

Design of an Automated Carrot Peeling Machine

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Abstract

The paper scope was to design an automated carrot peeling machine for use in Zimbabwe. Of particular target being local farmers and supermarket retailers who process carrots. In light of this, the project has the intention of availing design solutions of a machine that peels carrots for packaging purposes. Furthermore, with automation being a major facet of technological advancements, the study looked to automate the machine for ease of use and relatively less human interference as well as increasing accuracy of the processed product. Local farmers can fetch better on the market by value adding their carrots before selling them peeled. In conducting the study, objectives were formulated to solve the problem at hand and throughout the research these objectives were continuously addressed. In the design methodology, the peeling mechanism that machine will use was looked into. A further research was made on how to convey the carrots through the peeler as well as the powering mechanisms of different components that make up the machine. Study was also carried out on how to automate the machine through the use of latest flexible technology.

Keywords

Design, automated, carrot, peeling.

1. Introduction

In a world where industries are trying hard to improve on machine efficiency so as to maximize on outputs, it has become of great importance to design and develop concepts which result in more efficient machines with saving

energy importantly part of the agenda. Electric motor driven systems are estimated to consume more than one half of all electricity in the U.S and more than 70 percent of all electricity in food manufacturing applications (Werger, 2009). Therefore the first port of call in improving energy efficiency is the evaluation of motors. In addition, substantial energy and operating cost savings can also be gained by high efficient gearing and properly designed belt transmission systems (Werger, 2009) The modern industrial era has also seen immense technological advancements with control and automated systems a major part of design nowadays. The use of various control systems on equipment and machinery has gone a long way in saving energy and materials together with increasing quality, precision and accuracy of products. Equally important, automation has resulted in reduced labor costs and material use.

1.1 Background

Agriculture is a major contributor to the Gross Domestic Product (GDP) as shown by the fact that in the years 2009 and 2010 the sector contributed 14.9 percent and 19.1 percent respectively to Zimbabwe's GDP. (Tshuma, 2013) Local small scale farmers and supermarket retailers are however faced with challenges in equipment and machine access add value and benefit their products. Farmers are looking beyond the country's borders to access equipment and machinery for processing their products. Since these machines are not being manufactured locally, it presents a challenge to local farmers to access them. In light of this, it is convenient to avail a machine that peels carrots to ease on costs associated with manual peeling as well increasing the production rate of processing. Furthermore, automation being a major facet of technological advancements, it is necessary that automation being included on the machine for easy use and relatively less human interference as well as increasing accuracy of the processed product.

1.2 Problem statement

No carrot peeling machine has been made or is available in locally in Zimbabwe, overseas imports are made to access these machines.

1.3 Aims and objectives of research

To design an efficient and energy saving automated carrot peeling machine in the case of Zimbabwe. The objectives are:

- To develop a machine that weighs less than 150kg.
- To reduce peeling losses by at least 5% from the 17% associated with hand peeling.
- To develop a machine that processes 1000 - 1500 carrots per hour.

2. Materials and Methods

In order to come up with an effective design, it is important that properties of carrots be known. Mechanical and biological properties of carrots will affect the design directly in coming up with the allowable stresses on the machine and also the type of material that can be used respectively. In other words this enables the selection of effective peeling and cutting techniques. The carrots are expected to be exposed to different types of mechanical loading e.g. impact, vibration and compression during processing. Therefore the knowledge of mechanical properties such as shear strength, compressive strength is important in coming up with the design. Peeling is an important stage in preliminary vegetable and fruit processing. The quality of the final product much depends on this stage. Carrots can be peeled manually though this comes with high peeling losses and demands considerably a lot in time and labor. Mechanical, thermal and chemical peeling methods are currently being employed for post harvesting processing (Luh & Woodroof, 1988). These three conventional methods will be considered for the design. The machine will also be designed to handle different sizes and shapes of carrots. Focus will also be put in the design on easy maintenance and repair of machine parts for consumer satisfaction. Mitsubishi software will be used for PLC programming for purposes of automation. E-Designer 7 will be linked with a Human Machine Interface or SCADA through this software.

3. Results and Discussions

The carrot machine will be automated in basically three different ways: For the safety of the user or operator the conveyor belt should always be in a non-moving state as long as no object (carrot) is placed on it. The machine operator manually places a carrot onto the conveyor belt, a proximity sensor senses its presence and through the Mitsubishi GX Developer Programmable Logic Controller the conveyor belt is started automatically. Should the user place no carrot, the system automatically stops.

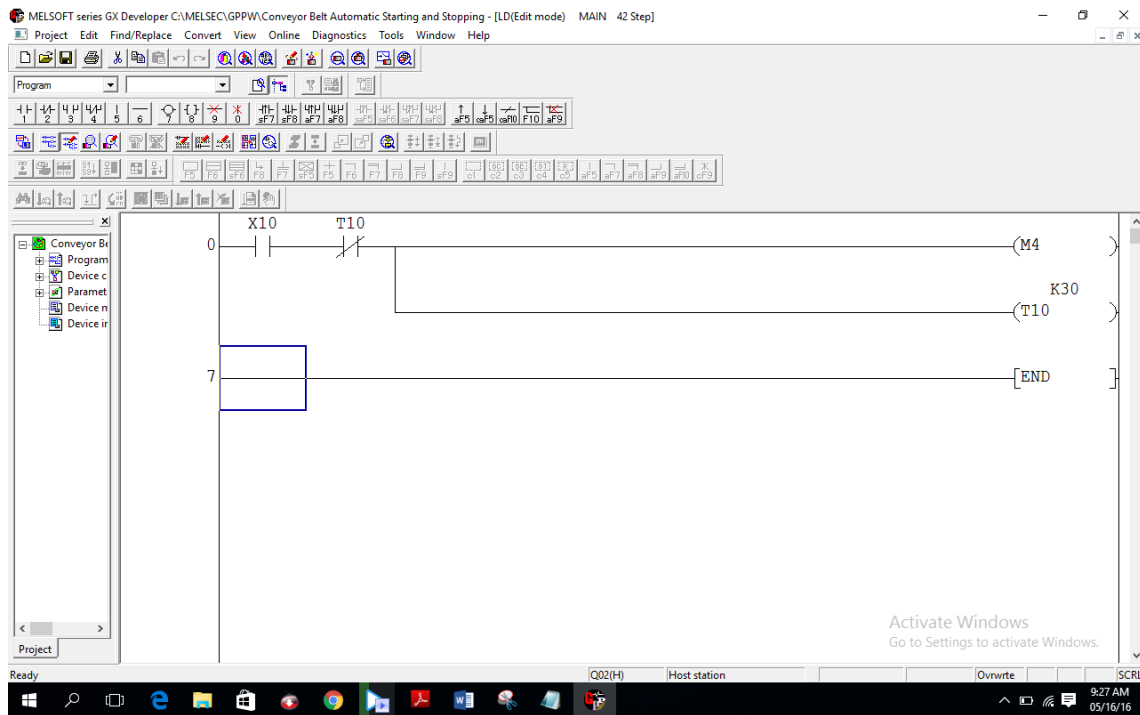


Figure 1. Conveyor belt automatic starting and stopping

In the above ladder logic diagram. A mechanical proximity sensor senses the presence a carrot and then it sends an electrical signal that closes the normally open (NO) contact X10. This results in completion of the circuit to turn on the conveyor belt motor (M4) and the delay on timer (T10) through a normally closed (NC) contact T10. After a delay of 5seconds (K50), the delay on timer becomes true prompting its normally closed (NC) contact to open. This shuts down the conveyor belt electric motor. The essence of the on delay timer is to stop the belt if there is no carrot placed on the belt within the set 3seconds. Thus the user should place a carrot after an interval of at most 5 seconds.

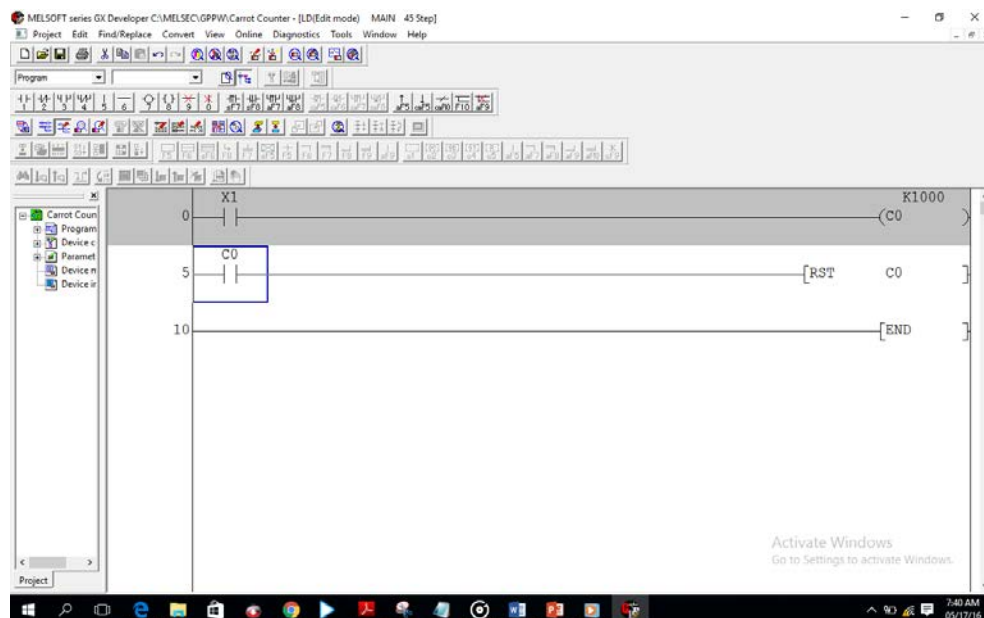


Figure 2. Carrot counter ladder diagram

The above ladder logic diagram counts every carrot that passes through the peeler through the photoelectric sensor placed just before the first peeling blade. The sensor sends a signal that closes the normally (NO) contact when a carrot passes across it. This starts the counter and will count up to 1000 carrots. When this value is reached, the normally closed contact C0 becomes true hence resetting the counter to 0. This counting process can be used as a quality control tool by the user being able to time how many minutes it would take to peel 1000 carrots. The design of processing 1000 carrots in an hour should be fulfilled.

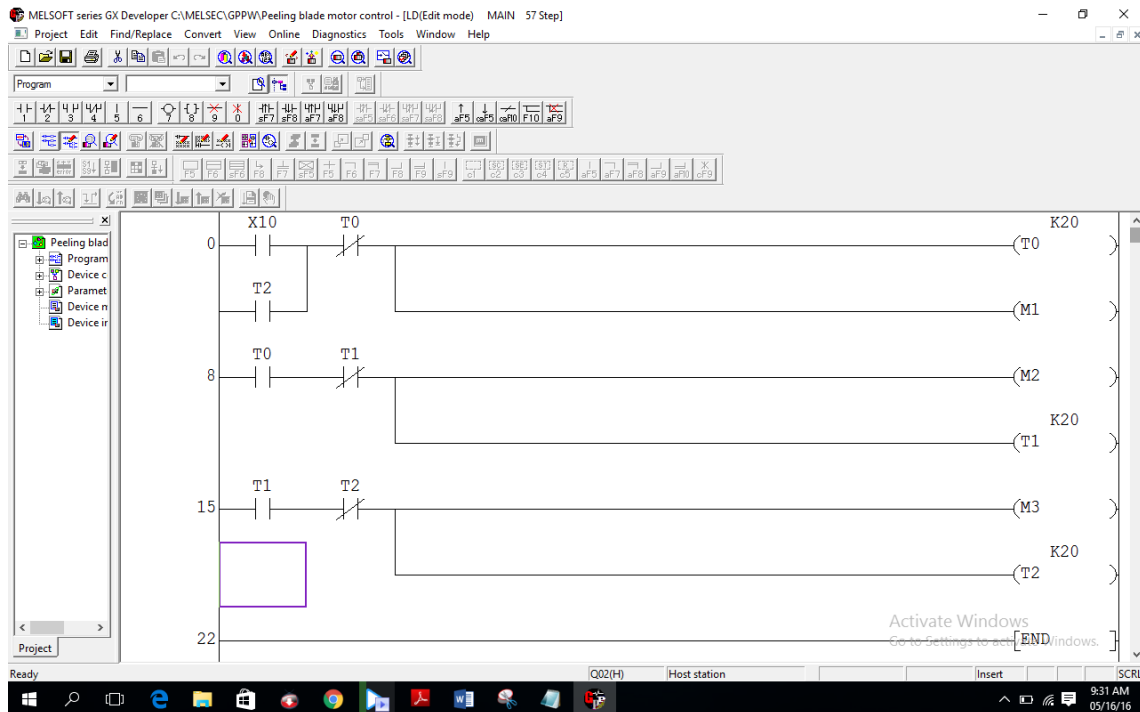


Figure 3. Peeling blades motor control ladder diagram

The above ladder logic diagram controls the closing of peeling blades as a carrot comes inside the peeler from the conveyor belt. A photoelectric sensor placed just before the first peeling blade senses a carrot passing through, the sensor sends a signal to the normally open contact (NO) which then closes to complete the circuit. The first motor (M1) starts running and the peeling blades close in to peel the carrot. At the same time a timer (T0) starts counting and after 2 seconds its time elapses resulting in its normally closed (NC) opening and its normally open (NO) contact closing. This action completes the circuit of the second motor (M2) as well stopping M1. The process repeats itself in the second peeling stage. After 2 seconds have elapsed in the last peeling stage, the normally closed contact (T2) stopping the third motor (M3) at the same time starting motor one through the normally open contact T2. The process continues repeating itself as carrots pass through the peeler.

3.1 Assembly drawings and analysis

Assemblies can be depicted in the following figures:

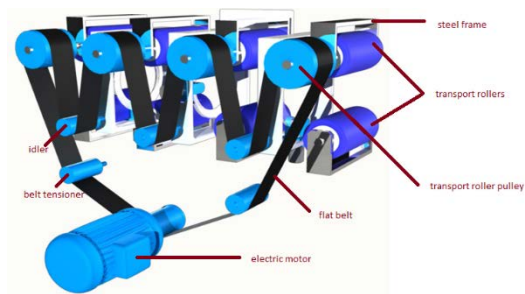


Figure 4. Transport roller drive mechanism

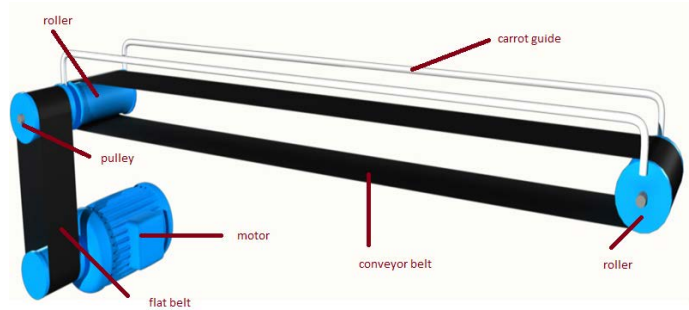


Figure 5. Conveyor belt

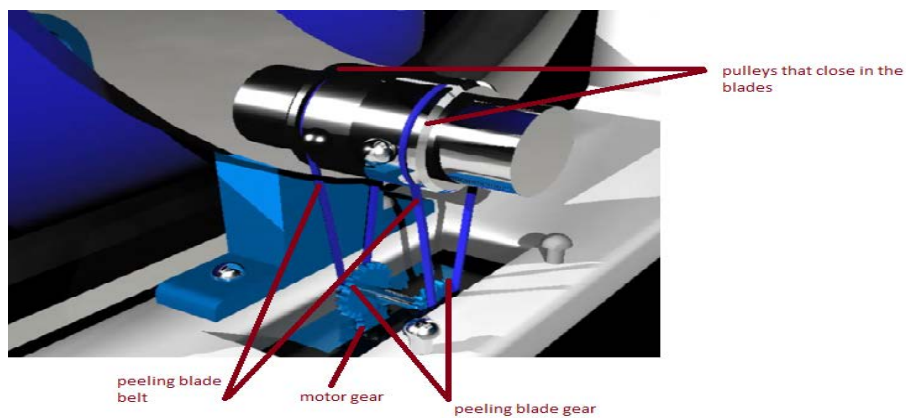
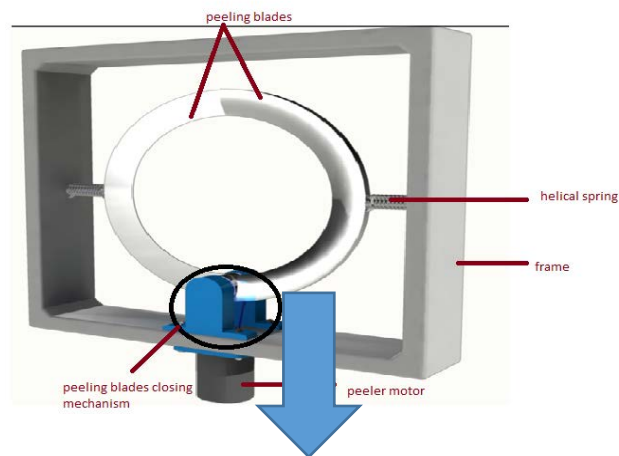


Figure 6. Peeling blades and the motor that control their motion

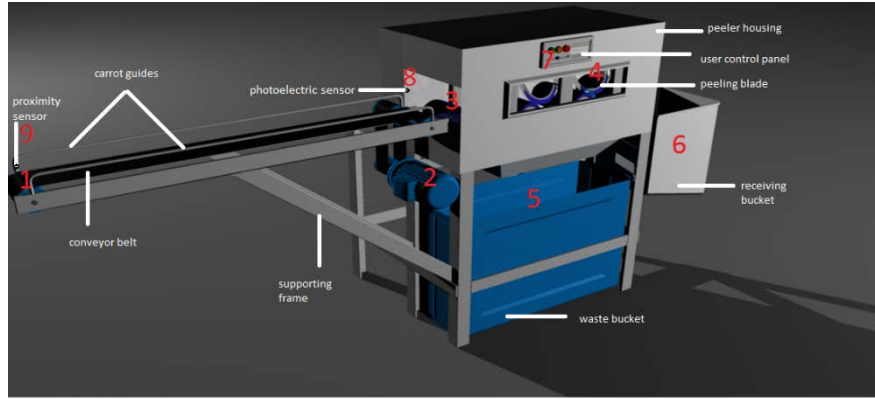


Figure 7. Machine assembly

3.2 Operating Principle

The user feeds a carrot manually at point 1, the proximity sensor (9) positioned on one of the carrot guides senses its presence. This prompts the starting of the belt electric motor (2) through a program embedded in the PLC CPU. The user should feed carrots consecutively within a space of 5seconds, the delay which was set in the PLC, before the automatic belt stopping mode is activated. As the carrot approaches the first set of transport rollers (3), which convey the carrots across the peeler, a photoelectric sensor (8) senses its presence prompting three actions,

1. The electric motor that powers the transport rollers starts.
2. The carrot counter starts counting carrots passing through the peeler.
3. The first peeling blade motor starts.

During peeling, waste peels are collected in the waste bucket and the processed carrot is collected in the receiving bucket.

3.3 Stress Analysis

The maximum theoretical stresses that would result to failure of different components of the machine are going to be determined using the Von Mises theory. The theoretical values will then be compared with results of a stress analysis conducted by Solidworks. According to the Von Mises' failure criterion, a material under multi-axial loading will yield when the distortion energy is equal or greater than the critical value for the material:

$$\frac{1+\nu}{3E} \sigma_{VM}^2 \geq \frac{1+\nu}{3E} \sigma_y^2$$

Therefore, $\sigma_{VM}^2 \geq \sigma_y^2$

Thus, a material yields or starts to yield when the Von Mises stress is greater than the yield stress of that material (the distortion energy theory).

$$\sigma_{VM} = \sqrt{(\sigma_{xx} + \sigma_{yy} - \sigma_{xx}\sigma_{yy} + 3\tau_{xy}^2)}$$

The torsional theory which states that, $\frac{G\theta}{L} = \frac{\tau}{r} = \frac{\sigma}{r}$ can be used to calculate the shear stress, τ_{xy}

Theoretical Von Mises Stress on the Peeling blade

$$\text{Stress in the } x \text{ direction, } \sigma_{xx} = \frac{F}{A} = \frac{6}{\pi t l} = \frac{6(2)}{\pi(0.004)(0.048)} = 19.9 \text{ kN/m}^2$$

$$\text{Stress in the } y \text{ direction, } \sigma_{yy} = \frac{F}{A} = \frac{6}{\pi w l} = \frac{6(2)}{\pi(0.01)(0.048)} = 7.96 \text{ kN/m}^2$$

Where, t , is the blade thickness, w is the blade width and l is the blade length.

$$\tau_{xy} = \frac{y(\sigma_{xx})}{r} = \frac{(0.1)(19900)}{(0.015)} = 133 \text{ kN/m}^2 \text{ from the Torsional Theory}$$

$$\sigma_{VM} = \sqrt{(\sigma_{xx} + \sigma_{yy} - \sigma_{xx}\sigma_{yy} + 3\tau_{xy}^2)}$$

Therefore, $\sigma_{VM} = \sqrt{(19900 + 7960 - (19900)(7960) + 3(133000)^2)} = 2.294 \times 10^5$

The calculated theoretical Von Mises stress is comparable to that which was obtained from a Solidworks simulation thereby validating the theory.

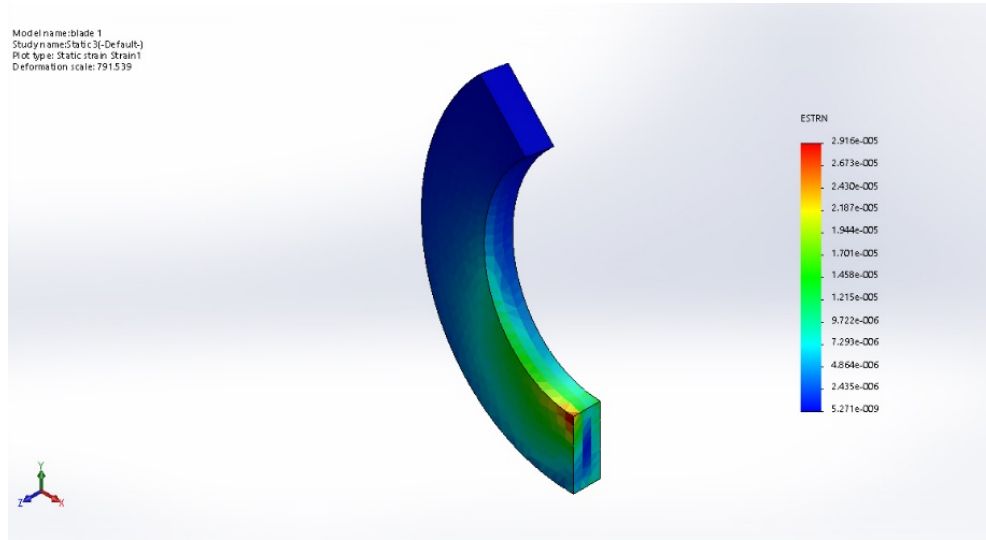


Figure 8. Solidworks Von Mises Stress on the Peeling blade

From the stress analysis graph, the Von Mises stress, $\sigma_{VM} = 2.916 \times 10^5$ N/m² which is less than the yield strength of the helical spring material $\sigma_y = 1.7 \times 10^8$. This shows that the blade design is safe.

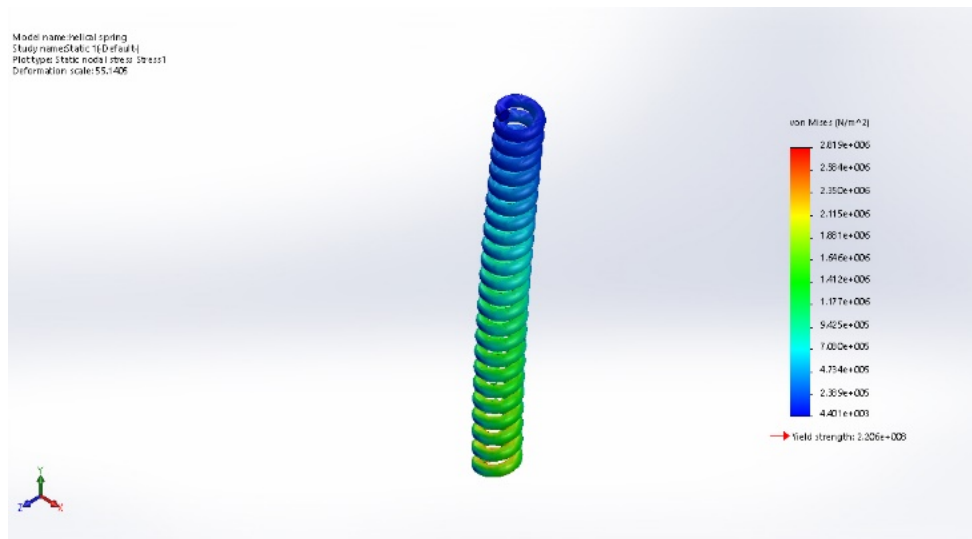


Figure 9. Solidworks Von Mises on the Peeling blade helical spring

From the stress analysis graph, the Von Mises stress, $\sigma_{VM} = 2.819 \times 10^6$ which is less than the yield strength of the helical spring material $\sigma_y = 2.206 \times 10^8$. This shows that the spring design is safe.

3.4. Quality Function Deployment (QFD)

An analysis for cost and functionality of the carrot peeling machine will be done using the Boothroyd method to come up with the payback period. The Quality Deployment Function will be employed to analyze the importance of each part of the machine in comparison with consumer needs. The above methods gives the consumer knowledge of how much time they will take to fall back on the money invested into buying the machine as well as informing them on the suitability of the machine in performing its function in relation to its cost. The Boothroyd price, which is the time taken to assemble or manufacture, is translated into monetary terms preventing the manufacturer from understating or overstating the manufacturing price of the machine. Quality Function Deployment is a systematic approach to design based on close awareness of customer desires, coupled with the integration of corporate functional groups. It consists of translating customer desires (for example, the ease of writing of a pen) into design characteristics (pen ink viscosity, pressure on ball-point) for each stage of the product development (Rosenthal, 1992). The objective of QFD is to turn subjective quality criteria into objective ones that can be measured and quantified and can be used for design and manufacture of a product. In a nutshell, this method determines how and where priorities are to be assigned in product development.

4. Recommendations and Conclusion

Recommendations will be made on how to realize the best out of the machine. Specifications will be outlined on maintenance procedures of machine parts, quality assurance and control on the peeled products as well recommendations on user safety when operating the machine.

4.1 Quality Control

For quality control, the following quality checks may be conducted:

- Size
- Color
- Appearance

Size: The carrot should weigh at most 12% less than its initial mass. The high peeling accuracy is achieved by the use of the variable frequency drive (VFD) motor controlled peeling blades. The user can conduct the size test by weighing the initial mass of a carrot before peeling and the mass after peeling. The peeling loss can then be calculated as

$$\frac{\text{initial mass} - \text{final mass}}{\text{initial mass}} \times 100\%.$$

Color: Color of the peeled product is also another important quality control tool. The initial color of the carrot should not be distorted.

Appearance: The outer surface appearance of a peeled carrot gives an indication of the peeled carrot quality. The carrot should not be bruised after the peeling process and the peeled surface should be uniform.

Safety: The machine operator should be kept safe from any form of danger that may harm or injure them by following the instructions on operation of the machinery. Rotating and moving parts have been housed and guarded as expected from modern day design to prevent contact with the user during operation. The machine has been designed to start the conveyor belt once a carrot has been placed on it through the use of a proximity sensor that communicates with the conveyor belt electric motor through the Mitsubishi GX Developer PLC. Once no carrot is being sensed to be on the conveyor, the belt electric motor automatically shuts down. In this regard the operator should not place their hands on the belt as this will start the belt and might lead to finger or hand injuries. Special attention should also be taken on good hygienic practices since the product being processed is consumed by human beings. The receiving buckets should always be kept clean all the time and should be washed by a disinfectant on a daily basis to ensure high standards of hygiene. The machine parts that the carrots get into contact with should also be regularly cleaned to avoid contamination. These parts include the conveyor belt, transport rollers and peeling blades. A provision is there to allow easy access of these parts when the need for cleaning arises.

Maintenance: To fall back on the money invested in buying the machine and to get the most out of the peeling action there is need for maintenance and servicing regularly. Preventive maintenance should be done on electric motor

bearings by lubrication of the bearing jackets after a certain time interval. The lubrication oil of the conveyor belt and belt drive electric motors should be checked after every two weeks of continuous operation.

Machine evaluation: The project can be further developed to cater for other processes involved in carrot processing. These are washing, cutting and packaging. If the peeling part of the machine is integrated with these other processes, the carrot processing becomes more complete and further reduces the human labor involved and also increasing the value of the carrot.

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Biography

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