

Design of a paper slitting and rewinding machine for a developing country, Zimbabwe

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Abstract

This paper is on the design of a paper slitting and rewinding machine for a developing economy which targets small to medium enterprises (SMEs). The current problem is the high cost of such machines on the market hence most SMEs in a developing economy cannot afford them. Through careful analysis of current machines, use of alternative cheaper materials and use of more energy efficient drive mechanisms, it was possible to come up with a low cost and efficient solution. Research on the paper slitting and rewinding industry was conducted on the internet, published scholarly articles and industrial visits to local companies in the same business. The implementation of this design has major positive benefits to the development of the economy.

Keywords

Design, paper slitting, rewinding, machine, developing country

1. Introduction

Paper is a renewable and recyclable plant-based product that connects us in so many ways to the important things in life (PAPERbecause, 2015). Great ideas are started on paper, the world is educated on paper, businesses are founded on paper, important news is spread on paper and love is professed on paper (Martin, 2014). Scrolls, books and diaries made from paper have made the transgenerational transfer of information possible allowing people to evoke

memories of the past back to the present and to build upon the knowledge of their ascendants (Seven Three, 2015). Paper has made the transfer of life's most valuable skills of reading and writing possible from adults to their children.



Figure 1. Paper products used in retail, office, hygiene and packaging (The Zen Cart™ Team, 2015)

Due to advancements made in the paper manufacturing industry, paper has found more mundane uses for hygiene, catering, packaging and as tender (Seven Three, 2015). In paper manufacturing factories, paper is produced in the form of large jumbo reels which cannot be used in most practical applications as these reels can weigh as much as four tonnes. In this case, machines called paper slitter rewinders are employed to cut down the large jumbo reels and then rewind them on new cores into multiple smaller slits which can then be used in subsequent machines to make the final paper product.

1.1 Background

In Zimbabwe, as a nation whose economy is still growing and in which job opportunities are few, most of the citizens have found themselves to be self-employed to sustain their lives. In a bid for a living, many have resorted to the high return on investment businesses which include photocopying, printing, and marketing, all in which the availability, the quality and cost of paper is critical to these small to medium enterprises (SMEs). According to Bloch, 2014, "Zimbabweans believe that the biggest contributors to Zimbabwe's economy are agriculture and mining. However, he outlined that, "whilst the magnitude of their economic contribution should not be disregarded, and every endeavour to achieve further development and growth of those economic sectors should be made, the reality is that the greatest single element of the economy is small and medium enterprises (SMEs)", (Bloch, 2014).

One major factor however, causes a major drawback to these small to medium enterprises (SMEs) dependent on the paper industry. It is the failure of the local markets to supply standard paper sizes on demand for such businesses due to the high demand of paper. Local paper suppliers could tackle this problem by purchasing faster and more efficient paper slitter-rewinders, but the duty fees paid at frontiers coupled to the transport expenses incurred during importing could mean the end of their businesses. The high costs of these high performance machines is largely due to the sophisticated technologies implemented for automation and real-time quality control check since most of them are manufactured in developed countries. Figure 1 below shows an example of a cutting edge slitter-rewinder manufactured in developed economies.



Figure 1. Slitting Rewinding Machine (DC-RSM-1092/1575II) (DC International Group Ltd, 2015)

Present paper slitting and rewinding machines are very expensive and therefore not affordable for the majority of the small to medium enterprises which are the thrust of the developing Zimbabwean economy. There is need to design such a paper cutting and rewinding machine. The objectives were to:

1. To design a machine that cuts paper sizes ranging from 189mm to 40mm.
2. To design a machine that mainly operates on basic mechanical principles and technology which do not require specialized training to reduce the cost of operation and maintenance.

2. Literature review

Paper slitting and rewinding is the process of cutting a large jumbo reel of paper by moving it through an array of knives before rewinding it on one or more shafts into smaller standardised winds for custom uses (Wikipedia, the free encyclopedia, 2015). Machines known as slitter-rewinders are used to cut parent reels into various roll widths and trim off the edges of the sheet in order to meet customer requirements (Convergence Training, 2015).

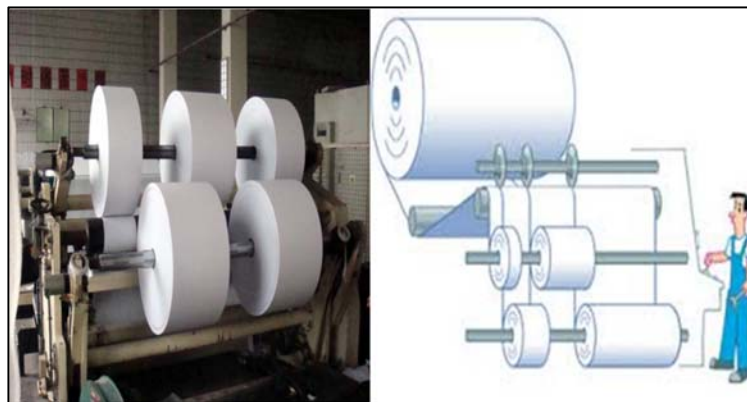


Figure 2. Paper slitting and rewinding process

The process has remained a vital part of every paper processing industry around the world since it has direct impact on the quality of the end paper product. Various slitting methods, winding techniques and tension control mechanisms for the web have been developed and successfully implemented in order to maximise the efficiency of the process and the edge quality of the cut paper.

2.1 Principle of operation of a paper slitter-rewinder.

A paper slitter-rewinder is a converting machine used to reduce a large parent roll of paper into rolls of smaller dimensions suitable for subsequent applications (Convergence Training, 2015).

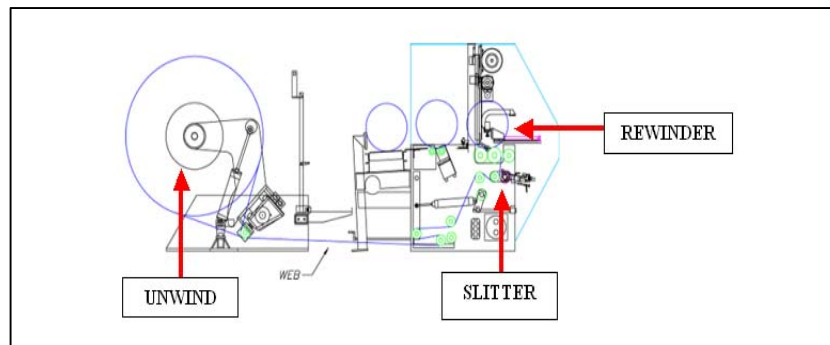


Figure 3. Basic components of a slitter rewriter (Jennerjahn Machine, Inc., 2015)

The three main stages of the machine are 1) the unwinding stage, 2) the slitting stage and 3) the rewinding or winding stage as shown in the figure above.

2.2 The Unwinding Stage.

The unwinding stage consists of an unwind stand onto which the parent roll of paper is loaded and secured. The stand holds the roll about its central axis and allows it to rotate. The roll is held either by inserting two chucks each with mechanical gripping elements on both ends of the roll which expand to grab it, or by clamping the two exposed ends of a shaft which runs along the whole length of the roll's core on bearings on the back stand (RollRazor, 2015). When initially unwinding heavy rolls, large inertial forces are experienced which may tear the paper or deform pressure sensitive materials. This is avoided by using driven unwinds which can be braked when necessary to maintain the accurate tension of the material during the process (RollRazor, 2015).

2.3 The Slitting Stage.

The slitting stage is where the actual separation of the web into multiple smaller slits occurs. From the winding stage, the unwound continuous web of paper is passed through a series of spreading rollers and through the slitter head. The slitter head is made up of a series of either rotating knives or razors and it does the cutting of the web. The desired slit widths are set manually or automatically depending on the type of machine being used by varying the locations of the knives on the slitter head. Before the slitter head are rollers to straighten the sheet to ensure good quality cuts (Convergence Training, 2015).

2.4 The Rewinding Stage.

From the slitter head, the slits are rewound onto smaller cores on the rewind stand to the desired footage or diameter (Jennerjahn Machine, Inc., 2015). Various factors such as the type of material being wound and the desired hardness of the final roll determine the type of winder to be used under the given conditions. The rollers which are after the slitter head keep the slit sections separate as they enter the winding and prevent the sheet from weaving back and forth between adjacent rolls in the roll set (Convergence Training, 2015).

2.5 Slitting methods.

These are techniques used to effect separation of the large machine-width web into multiple webs of smaller breath. The method which gives the cleanest cut depends on the material's characteristics (Parkinson Technologies Inc, 2015). The three most common slitting techniques are shear slitting, razor slitting and score slitting.

2.5.1 Shear Slitting.

Two rotary knives, one at the top of the web and the other at the bottom, work in conjunction to give a cutting action as obtained by pushing a pair of opened scissors through a sheet of paper to effect separation of the web as shown in Figure 5a below (Carolina Knife Co, n.d.). The top knife is called the male knife and the bottom knife is termed the female or anvil.

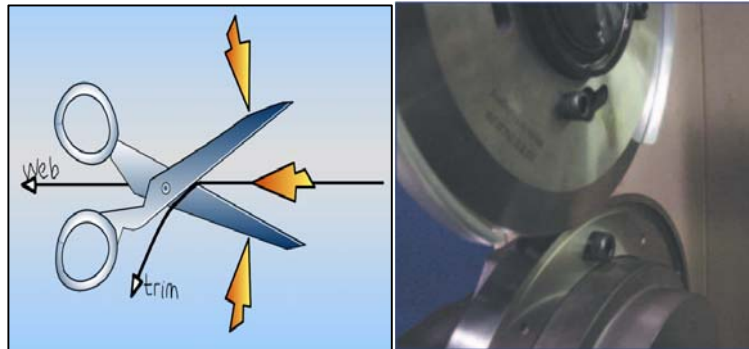


Figure 4 a) principle of operation of shear slitting. b) Top and bottom knives (Dienes Corporation, 2015)

The method is preferred for slitting relatively thick material such as thicker sheet, paper and laminates (Parkinson Technologies Inc, 2015). The path that the web follows on the bottom knives divides the shear slitting method as either wrap slitting or tangent slitting. Proper web tension should be maintained in either case to produce consistent quality cuts.

3. Methodology

SOLID Works 2015 Software was used for the 3D modelling of the design and its various components. Stress analysis to assess the safety of the design on the loaded members such as shafts was carried out using SolidWorks 2015 software. AutoCAD software was used during to generate 2D drawings. Mat lab R2015a software was used for vibrational analysis, for performing complex calculations for optimum machine design.

Table 1. Machine Specifications of the rewinder

Working Width	1500mm
Maximum parent roll diameter	1000mm
Maximum parent roll weight	500 kg
Slitting with circular knives (minimum)	50mm
Rewind core Diameter	80mm
Rewind Speed	100m/min

4. Results and discussion

4.1 Design

All materials for the manufacture of the paper slitter rewinder machine were locally available to prevent any need for imports which might raise the overall cost of the machine. All shafts including the surface winder rollers were made from EN19T steel alloy. EN19T is a high tensile steel grade with excellent shock resistance combined with high wear resistance. This is very important for shaft mounted dished top knife blades where the inside diameter of the knife will be rubbing along the circumference of the knife during knife changes or slit width changes. It has a tensile strength of 850-1000N/mm² and is generally used for applications including machine tools, shafts, spindles and gears. The frame of the machine was constructed from EN9 which is a medium carbon steel grade with a high surface hardness and excellent wear resistance. It is cheaper than EN19T with a tensile stress of about 700N/mm² which is large enough to take the stresses induced in the frame by the 500kg paper roll without failure under normal operating conditions of the machine.

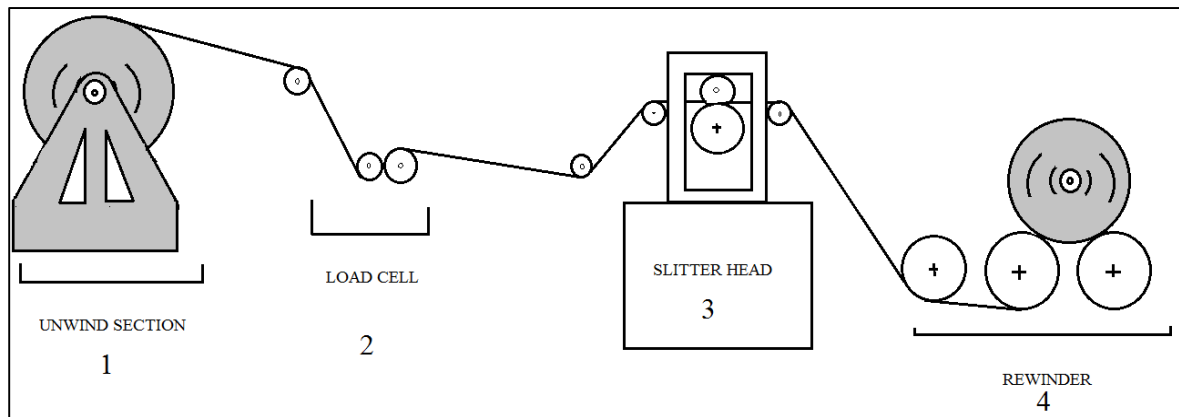


Figure 6. 2D layout of the paper slitting and rewinding machine.

The web of paper moves from the left hand side (section 1) to the right hand side (section 4). Section 1 consists of the unwind stand (shaded) on to which the parent roll (also shaded) is secured horizontally about its axis by means of an unwind shaft running along its axis end by 3-jaw self-centering chucks on either side. The web then passes through the load cells (section 2) which measure the total tension in the web so that it is within the permissible range for the web material under consideration. The load cells send signals to the unwind motor to increase, lower or t keep its speed constant according to the correction in tension that needs to be made. From the load cells a series of rollers straighten the web and keep it tangent to the bottom knives as it passes through the slitter head where it is cut into multiple slits of pre-set width. The web then goes straight to the two drum surface winder (section 4) where it is rolled onto a new core and to the desired diameter.

The design of the machine was separated into four main stages.

1. Design of the two drum surface winder.

The required line speed of the web was known. This was used to calculate the rotational speed of the surface diameter whose diameter had been assumed. Multiplying the radius of the surface drum with the value of the maximum total tension in the web at the surface of the surface drum gave the theoretical value of the torque required from the electric motor needed to drive the surface drum. Losses and other design considerations were also accounted for as shown under the various design steps.

2. Design of the rotary shear slitting system.

A standard size bottom knife of diameter 8” was first preselected. Using this diameter value, several calculation were made to determine the required standard size of the top knife which would maintain correct geometric configurations such as arch of travel, penetration depth and center distance of the top and bottom knives under normal operating conditions of the machine. All forces acting on the top and the bottom knives were taken into consideration when calculations for the power required to drive the slitter head were made.

3. Design of the unwind section.

This involved the design of the unwind core and the selection of the motor required to drive the unwind stand.

4. Selection of the load cells for controlling the tension of the web.

Table 2. Recommended standard design parameters for paper

Parameter	Value
Over-speed of 8 inch bottom blades	3-5% of line speed of web
Blade overlap for 8 inch bottom knives	0.5-1mm
Side load force	1.4-1.8kg
Bevel angle of top knife for heavy paper	30°

Maximum web tension in web (paper)	4 Pounds per linear inch
Cant angle	0.25-0.5°

Line speed of web for surface winding = 100m/s.

4.2 Von Mises Stress analysis.

Von Mises stress analysis is a method used by design engineers to check whether their design will withstand a given load condition without failure. For a good design, the maximum von Mises stress in the components should be less or equal to the design stress of the component. In the von Mises diagram, von Mises stresses are lowest in the blue regions and the red regions indicate the areas of highest von Mises stresses.

For a good design:

$$\sigma' \leq \sigma_d$$

Where, σ' is the maximum von Mises stress in the component under test.

And σ_d is the design stress given by $\sigma_d = \frac{\text{yield strength of material}, S_y}{\text{factor of safety}, N}$

4.2.1 Von misses Stress analysis of the bottom knife.

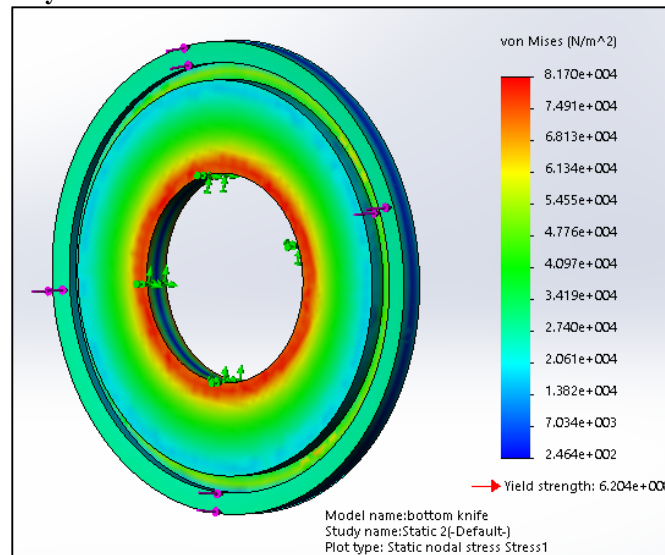


Figure 7. Von Mises results from Solidworks

Interpretation of results.

The maximum von Mises stress in the bottom knife occurs on the region closest where the knife is attached on the bottom knife shaft. The design is therefore safe.

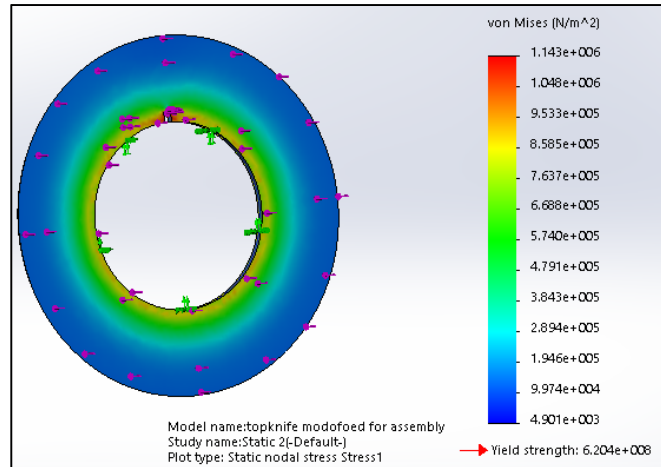


Figure 5 Von Mises stress on the top knife under static loading conditions.

Interpretation of results.

Assuming a factor of safety of N=10,

The design stress $\sigma_d = \frac{6.204 \times 10^8}{10} = 62.04 \text{ Mpa}.$

$$\sigma' \leq \sigma_d$$

$$1.143 \text{ MPa} \leq 62.04 \text{ MPa}.$$

The maximum von Mises stress is less than the design stress for the top knife. The design is therefore safe. The von Mises stress analysis results above showed that the maximum von Mises in each of the tested components were well below the yield stresses of the respective components. Therefore under no normal operating circumstances shall these components fail.

4.3 Final Assembled Drawing.

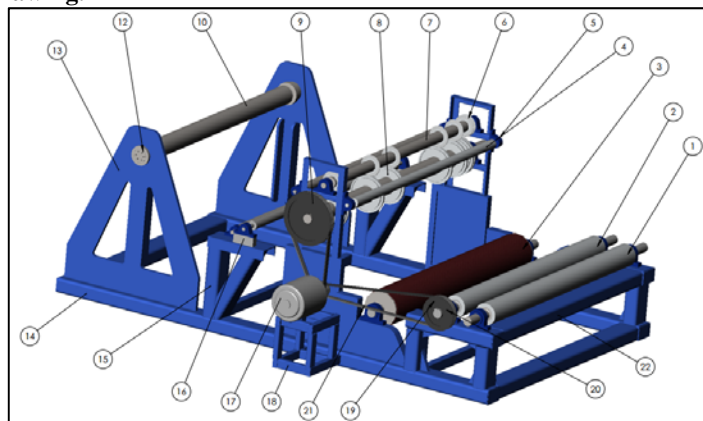


Figure 6 final 3D assembly showing machine components (Courtesy of Solidworks).

Table 32. List of machine components.

Balloon Number	Part Name
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1 and 2	Surface drums
3	Traction roll
4	Straightening roller
5	bearing
6	Top knife
7	Top knife shaft
8	Bottom knife
9	Bottom knife shaft pulley
10	Unwind core
11	Bottom knife shaft
12	Unwind core chuck
13	Unwind stand
14	Main frame base
15	Load cell unit stand
16	Load cell
17	Slitter head/ surface drum electric drive motor
18	Electric motor stand
19 and 20	Surface drum pulley
21	'V' belt
22	Surface winder stand

5. Recommendations and conclusions.

5.1 Design Considerations.

5.1.1 Pneumatic Trim and Dust Remover.

During the paper slitting process, a lot of dust is generated. Thin strip of paper called trims removed from the edges of the paper fall to the ground. In order to maintain a clean working environment it is recommended that a pneumatic trim and dust removal system which uses a vacuum pump to suck the dust and the trims be installed on the paper cutting and rewinding machine.

5.1.2 Overload protection.

There is need for an overload protection system which will make sure that the drive mechanism of the machine will not be functional should the machine be loaded beyond its design capacity of 500kg. This provides an additional margin of safety to the operator and ensures that the machine performs at its best.

5.2 Safety

A slitter rewinder machine has numerous moving members and sharp knives which pose a major risk to the operator or any other persons around the machine any negligence should occur. Unsafe conditions and unsafe acts should at all costs be avoided by exercising proper behaviour around the machine to avoid any form of injuries. This being the case, safety devices are no substitute for safe and proper operating procedures.

5.2.1 Rewinder Barrier Guards.

All nip points should be guarded by barrier guards to protect anyone working around the machine. The barrier guard must be interlocked with the drive mechanism to prevent rotation when the guard is not in place.

5.2.2 Danger High Voltage

Electrical drives in the slitter rewinder are high voltage devices. These drives should be well earthed and all wiring checked from time to time for loosening or damage and replaced if required.

5.2.3 Emergency Stop Devices.

The devices for stopping the machine in times of emergency should be fully functional all the time. Such devices should be marked in red and provided within the easy reach of the operator on all sides of the machine.

5.2.4 Maintenance.

The following safety regulations should be observed before performing repairs on the slitter rewinder.

1. All drives and locks should be locked before any maintenance work is carried out on the machine.
2. Only one person should be operating the machine at any instant.
3. Cables should periodically checked for any form of damage and replaced if necessary.
4. Gloves should be used to handle knives during changes.

5.3 Conclusion.

The paper slitter rewinder machine was successfully designed within the given budget of USD5000.00 and the machine can cut paper sizes ranging from 1189mm to 40mm as stated in the project's objectives. Locally available materials were used during the design process in order to keep the cost of the machine down and at the same time promoting the local businesses. Therefore the project was successful. However, it is only after a prototype has been manufactured and necessary adjustments made to the design, and when the design has been implemented that the purpose and positive impacts of this project shall be evident to the SMEs and the Zimbabwean economy.

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