heras, 2014). The different polymerization processes that convert Vinyl Chloride (VC) into PVC are bulk, emulsion, suspension, and solution polymerization (Joesten, et al., 2006). This is because the individual PVC polymer cannot be used in its original form due to its colorless rigid structure, limited heat stability, and it usually binds to metallic surfaces under heat (Carraher, 2016). It is thus commonly compounded with ingredients to customize its properties for use in a wide range of applications. A PVC Compound contains chain extenders that are used in the synthesis, stabilizers to eliminate the degradation of PVC during the processing, plasticizers are added to weaken the polymer, lubricants aid the release PVC from metallic surfaces of the equipment used during processing, pigments color the compound, polymeric processing aids, and fillers are for reinforcements (Stepek & Dauost, 2012).

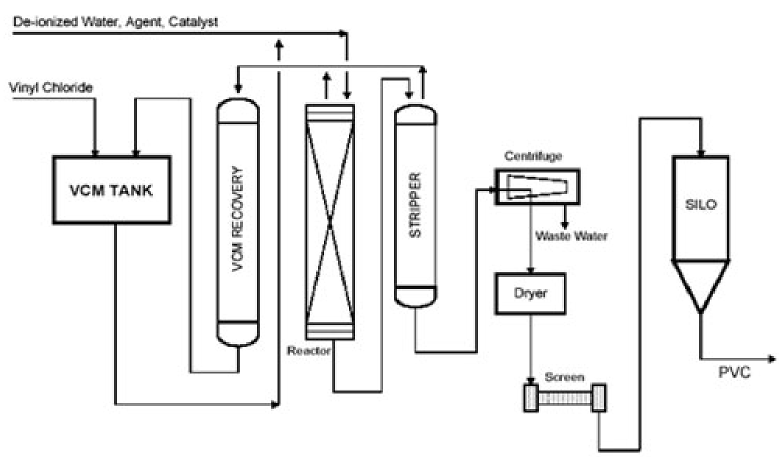

Figure 1. Polymerization Process

2.1 PVC processing

Extrusion is a process of making long products of continuous cross-sections by constraining softened polymer through a die (Varghese, 2015). PVC resin, in pellet-form, is not appropriate for immediate processing. To deliberate the essential processing and end volatility, it is crucial to mix condiments to the resin (Joesten, et al., 2006). The condiments are plasticizers, stabilizers, colorants and lubricants. These additives have an effect on the physical and chemical properties on the PVC like density, hardness, tensile, flexural and impact properties.

The theory of thick and thin cylinders were studies as it was useful in the design of the blade in the machine. For schedules 80, 120 and the first half of Schedule 40 pipes the theory of thick cylinders is employed. The lower half in schedule 40 is considered as thin cylinders (Tooley, 2009).

2.2 Cutting Mechanics

The small strength of thermoplastics allows high cutting velocities. However thermoplastics have a low ability to conduct heat and their increased resilience require relief angles that are high and a reduced rake angle so as to prevent unwanted cutting. The tools that are used are sharp and tough. Plastics cause wearing out of the blade which the ultimately become blunt and such tools. These cause generation of heat. A small depth of cut is ideal. The cutting process is in the form of plastic deformation to form a chip (Ebewele, 2000).

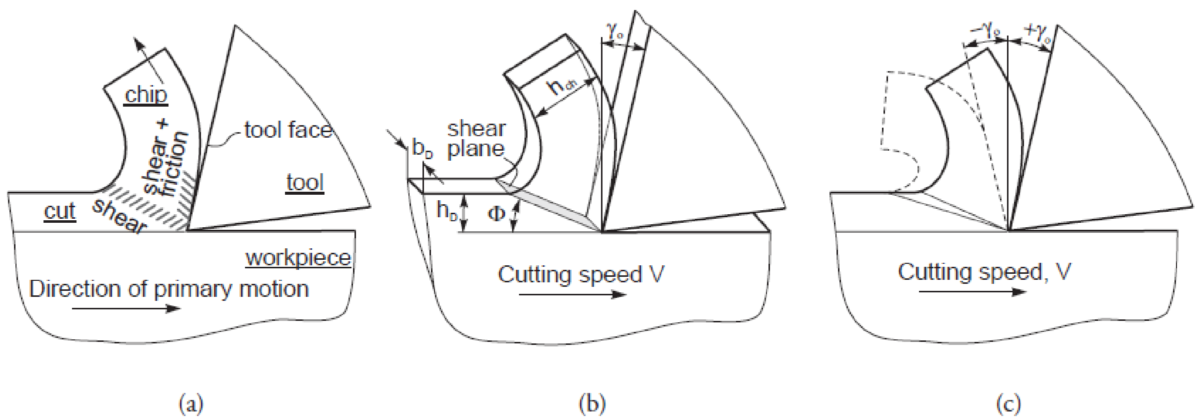

Figure 2 Chip formation in metal cutting

A precise cut is made with the blade moves at a linear velocity. The rake angle has a significant influence deformation produced as a cut is made and on the thickness of the chip. The shear angle and rake angle determine the thickness of the chip. The shear angle controls the thickness of the chip and has a great impact on the efficiency of cutting (Sadegh & Worek, 2017). The material undergoes shear strain. Chip formation occurs in *primary (between the cut)* and *secondary shear zones*, along the cutting tool face. Cutting speeds for thermoplastics range from 5 to 20m/s and for thermosetting plastics from about 15 to 28m/s, with the higher speeds for thinner stock. High-carbon-steel blades are recommended (El-Hofy, 2013).

2.3 Automation

The degrees of automation are of two types, full automation and semi automation. The principal concern of this project is to carry out the operations feeding, clamping and cutting. The sequenced operations of the system must be precisely timed. The major work of this system is to slice out a large number of pipes according to the batch production. The selection of the cutter is based on the stress calculated considering the pipe. The cutter to be used in the machine system has been considered by calculating the torque required for cutting PVC object by help of the design data available. With the help of a PLC, the time required to slice the pipe will be less and the accuracy of slicing or cutting of the material will also be improved. The PLC is to be designed to read digital and analog inputs from numerous sensors, execute a user defined rationality program, and writes the resulting digital and analog output values to various output elements for the cutting process to occur. These are the blade, the rack and pinion that move the blade and the feeder and clamper rollers. The layout of the machine will be compact to be placed in a small workshops.

3 Methodology

The details of the project as a means of developing the solution chosen were developed. The formulas needed for the working principle were outlined and the variables (known and unknown) identified. Solid works was used in the detailed design to accurately show the model, its dimensions and all the components for the machine. A programming code was created on SMT Client to execute the automation of the machine. The specifications of the machine were calculated and shown as follows

Blade rotary speed = 1100 rpm

Mass of Blade = 2.6 kg

Torque = 15.84 Nm

Cutting force = 91N

Shaft diameter = 25 mm

Motor Specification for Blade = 3 hp, 220/240V 2-TDA90 LS motor

Maximum rotational speed of pinion = 954 rpm

Maximum bending moment of pipe = 0,01408kNm

3.1 Drawings

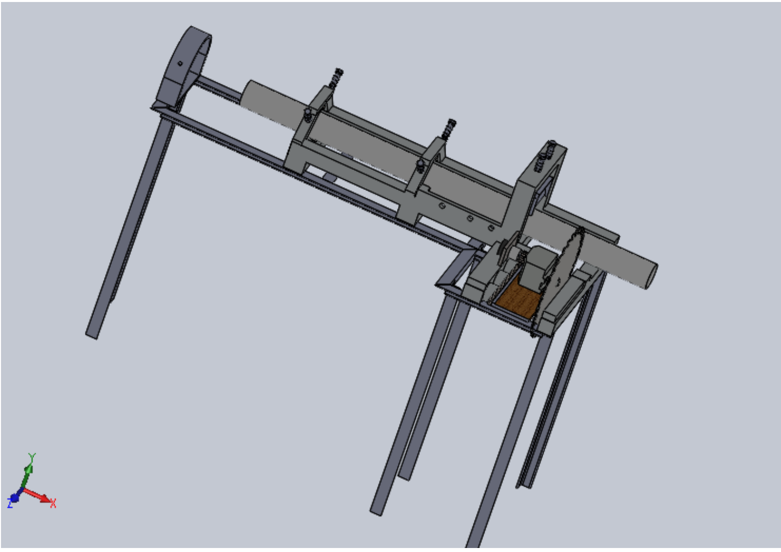

Figure 3. Front View of PVC pipe cutter

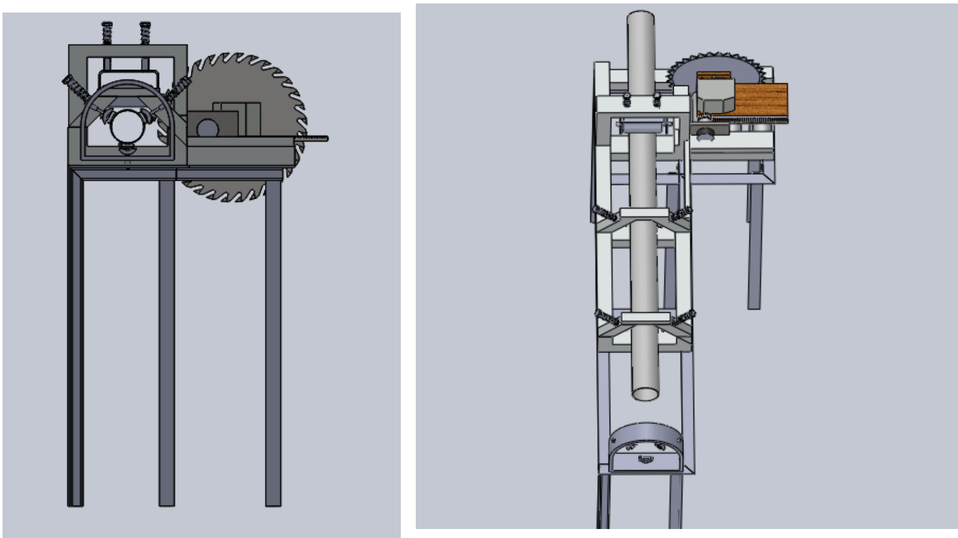

Figure 4. a. Side view b. Top view

3.2 SMT Client Programming

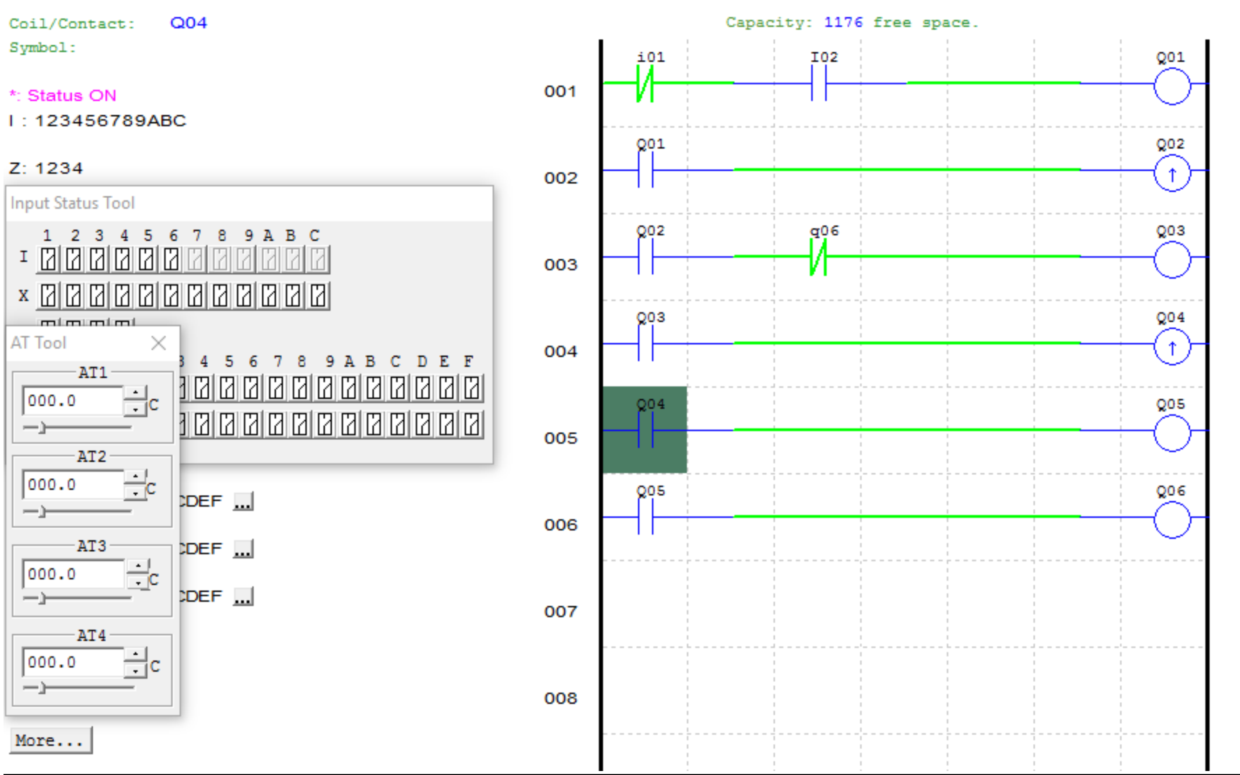

Figure 5. Before starting the machine

At this state, the program is not running. All inputs and outputs are not switched on.

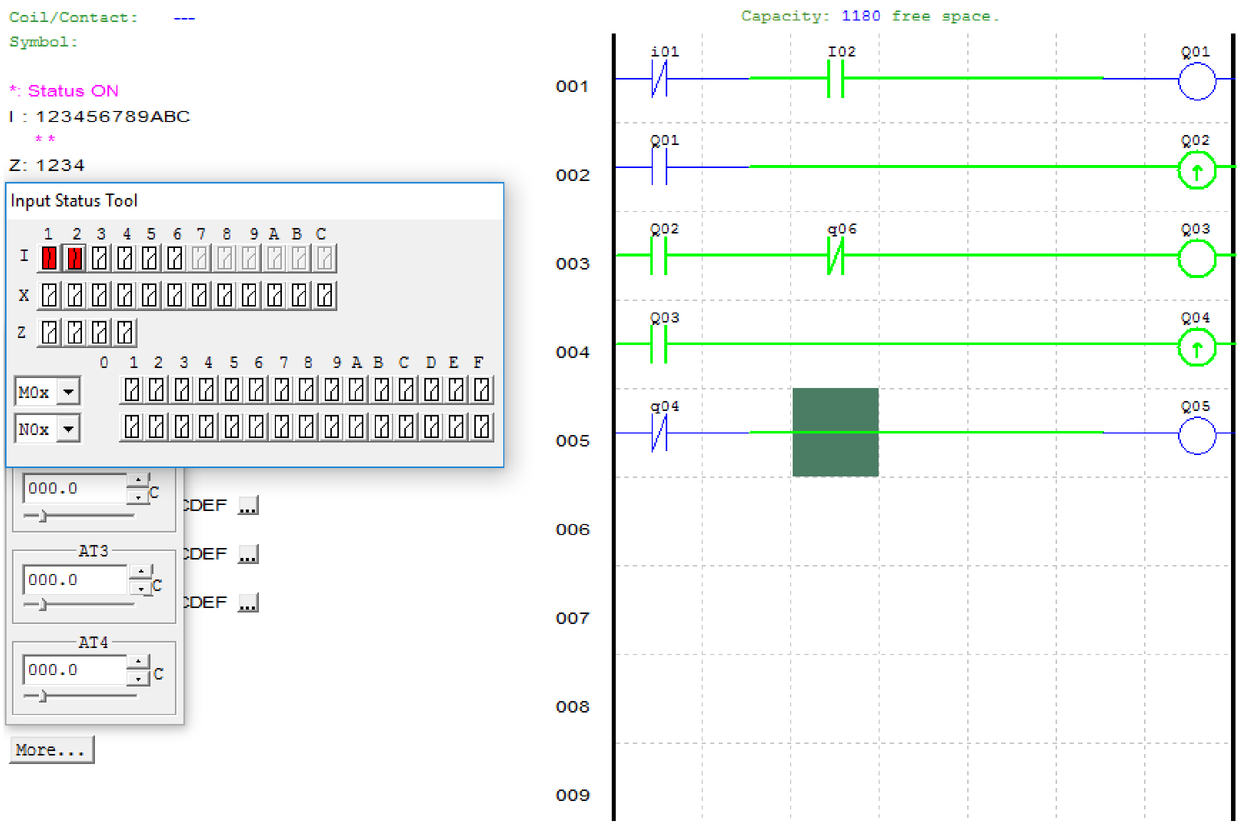

Figure 6. When blade is rotating

At this state the power button is on, the roller is off. The cylinders have clamped the pipe triggering the pinion to move forward and the blade to start rotating. The reverse pinion output is off.

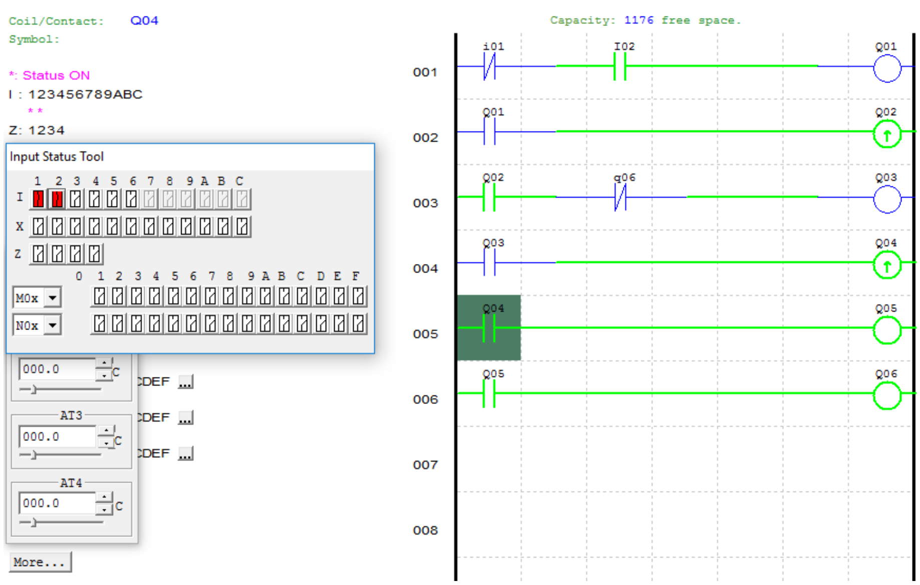

Figure 7. When the pinion is in reverse

After the cutting process is complete, the pinion starts reversing, retracting the blade. Q03 is therefore switched off via Q06, an impulse signal to stop the forward motion of the blade and switch to the reverse mode.

4 Results and Discussions

The scope of the project was to design an automated PVC pipe cutter that will cost less than $5000 and the researcher designed a machine which has an overall cost of $4545. This machine can be used by small to medium enterprises. The researcher was able to design a blade to cut a maximum of 110mm. The project was completed in the stipulated time frame. The specifications of the expected design were met. The maximum power capacity was to be less than 4hp, the designed machine has a capacity of 3hp. The machine was expected to run at maximum of 1500rpm with a torque of less than 20Nm, the researcher designed a machine that operates at 1100 rpm and 15,84Nm. The machine was to weigh less than 100kg. A report generated by SolidWorks of the properties of the machine concluded that the machine weighs an overall of 20,8kg.

4.1 Limitations

- The machine has not been designed to cut pipes larger than 110mm or those in schedule 120 which contains thicker pipes.
- The machine is not portable however small it is. There are no detachable parts.
- Additional cost required to do further automation

4.2 Recommendations

- Can be modified to cut CPVC Pipes and metal tubes
- A Perspex cover to be installed over the blade and proximity sensors within a short distance from the blade can be added to ensure safety
- 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.
- It would be more effective if the machine can be modified not to start without a safety mechanism correctly installed.
- The safety mechanism should be retrofitted to all cutting machines (e.g. table saw, panel saw and bench saw machine)

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5 Biographies


Thandolwenkosi E Ncube is a female who was born in Bulawayo at Mater Dei Hospital. She accomplished her primary level at Portland Primary School in Colleen Bawn in 2008. She studied at Anderson Adventist High school and during form 5 was one of two students in the Midlands Province who were awarded a scholarship by Zimbabwe Power Company which funded her from Advanced Level up to and including her undergraduate studies at the University of Zimbabwe in Mechanical engineering. She developed a profound interest in Condition Monitoring and Fuzzy Logic Systems under the guidance of Dr. T Mushiri. Thandolwenkosi is particularly interested in the design and maintenance field of the Mechanical Engineering discipline and aspires to one day be part of a team which will spearhead the innovative design and upkeep of more efficient and technologically advanced equipment in thermal power generation.


Dr. Tawanda Mushiri received his Bachelor of Science Honors Degree in Mechanical Engineering (2004-2008) and a Masters in Manufacturing Systems and Operations Management (MSc. MSOM) (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 PLC Programming. His doctorate involved fuzzy logic and automated machinery monitoring and control. Currently, he is a Senior 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, robotics and machine mechanisms.