KAUNAS UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND DESIGN

Marija Mačiulytė

MODERNIZATION OF CUTTING MECHANISM IN CARDBOARD TUBES PRODUCTION LINE

Master's Degree Final Project

Supervisor

Assoc. prof. dr. Inga Skiedraitė

KAUNAS, 2017

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Master's Degree Final Project

INDUSTRIAL ENGINEERING AND MANAGEMENT (code 621H77003)

Supervisor

(signature) Assoc. prof. dr. Inga Skiedraitė

(date)

Reviewer

(signature) Assoc. prof. dr. Saulius Baskutis

(date)

Project made by

(signature) Marija Mačiulytė

(date)

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KAUNAS UNIVERSITY OF TECHNOLOGY

Faculty of Mechanical Engineering and Design

(Faculty)

Marija Mačiulytė

(Student's name, surname)

Industrial engineering and management, 621H77003

(Title and code of study programme)

"Modernization of cutting mechanism in cardboard tubes production line"

DECLARATION OF ACADEMIC HONESTY

19 May 2017

Kaunas

I confirm that a final project by me, **Marija Mačiulytė**, on the subject "Modernization of cutting mechanism in cardboard tubes production line" is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarized from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this thesis.

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Approved:
Head of
Production engineering
Department

_____
(Signature, date)

Kazimieras Juzėnas
(Name, Surname)

MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme INDUSTRIAL ENGINEERING AND MANAGEMENT

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologie sand correct language, ability to formulate proper conclusions.

1. Title of the Project

Modernization of cutting mechanism in cardboard tubes production line

Approved by the Dean Order No.V25-11-8, 21 April 2017

2. Aim of the project

To modify and update the cutting mechanism, improve working conditions and accelerate the cutting process by adapting the modernized cutting unit to the existing cardboard tubes production line.

3. Structure of the project

Introduction; cardboard tubes, cores, their types and primary uses; cardboard tube production analysis; analysis of the cutting mechanism in cardboard tubes production line; designing appropriate model of cutting unit; experimental analysis of modernized cutting mechanism; economic costs and prices analysis; conclusions; references, appendixes.

4. Requirements and conditions

1. To increase cardboard core cutting quality according to customer requirements; 2. To improve employees working conditions related with the cutting unit according to the "Control of Noise at Work Regulations"; 3. To increase safety level of cutting unit on the basis of EU Council Directive 89/391/EEC; 4. To integrate modified cutting unit to original cardboard tubes production line.

5. This task assignment is an integral part of the final project
6. Project submission deadline: 20__ _____ __st.

Student _____ _____
(*Signature, date*) (*Name, Surname ofthe Student*)

Supervisor _____ _____
(*Signature, date*) (*Name, Surname ofthe Student*)

Mačiulytė Marija. Modernization of Cutting Mechanism in Cardboard Tubes Production Line. Master's Final Project / supervisor assoc. prof. dr. Inga Skiedraitė; Faculty of Mechanical engineering and Design, Kaunas University of Technology.

Research field and area: Technological science, production engineering.

Keywords: *cutting mechanism, cardboard tubes production line, cutting quality analysis, noise analysis.*

Kaunas, 2017. 61 p

SUMMARY

The Master degree project examines the existing options of cutting systems in cardboard tubes machines and introduces a special device – the cutting mechanism that is used that for cutting cardboard tubes. In this case circular saw blade and “target” (a plate) is used. The disc is connected with the target. When the cardboard core is formed, it pushes the target and the circular saw blade cuts the core. By pushing the target the inductive sensor transmit the signal to the pneumatic cylinder which moves the circular cutting disc and cuts the cardboard tube. The cutting disc moves along the cardboard tube movement, so it is important to synchronize the disc speed with core linear speed. Such a cutting unit slows down the core manufacturing speed and reduces the final product quality. Also, this machine creates a lot of noise and dusts in the workplace, and thus, worsens the working conditions. Because of jagged and uneven cut tube edges, the tube cannot be used for further processing operations and is thrown away. The analysis of the original cutting mechanism is conducted in this project, modernize cutting unit is created, because of poor cutting quality, high waste of material, equipment and labour force of original cutting unit. The cutting quality and noise analyses of cutting unit are performed and compared with the data of modernized cutter. In the economic part of this project the costs for producing an interconnection unit are calculated.

Mačiulytė Marija. Pjovimo mechanizmo modernizavimas kartoninių tūtų gamybos linijoje. Magistro baigiamasis projektas / vadovas doc. dr. Inga Skiedraitė; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Studijų kryptis: technologiniai mokslai, gamybos inžinerija.

Reikšminiai žodžiai: *pjovimo mehanizmas, kartoninių tūtų pjovimo linija, pjovimo kokybės analizė, triukšmo analizė.*

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SANTRAUKA

Baigiamajame magistro darbe nagrinėjamos esamos pojvimo sitemos, naudojamos kartoninių tūtų gamybos linijose ir pristatomas specialus prietaisas – pjovimo mechanizmas, naudojamas pjaunant kartonines tūtas. Šiuo atveju prietaisas yra sudarytas iš diskinio pjūklo ir „taikinio“ (plokštės). Peilis yra sujungtas su taikiniu. Kai suformuojama kartoninė tūta, ji pastumia taikinį ir pjūklas nupjauna tūtą. Toks pjovimo mechanizmas lėtina gamybos greitį bei blogina galutinę produkto koybę. Taip pat toks mechanizmas sukelia daug triukšmo ir dulkių darbo aplinkoje, bei taip pablogina darbo salygas. Dėl netolygių bei išdrąskytų nupjautos tūtos kraštų, tūta negali būti naudojama tolesnėse apdirbimo operacijose ir yra išbrokuojama. Šiame projekte yra atlikta pjovimo mechanizmo analizė, bei dėl prastos originalaus pjovimo mechanizmo pjovimo kokybės, didelio atliekų, įrangos bei darbo jėgos eikvojimo modernizuotas pjovimo mechanizmas. Išanalizuota pjovimo mechanizmo pjovimo kokybė bei atlikta triukšmo analizė, o gauti duomenys palyginti su modernizuoto pjovimo mazgo duomenimis. Ekonominėje šio projekto dalyje yra apskaičiuoti sujungimo mechanizmo gamybos kaštai.

Gratitude

I would like to express my gratitude to the supervisor I. Skiedraitė, for help in my master's project investigation.

Table of Contents

INTRODUCTION

Packaging is a technology focused on stylized product form and functionalism. It focuses on carrying, presenting and protecting the product. Also, packaging helps to create intention for the product within, delivers on the brand promise, and enriches the user experience at every interaction. Paper and paper-based packaging are essential components of modern life. It is engineered to be sturdy, yet lightweight and is customizable to meet specific needs of product or customer [1]. Paper packaging can be used unlimited in food, communication, transportation, production, even in architecture and other industries.

Different manufacturing machines or production lines are used for different packaging types. The cardboard tube and core production line is used for producing various material, colour and design tubes and cores that can be used in paper towels, film, adhesive tape, thread and yarn industries, concreting and metallurgical industry (for inserting the thermocouple).

This project takes interest in cutting mechanism that is used in cardboard tubes and cores production line for cutting them into pieces of needed length. The main material used to produce a core is cardboard. In other words, it is a porous kraft paper with high elasticity and high tear resistance designed for packaging products with high demands for strength and durability [2]. Much time is needed to make a cardboard core from kraft paper rolls. Paper is wrapped around a spindle on a spiral winder and secured with adhesives. Excess glue is collected and directed back into the manufacturing process. The core is cut into pieces of needed length, put into special boxes and dried to solidify the glue. After drying process is done, the cores can be packed according to customer needs. Various cutters or cutting units can be used in core cutting process.

In this case circular saw blade and “target” (a plate) is used. The disc is connected with the “target”. When the cardboard core is formed, it pushes the target and the circular saw blade cuts the core. By pushing the target the inductive sensor transmit the signal to the pneumatic cylinder which moves the circular cutting disc and cuts the cardboard tube. The cutting disc moves along the cardboard tube movement, so it is important to synchronize the disc speed with core linear speed. Such a cutting unit slows down the core manufacturing speed and reduces the final product quality. Also, this machine creates a lot of noise and dusts in the workplace, and thus, worsens the working conditions. Because of jagged and uneven cut tube edges, the tube cannot be used for further processing operations and is thrown away. Such a poor cutting quality and high waste of material, equipment and labour force creates losses and prolongs core manufacturing process, so the cutting unit with circular saw blade needs for a new solution by modernizing the cutting unit.

The aim of this research is to modify and update the cutting unit, improve working conditions and accelerate the cutting process by adapting the modernized cutting unit to the existing cardboard tube manufacturing machine line, so that there would be the lowest possible cost for replacing the old one.

The modernizing of cutting unit has several tasks:

1. to design the appropriate model of cutting unit;
2. to increase cardboard tube cutting quality;
3. to improve employees working conditions related with the cutting unit;
4. to increase safety level of cutting unit.

1. CARDBOARD TUBES, CORES, THEIR TYPES AND PRIMARY USES

Paperboard or cardboard tubes are universal and can be found in every aspect of modern day life. The terms “paperboard tube” and “paperboard core” are used interchangeably in industry. Cardboard tubes, or paper tubes, are cylindrical-shape products that are fabricated from wood pulp. Different varieties of cardboard such as fiberboard, paperboard, kraft paper and paper-adhesive composites have been made from wood pulp. Cardboard tubes are used for a wide variety of functions in different industries. They are typically fabricated from ribbons of cardboard wrapped around a mandrel in the desired dimensions [3].

Cardboard tubes are classified into:

1. spiral tubes and cores;
2. convolute tubes and cores;
3. specialist tubes and cores;
4. waxed cones.

Spiral tubes & cores are made from continuous strips of cardboard (chosen to meet the requirements of the application) and various types of adhesives. Spiral tubes offer excellent dimensional tolerances and crush strength [4]. The composite nature of their structure allows easy customization with printed, coloured or embossed covers and liners. Spiral tubes and cores are usually used in labels and tapes, textiles, packaging, postal tubes, fabrics and films [5]. The example of spiral tubes is shown in Fig. 1.1.

Fig.1.1. Spiral cardboard tubes [6]

Convolute or spiral tubes and cores are made from single sheets of cardboard (chosen to meet the requirements of the application) and various types of adhesives. The structure of adhesives gives convolute tubes higher beam strength than their spiral equivalent. Smaller inner diameters are easier to achieve and their single-sheet manufacturing process forms a tube able to withstand internal pressure more consistently, which can be ideally used for pyrotechnic applications. Likewise, their single-sheet manufacturing process makes it easy to create a flap on the outside of

the tubes and it can be of particular advantage in textile applications [7]. The example of convolute tubes and cores is shown in Fig. 1.2.

Fig.1.2. Spiral cardboard tubes [8]

Specialist tubes can be made to fit a broad range of products. They are made in different levels of structural strength and thickness, depending on the level of protection required. Most commonly these tubes are used for mailing and shipping. Specialist tubes are also readily available for papers, posters, documents and pieces of artwork which are able to be rolled into a cylindrical shape. These tubes are able to withstand the pressure and stress that can occur during transit as they are formed from a material such as high quality kraft paper [1]. The example of specialist tubes and cores is shown in Fig. 1.3.

Fig.1.3. Special cardboard tubes and cores: *a)* mailing and shipping tubes, *b)* threads and yarns tubes, *c)* fabric tubes with double-sided adhesive tape and *d)* food packaging tubes [9]

Specialist tubes are strong and are often used for shipping and packaging. Other common uses for cardboard tubes are as follows: paper cores providing structural strength to items such as rolls of fabric, electrical wires, coin banks for collecting money and donations, caulking tubes for construction projects, grease cartridges for using in the automotive and mechanical industry and paper cans, that are widely used in packaging for foods, cosmetics and merchandise. Another particular use for specialist tubing is by contractors or construction industries that are using large, highly durable and heavy duty cardboard tubes for concrete pillar forming [1].

Conical Bolt Cones or waxed cones are manufactured from waxed cardboard. When they are used with a holding down bolt it will provide a conical void for easy bolt location adjustment, with minimum displacement of reinforced concrete. Waxed cones can be reused by leaving 25mm of the box protruding and/or rotating them before the concrete is completely set. Applications of conical bolt cones include fixing station and machine bases [10]. Waxed cones and cardboard conical bolt boxes are also widely used by construction industries and in pre-fabricated steel buildings. Conical bolt boxes provide a perfect way of sitting fixing bolts into ground floors of steel frame buildings or similar applications [7]. The example of waxed cones is shown in Fig. 1.4.

Fig.1.4. Waxed cardboard cones [11]

In this case the cardboard tube production line produces various spiral tubes. For example a small spiral cardboard tube of 290 mm length, 16 mm internal diameter and 18 mm outer diameter is cut by using circular saw blade cutting unit. 3 paper plies of 57 mm width were used for manufacturing this tube. The example of such cardboard tube is shown in Fig.1.5.

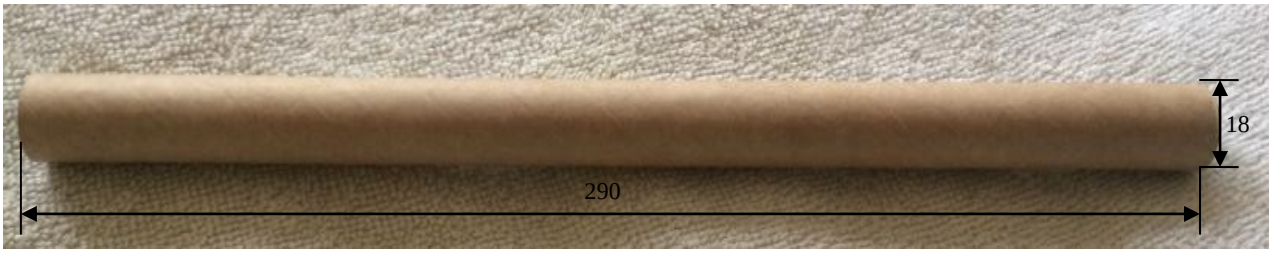


Fig.1.5. Spiral cardboard tube

These tubes were ordered by a client specifically for packing wire coil nails. The example of how these tubes are used for packing wire coil nails is shown in Fig. 1.6.

Fig.1.6. Spiral cardboard tube used for packing wire coil nails [12]

The quality of spiral cardboard tube is highly dependent on the tube manufacturing operations and their steps altogether. The final tube edges are uneven and mauled with much scurf on the corners due to poor cutting quality. Such corners need to be manufactured once again with another cutting machine what means additional cost and labor for final product to be of needed quality. The example of poor quality of spiral tube corner and good quality of another tube edge is shown in Fig.1.7.

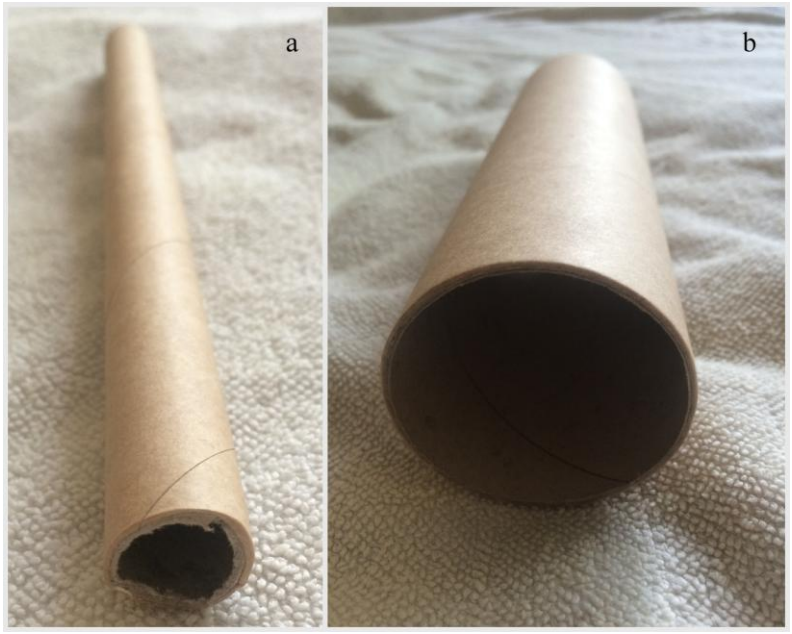


Fig.1.7. Cut edges of cardboard tubes: *a)* poor quality, *b)* good quality

Corners of poor quality tube are uneven in shape, have much scurf on their edges, while good quality tube corners are smooth and clean. The bigger the thickness of the tube the more

difficult for the cutter is to cut tube precisely and burr-free. The example of another poor and good quality specialist tube that is used for textile is shown in the Fig.1.8.

Fig.1.8. Cut edges of specialist tube: *a)* poor quality, *b)* good quality

These tubes are made in similar way the only difference is that after winding the carton into the shape of tube another winder is used to wind additional layer of a special color and texture paper onto a carton tube. Clients can choose any paper from a rich spectrum of different colors and textures. Variety of different papers used for textile tubes and their winding principle are shown in Fig.1.9.

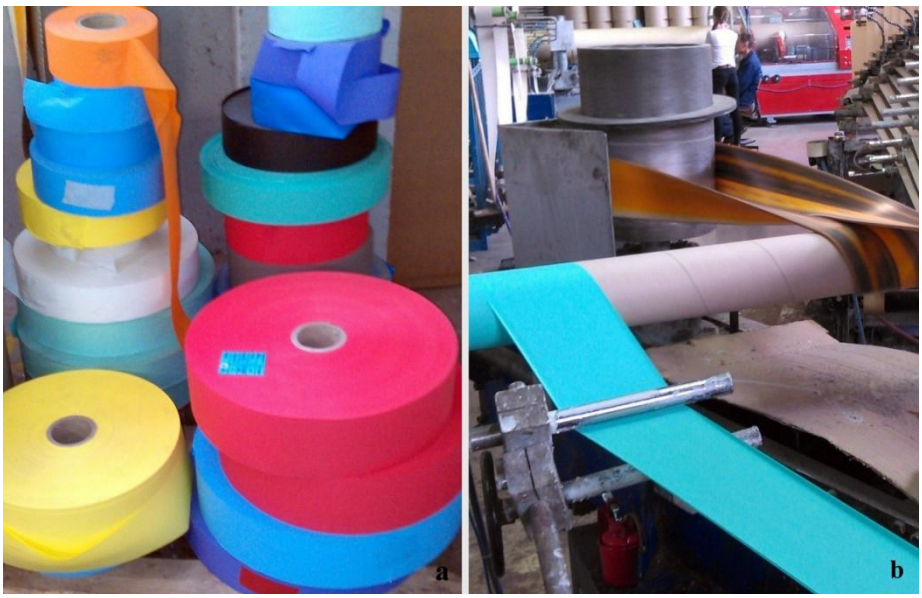


Fig.1.9. Variety of different papers used for: *a*) textile tubes and *b*) textile tubes winding principle

2. CARDBOARD TUBE PRODUCTION ANALYSIS

2.1. Cardboard tube production process

Over the last decades many various and unique cardboard manufacturing machines and production lines were introduced to the market for a single purpose to offer the customers the most cost-efficient, productive tools as possible. Different and replete cardboard manufacturing equipment and systems can be used to get novel packaging solutions and ensuring continuing productivity at the highest level.

Big and heavy cardboard reels are covered with a plastic film to protect against moisture and dirt, laid on wooden pallets and stocked in a storage until further manufacturing processes. The example of cardboard reels storage is shown in Fig.2.1.

Fig.2.1. Storage of cardboard reels

Reeling and slitting machines are used in cardboard-making industry to carry out the first slitting operation on cardboard. They are typically used to produce narrower reels from a large parent reel, to re-reel poorly wound reels or to produce one-offs for customer orders. A parent reel on reeling and slitting machine is mounted at an unwind stand. This reel could weigh up to 40 tones and be up to 10 m wide and more than 3 m in diameter. The sheet of cardboard is pulled off this reel and fed around a series of steel rolls to the slitting knives where it is cut to the required widths. The

slit webs are then rewound at the opposite end, usually onto cardboard cores, to produce the required size of smaller reels [13]. The example of reeling and slitting machine is shown in Fig.2.2.

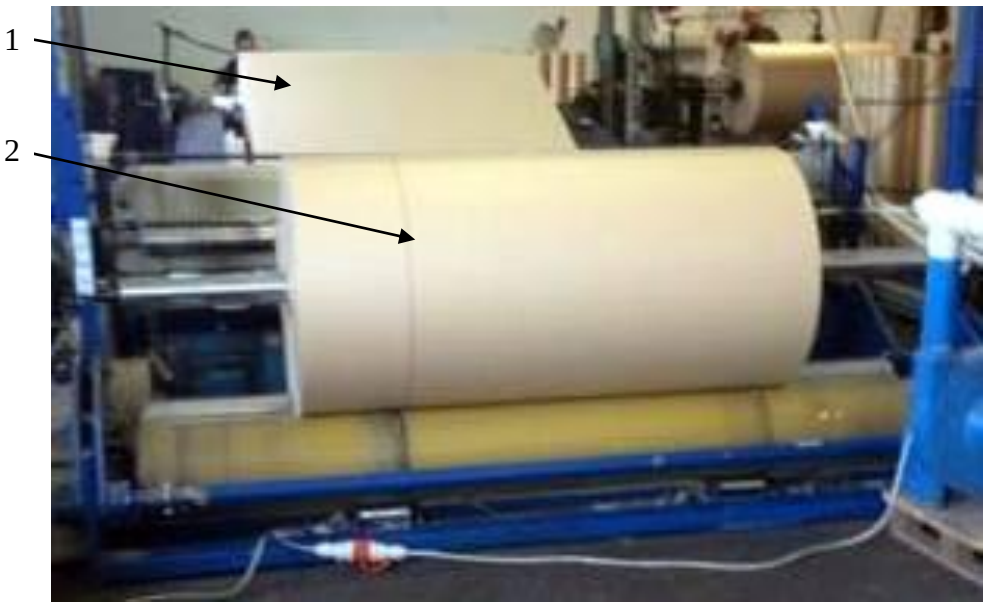


Fig.2.2. Reeling and slitting machine with parent reel *1* and slitting line *2*

After cardboard reels are of right dimensions, they can be mounted onto revolver winder. Revolver winder helps to continuously supply the needed amount of cardboard. It is shown in Fig.2.3.

Fig.2.3. Cardboard roll *1* onto revolver winder *2*

Cardboard plies from revolver winder goes through stretching and retaining system that secures, straightens and supports cardboard. The example of stretching and retaining system is shown in Fig.2.4.

Fig.2.4. Stretching and retaining system with paper stretchers *1*, paper plies *2* and paper retainers *3*

Gluing system lubricates cardboard plies with glue and removes the excess glue from paper. This system can be one-sided or both-sided, depending on glue sprayers that can cover one side or both sides of cardboard plies with glue. The excess of adhesives is removed into the glue tank by using glue wipers. From the glue tank the adhesive material travels to glue sprayers and the process is repeated again and continuously. The example of one-side spraying glue system for 12 paper plies is shown in Fig.2.5.

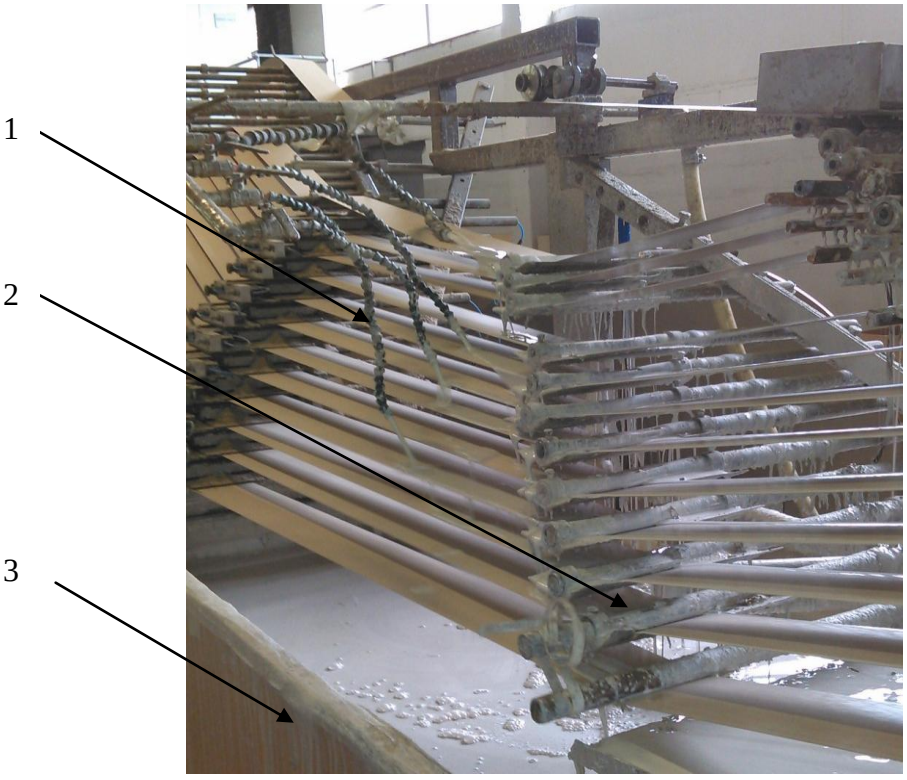


Fig.2.5. One-side spraying glue system with glue sprayers *1*, glue wipers *2* and glue tank *3*

Winding mechanism winds the needed amount of cardboard stripes in order to get a cardboard tube. It consists of 3 main parts: paper plies *1*, belt *2* and two rotating spindles *3*. The belt is mounted onto two spindles that rotate with assistance of the motor. The rotating belt gives the rotation motion to cardboard plies, so they are rolled and adhered into the shape of a tube. The example of such winding system is shown in the picture below in Fig.2.6.

Fig.2.6. Cardboard plies winding mechanism

A knife cutter cuts the cardboard tubes into the pieces of needed length. Knife cutters for cutting cardboard tubes can be automated, semi-automated or manual. At the picture below an automatic knife cutter is shown when the cutting unit is controlled by infrared sensor (Fig.2.7.).

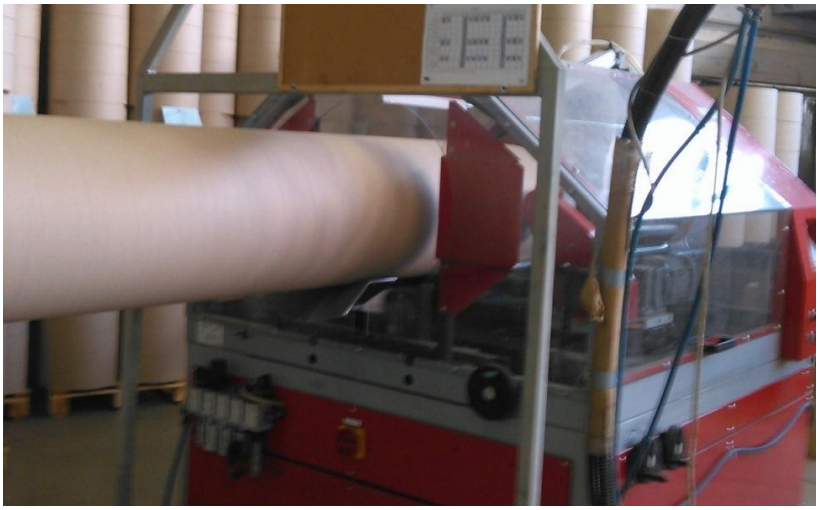


Fig.2.7. Automatic knife cutter

Depending on a size, number of plies, and gluing type some cut cardboard tubes are loaded into frames and transported to drying station. Basically, a drying chamber is a confined area where the products are dried by means a heat water/air exchanger equipped with a traditional heat generator. Alternatively, such a drying station can be equipped with a classical system of generation of hot air with high efficiency air exchanger. The dimensions of drying chamber can be sized for

any requirement and thermal potential can be customized in a very wide range of solutions. The example of heated air drying station is shown in Fig.2.8.

Fig.2.8. Drying station with *a)* closed entrance and *b)* heated air drying system

Cardboards tubes production process can be supplemented by labeling, marking, finishing or decorating mechanisms which give additional features to the manufacturing of cardboard tubes. Various machines can perform a number of core preparation steps, including notching, curling, waxing, etc.

The function of curling machine is to curl the edge of paper tube inside or outside & expand the mouth of paper tube, to make it easy to seam cap/lid. It is used for cylindrical textile tubes and bobbins to curl their tops or both ends. The curling machine and inside-curl tube are shown in Fig.2.9.

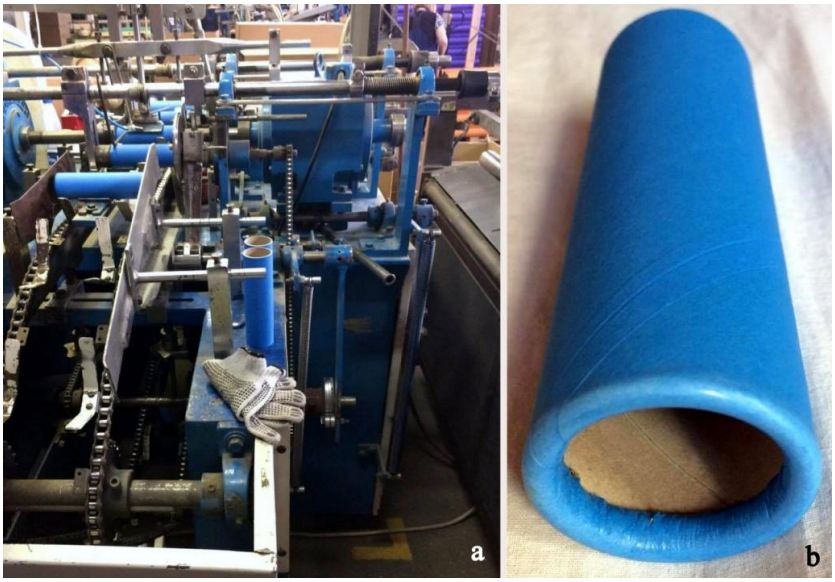


Fig.2.9. A view of: *a)* curling machine and *b*) inside-curled tube

Notched tubes and cores can be used in various industries and applications such as reel barrels, yarn cores, tag insertion, and for a drive chuck on converting equipment [14]. Various sizes of rectangular notches along with the Y-notch, half-circle notch, and hole-notch cores can be offered to the customer. The notching machine and notched tube are shown in Fig.2.10.

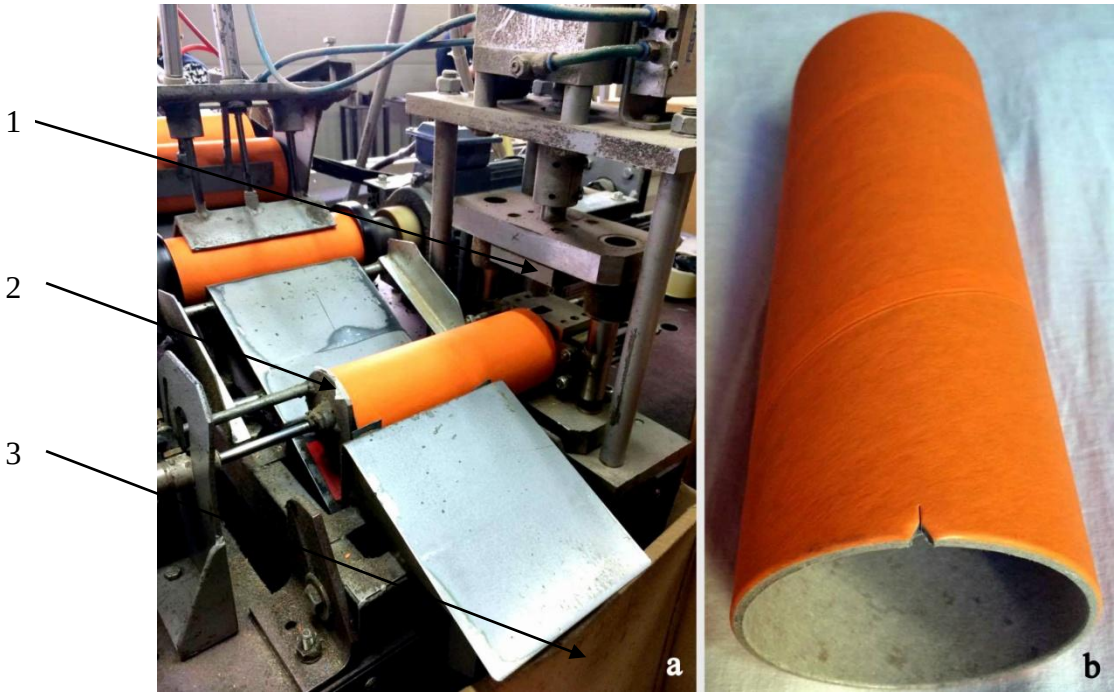


Fig.2.10. A view of: *a*) notching machine and *b*)Y-notched tube

The notching knife (*1*) cuts the notch onto a tube according to customer wishes and the holder (*2*) supports and stabilizes tube into horizontal direction while the notch is made. After notching a tube holder releases tube and it is dropped into a wooden box (*3*).

After production process is done, the final cardboard tubes are packed and sent to the customer.

2.2. Cutting systems and knife cutters

Different manufacturers of cardboard tube machines use different cutting systems or knife cutter systems for cutting the cardboard tube. The “Sodalteh” company proposes an Automatic Core Cutter that is used for cutting jumbo-length cores into smaller pieces. This machine is perfect for users of paper cores such as paper mills; newsprint mills; BOPP Film manufacturers; converters etc. This core cutter may reduce inventory and hassles of buying cores in different lengths from core manufacturers. They can stock jumbo-length cores and divide into required lengths suiting their production plans using it. The core cutter is simple to operate, maintain and has safety devices for operator’s protection. Programmable control panel is also available as an additional option. No excess dust or sound pollution is caused as saw blade is used. The machine is

CE certified and provided with standard safety norms including interlock [15]. The example of “Sodaltech” Automatic Core Cutter is shown in Fig.2.11.

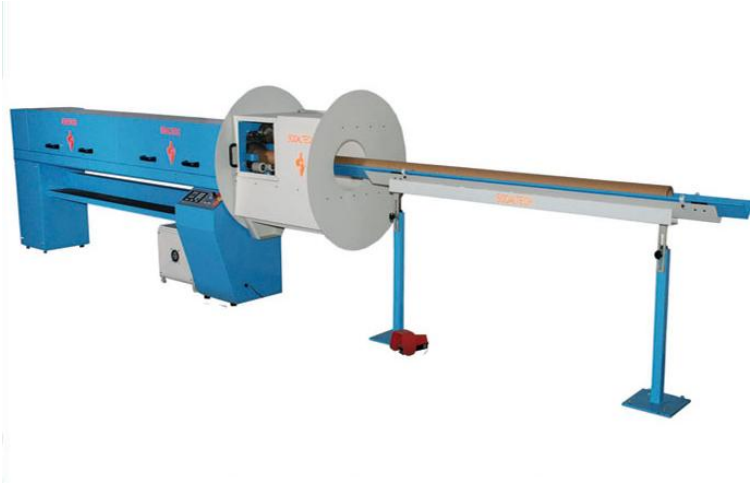


Fig.2.11. The “Sodaltech” Automatic Core Cutter [15]

“UBR Paper Machinery” company offers Paper Tube Re-Cutter Machine by Servo Cutting System. This machine is designed to reach high speed production capacity. It is also easy to use, more safe in general and helps to avoid core-waste. The tube re-cutter machine’s cutting system is controlled by servo motor, so the cutter is able to cut very precisely. The cutting accurate is ± 0,5 mm. This tube cutting machine can be programmed using an operator’s touch screen panel [16]. The example of UBR Paper Machinery Tube Re-Cutter Machine by Servo Cutting System is shown in Fig.2.12.

Fig.2.12. The UBR Paper Machinery Tube Re-Cutter Machine by Servo Cutting System [16]

“Pakea” company proposes Knife cutter Excel 225 E. This machine enables in-line cutting with its 2 opposite and motorized knives. The cutting carriage is synchronized by a frequency variator with the core speed, which gives it a very tight cutting tolerance even with variable speed. The cutting mandrel is pulled back with a cable and an air cylinder with half stroke. This system enables fast cuts (up to 60 cycles/min) and a random wearing of the cutting mandrel. It

allows also an easier start and a better accessibility. One tube discharge system type V3000 by continuous vees is designed for a perfect tube guiding. The modular design of this unit of 3 meters each enables to easily place them one after another. Only hand-wheel enables the easy height adjustment according to the new diameter. A machine has a cover that protects its inside parts and element from rain and dust. The example of Knife cutter Excel 225 E is shown in Fig.2.13.

Fig.2.13. The Pakea Knife cutter Excel 225 E [17]

The cardboard tube cutter that will be modernized is basically a circular saw blade that uses a "target" (a plate) for cutting the cardboard tube into pieces of needed length. The disc is connected with the "target" by using pneumatic cylinder with inductive sensor. When the cardboard tube is formed, it pushes the target away from the inductive sensor and machine recognizes it as the right length of the tube and the circular saw blade cuts the tube. By pushing the target the inductive sensor transmits the signal to the pneumatic cylinder which moves the circular cutting disc and cuts the cardboard tube. Such a cutting unit and its' main parts are shown in Fig.2.14.

Fig.2.14. The cutting unit with a target *1* and circular saw blade *2* for cutting cardboard tubes *3*

The cutting disc moves along the cardboard tube movement, so it is important to synchronize the disc speed with core linear speed. Such a cutting unit slows down the core manufacturing speed and reduces the final product quality because of poor cutting quality. Cut tube edges look jagged and uneven, so for a better cut the paraffin wax is applied onto the circular saw blade. If the client requires for a better quality cut cardboard tubes the nosing and burnishing machines can be used for polishing the edges of the tubes. Because of poor cutting quality and prolonged core manufacturing process the cutting unit with circular saw blade needs for a new solution by modernizing the cutting unit. The quality of cut cardboard tubes by using circular saw blade is shown in Fig.2.15.

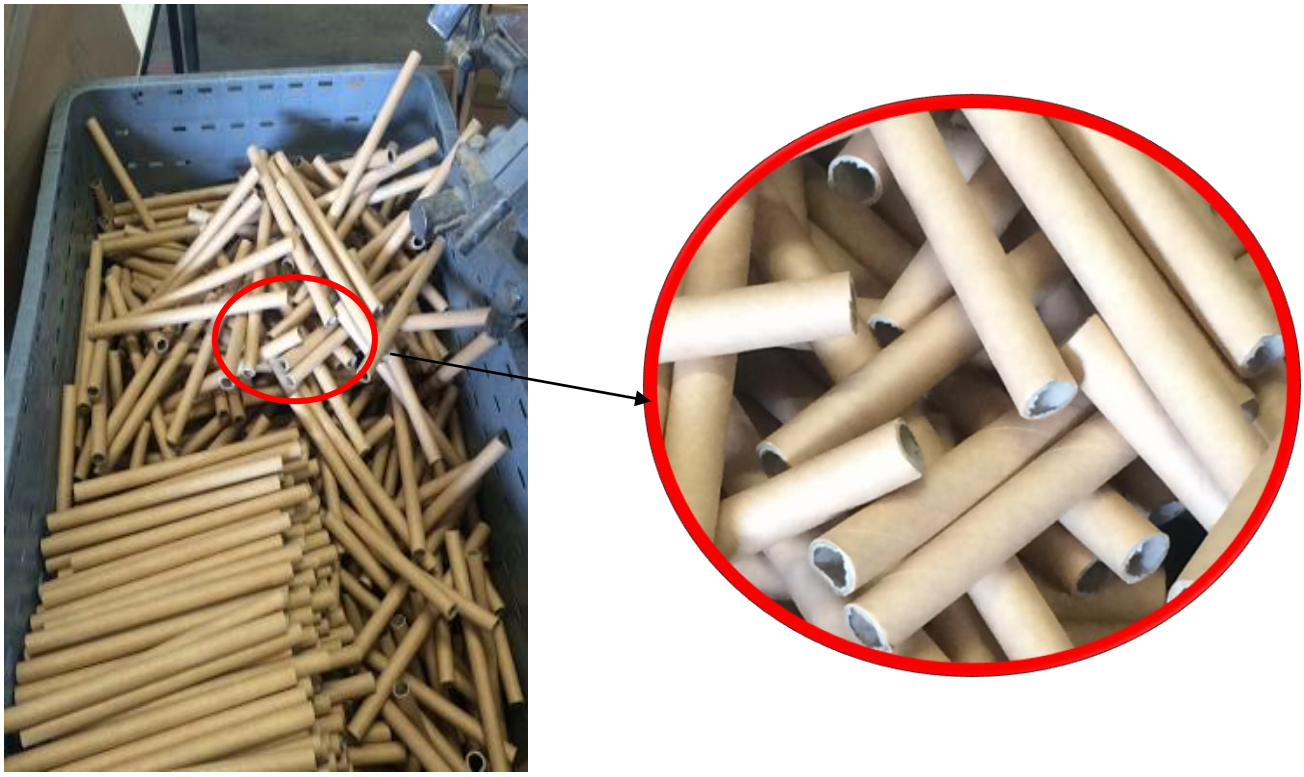


Fig.2.15. The quality of cut cardboard edges

The poor quality of cut cardboard tube corners is not the only one disadvantage of this circular saw blade cutting unit. The cutter can cut only one tube per one cut, so the cutting process is prolonged and requires of working three shifts per day to meet the customer order quantities. Such a work requires high expenditures for workers salaries and the cutting quality still does not meet the needed expectations. Because of poor cutting quality and prolonged core manufacturing process the cutting unit with circular saw blade needs for a new solution by modernizing the cutting unit.

3. ANALYSIS OF THE CUTTING MECHANISM IN CARDBOARD TUBES PRODUCTION LINE

3.1. Analysis of existing cutting mechanism

In order to modernize a cutting unit, the analysis of already existing one must be done. Current cutting mechanism consists of 11 elements that are shown in Fig.3.1.

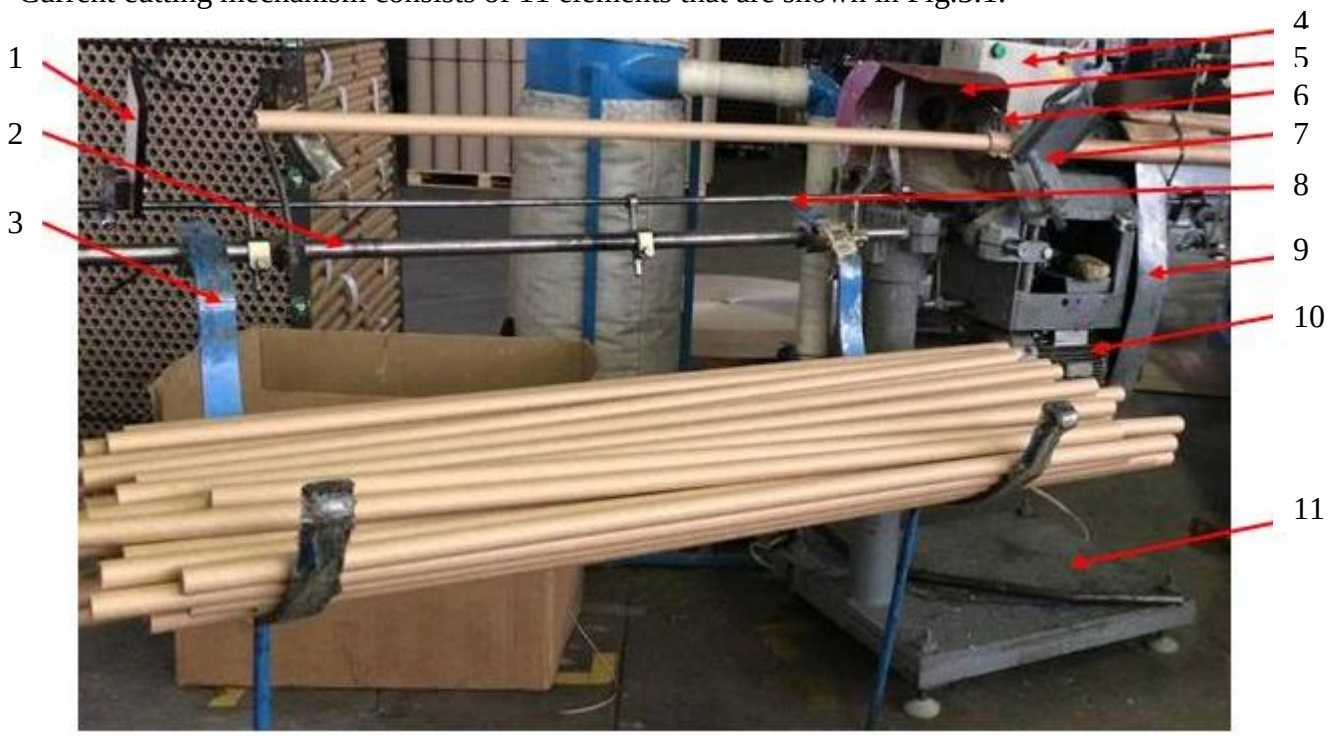


Fig.3.1. Original cutting unit with target *1*, supporting rod *2*, frame *3*, control board *4*, cover *5*, circural saw blade *6*, chuck *7*, pneumatic cylinder *8*, cover *9*, motor *10*, stand *11*

Control board is used for turning on/off the machine and setting the length of a cut cardboard tube. Circular saw blade is connected with the "target" a plate by using pneumatic cylinder with inductive sensor for cutting the cardboard tube into pieces of needed length. Circular saw blade is sheltered under the cover that protects blade from dusts and other environmental factors. When the cardboard tube of needed length is formed, it pushes the target away from the inductive sensor and machine recognizes it as the right length of the tube and the circular saw blade cuts the tube. By pushing the target the inductive sensor transmits the signal to the pneumatic cylinder which moves the circular cutting disc and cuts the cardboard tube. A chuck supports tube to make a more accurate and precise cut. The 4,5 KW power motor (and other machine elements are covered under a cover. Frame with the storage for cut tubes is fixed to the supporting rod.

Original cutting mechanism technical specification is shown in Table 3.

Table 3. Technical information of cutting unit

Designation of the machine	In-line-cutter

Minimum interior diameter of the tube	15 mm
Maximum exterior diameter of the tube	80 mm
Minimum thickness of the tube	1 mm
Maximum thickness of the tube	3 mm
Minimum length of cut	55 mm
Tolerance of cut	± 1 to 2 mm
Number of mounted knife-holders	1
Number of knives per knife-holder	1
Knife	Ø170 - 220 mm circular saw blade (optionally)
Motor	4,5 kW power
Ventilator	1,2 kW power
Operator	One person
Production speed (output)	Up to 15 m/min depending upon the sizes of the tube
Evacuation direction of the tubes	On the left
Control board	Behind the machine

3.2. Original cutting mechanism disadvantages

The biggest and most important disadvantage of current cutting unit is poor cutting quality. Circular saw blade cuts unevenly by making many rips, burrs and jags of 1-2 mm size that are shown in Fig.3.2.

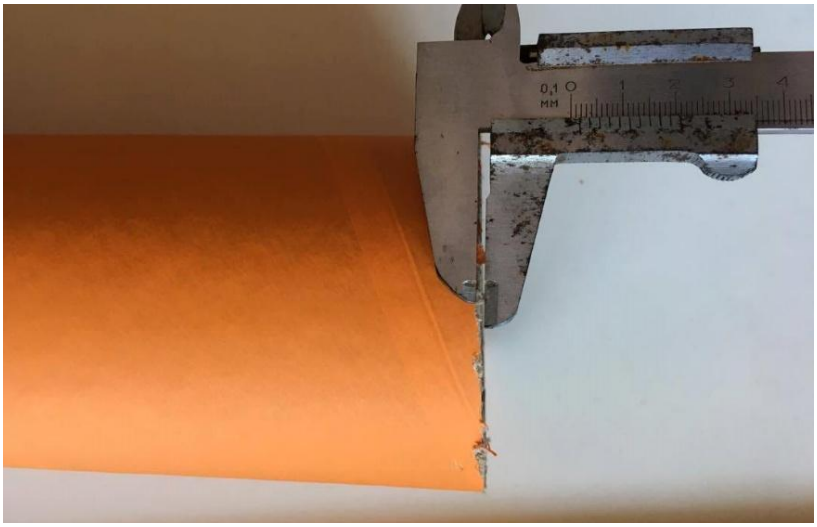


Fig.3.2. Rips, burrs and jags on cutting edge

Because of poor-quality edges, inner and outer diameters of the cardboard tube are affected and these tubes cannot be further processed (e.g. waxed, shortened, curled or notched). These poor-quality tubes are simply thrown away as a waster. High waste of material, equipment and labour force is very unprofitable and detrimental to the company.

Second disadvantage is noise and dusts that appear during cutting process. Circular saw blade scratches out the cutting line and creates lots of microscopic and visual dusts that are shown in Fig.3.3.

Fig.3.3. Dusts on the cutting mechanism

The bigger the thickness of the cardboard tube is the more difficult for the blade is to cut and the more dusts are created during the cutting process. The noise also depends on the tube thickness, so such a noisy and dusty environment negatively impacts the quality of working conditions.

Small inner diameter of the tube that can be cut with original cutting unit is also a significant disadvantage in cutting process. Bigger than 80 mm diameter tubes cannot be processed with this cutting mechanism because of low-quality cutting possibilities.

The thickness of a tube should also not exceed 3 mm, because the cutting unit is not able to cut tubes of bigger thickness. It means that only a small part of cardboard tube production can be cut by using this cutting mechanism.

Furthermore, the cover of the circular saw blade is inadequate to protect workers from injuries. Blade cannot be fully covered, because it wears out quickly and paraffin wax must be manually applied onto it every hour to lubricate the blade and increase cutting quality.

3.3. Requirements for cutting mechanism

The key requirement for a cutting unit is to cut cardboard tube precisely to meet cardboard tubes quality standards. However, there are many other requirements that qualitative cutting unit should satisfy to get high-quality final product.

It is very important to get a clean and accurate cut without any burrs, because only such cardboard tubes can be further processed on shortening, labeling, marking, finishing or decorating machines according customer requirements. For example a special surface treatment that is used for securing yarn before wrapping it on the cardboard tube can be added according to customer wishes. Such a groove on a cardboard tube is shown in Fig.3.4.

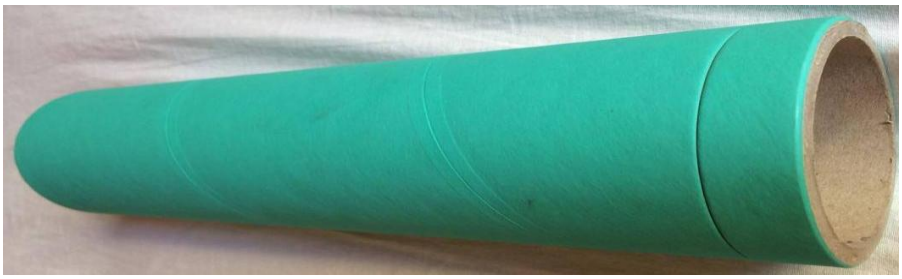


Fig.3.4. Special groove on a cardboard tube for securing string

In order to make such a groove, cardboard tube has to be burr-free; otherwise it would not mount onto the shaft of a marking machine and will be thrown away as a defected product. The example of groove-making mechanism and its' main parts are shown in Fig.3.3.

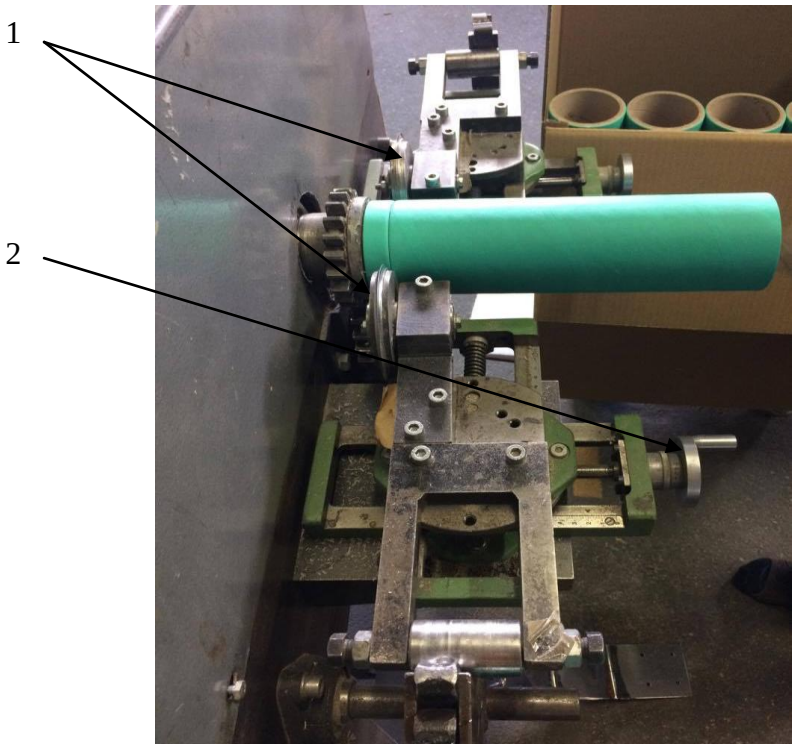


Fig.3.5. Manual groove-making mechanism with two cutters *1* and handle *2*

The tube is manually mounted onto a shaft that is between two cutters. By turning the handle o a mechanism tube rotates and the cutters make a groove onto a tube. Then tube is removed from the shaft and the same process is repeated with another tube. All of these additional operations like notching, waxing, curling, grooving and additional surface treatment need clean and burr-free tube edges in order to make a high-quality final product.

High waste of material that doesn't end up as saleable product increase production cost and prolongs manufacturing process, so the cutting mechanism has to be sharp enough to precisely cut tubes of different thickness and do not damage the cut edges.

Another relevant requirement for a cutting mechanism is an appropriate model, which influences not only the quality of cutting but also the adaptation to current cardboard tube production line. It should be designed by adapting the modernized cutting unit to the existing cardboard tube manufacturing machine line, so that there would be the lowest possible cost for replacing the old one.

Furthermore a convenient, safe and south working environment is very important for good, fast and qualitative work flow. The Control of Noise at Work Regulations (2005) require employers to take action if daily or weekly exposure to noise is at or in excess of certain Exposure Action Levels. According to these regulations it is recommended employers eliminate exposure to noise at source where possible and control exposure to noise [18]. By modernizing a cutting unit the noise at cutting station will be also attempted to decrease to the lowest as possible to ensure that workers' hearing is protected from excessive noise which could cause them to lose their hearing and/or to suffer from tinnitus (permanent ringing in the ears) [19].

The excess of dusts - solid particles ranging in size from 1 μm up to 100 μm, which may be airborne, depending on their origin, physical characteristics and environmental conditions, are also be hazardous in the workplace. Prevention of exposure to dust is also a relevant requirement for modernizing the cutting mechanism.

Safe working environment is also very important requirement for cutting mechanism to prevent workplace incidents and injuries. Cutting unit should be covered by a shelter that not only protects its inside parts and elements from water and dust, but also protects the human from sharp multi-cutters that could cause any harm to human safety and well-being.

All of these requirements are significant to know to analyze current cutting mechanism and to modernize it to a better one.

4. DESIGNING APPROPRIATE MODEL OF CUTTING UNIT

In designing process, the main idea was to take into consideration all the disadvantages of original cutting mechanism and create a modernized one.

By summing up all disadvantages it was clear that modernized cutting mechanism has to cut clean, clear and burr-free; cutting process has to be silent and dust-free; cutting unit must be safe and south for the operator and should be adapted to the current cardboard tube production line. Modernized cutting unit should be created to fulfill all the expectations with the lowest possible cost.

4.1. General provisions

After many experiments, discussions with the cardboard tube machine manager and manufacturing specialists, the final cutting principle of two non-self-rotating and opposite to each other knifes were chosen in order to satisfy high-quality, dust-free tube cutting and minimize electricity consumption. These knifes would have free movement and would take over the rotation after touching the rotating cardboard tube. At the same moment the knives would take over the rotation from tube, they would cut it. The movement of knifes would be controlled with the help of sensors. Sensors will give the signal to the controller, where the program of the cutting machine will be installed and so the programmed actions of the cutting unit will be performed.

EDR 120-24 power source was used for a modernized cutting mechanism. It is an economical slim 120 W DIN rail power supply series, adapt to be installed on TS-35/7,5 or TS-35/15 mounting rails. The body is designed 40 mm in width, which allows space saving inside the areas. This power source adopts full range AC input from 90 VAC to 264 VAC and conforms to EN61000-3-2, the norm of European Union regulates for harmonic current [20]. The example of “EDR 120-24” power source is shown in Fig.4.1.

Fig.4.1. EDR 120-24 power source [20]

EDR 120-24 is designed with a metal housing that enhances the unit's power dissipation. With working efficiency up to 88,5 % this power source can operate at the ambient temperature from -20ºC to 60ºC under air convection. It is equipped with constant current mode for over-load protection, fitting various inductive or capacitive applications. The complete protection functions and relevant certificates for industrial control apparatus (UL508, TUV EN60950-1 and etc.) make EDR-120-24 a very competitive power supply solution for industrial applications.

DVP-14SS2 programmable logic controller (PLC) and digital input/output extension unit DVP-16SP were built-in for modernized cutting mechanism. Second generation DVP-SS2 series slim type PLC keeps the basic sequential control functions from the DVP-SS series PLC but with faster execution speed and enhanced real-time monitoring capability [21]. The example of DVP-14SS2 and DVP-16SP is shown in Fig.4.2.

Fig.4.2. DVP-14SS2 PLC and DVP-16SP I/O extension unit

Specification of second generation DVP-14SS2 standard slim programmable logic controller is shown in the Table 2.

Table 4. DVP-14SS2 PLC specification [22]

MPU points	14 (8DI + 6DO)
Max. I/O points	494 (14 + 480)
Program capacity	8k steps
COM port	Built-in RS-232 & RS-485 ports, compatible with Modbus ASCII/RTU protocol.
High-Speed Pulse Output	Supports 4 points (Y0 ~ Y3) of independent high-speed (max. 10kHz) pulse output
Supports PID Auto-tuning	DVP-SS2 saves parameters automatically after the PID auto temperature tuning is completed.

Walter SK 30 air compressor is used for all the equipment of the company, so it will also be used for a modernized cutting mechanism. This screw compressor has two-stage oil separation system that ensures not more than 3 mg /m3 oil emission to compressed air. Also this compressor works quietly and saves electricity consumption. Serial SK screw compressor 30 has a belt drive and is free-standing. This compressor is of 10 bars. Its' power is 30 kW. Walter SK 30 air compressor is shown is Fig.4.3.

Fig.4.3. Walter SK30 screw air compressor [23]

From a compressor air flows to the dehumidifier, where pressed gas is heating up and condenses the moisture. From the dehumidifier air flows to the receiver – a compressed air tank – where the pressure is equalized and air reserve is sustained. Condensate collector and a pressure regulator stand next to the equipment. They help to establish the required pressure for the equipment. Pressure cannot be increased more than the compressor provides, so condensate collector and a pressure regulator help to reduce the pressure until the required one. 4 bars pressure is established for the modernized cutting mechanism.

A human machine interface (HMI) is a platform, permitting interaction between users and automatic equipment. Delta's HMI products supply communication ports for fast and convenient control and communication of a diverse range of machines, systems and facilities. The color touch screen allow intuitive parameter entry and a variety of ways to display variable data, including trend graphs and alarm elements. Visualization operating, monitoring and efficient control in real time is displayed by high resolution LCD [24]. Delta HMI (Human Machine Interface) DOP-B075515 touch panel was used for convenient controlling of cutting machine functions. It is shown in Fig.4.4.

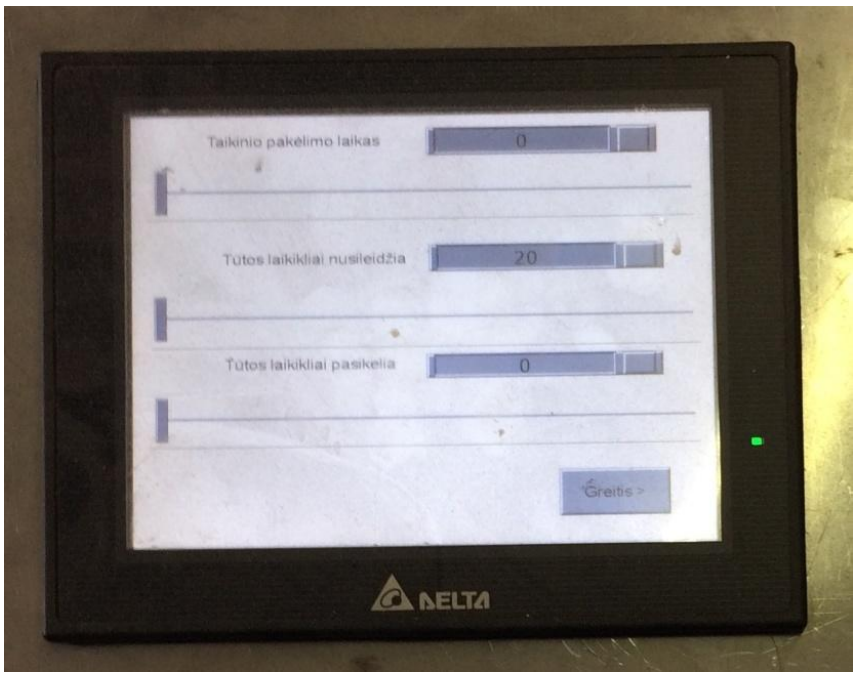


Fig.4.4. Delta HMI touch panel DOP-B075515

"Delta ISPSoft" software was downloaded for free from international company Delta Electronics. Modernized cutting mechanism will be controlled by using this program. Open program window is shown in Fig.4.5.

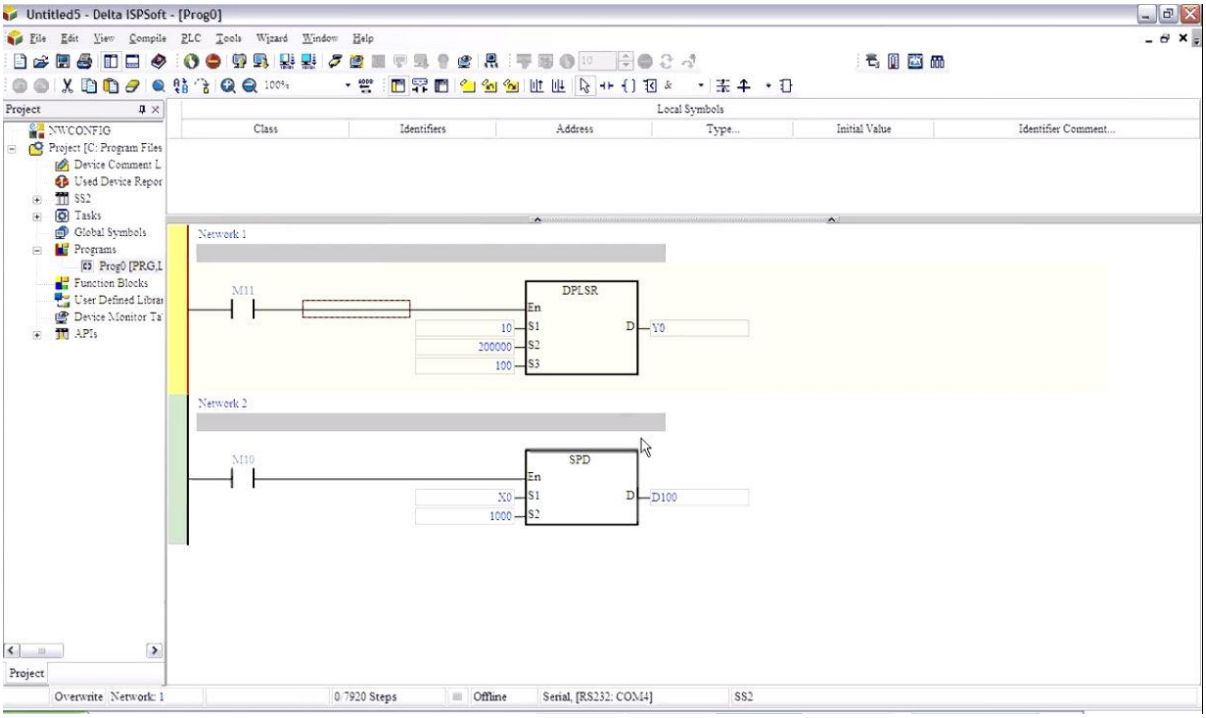


Fig.4.5. "Delta ISPSoft" program window

The movement of cutting mechanism will be controlled with the assistance of six air cylinders. When applications involve linear motion, high speed and moderate loads, air cylinders are usually used to provide the actuation. Compressed air is broadly used almost in every industrial

facility. Many manufacturers offer various sizes and special designs economical pneumatic cylinders with endless array of configurations. The versatility of air cylinders not only makes more innovative and modern designs possible, but also makes a reality of many linear applications that would not be possible or practical without them [].

Four sensors will be placed into four different locations that the cutters are moving along: starting point, movement point, oncoming and cutting point, retreat and regression point. Sensors gives information to the controller and the controller controls air cylinders with the assistance of "Delta ISPSoft" program.

4.2. Control board

The control board of modernized cutting mechanism and its'parts are shown in Fig.4.6.

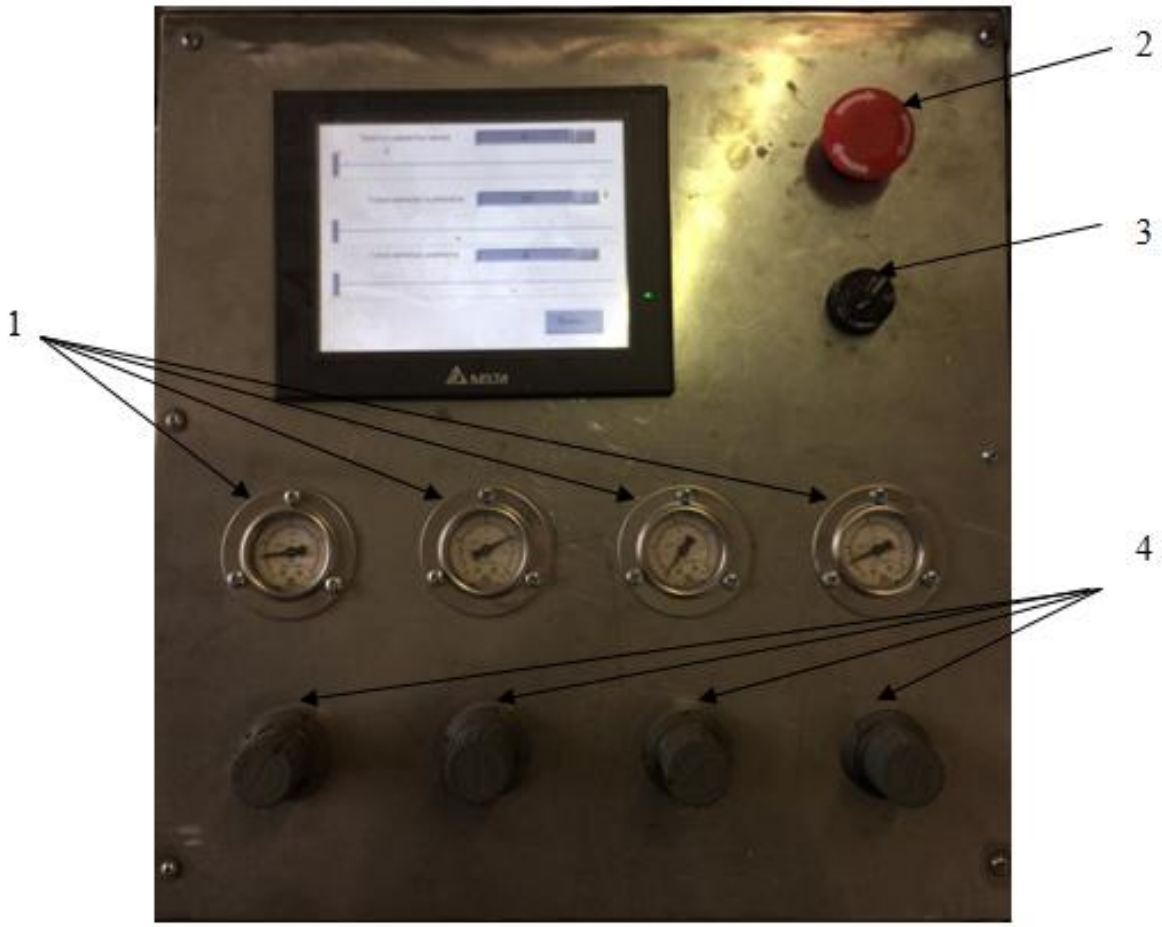


Fig.4.6. Control board of modernized cutting mechanism with four indicators *1*, emergency stop button *2*, black turning button *3* and four pressure regulators *4*

There are four grey turning buttons and four indicators on the control board that are used for adjusting pressure at the pneumatic parts: Adjusting start pressure is from 0,5 Bar to 1 Bar. Adjusting the movement pressure, that synchronizes speed of the cutters with the tube is from 0,2 Bar to 0,3 Bar. Adjusting the cutting pressure, that brings the cutters nearer and performs cutting

operation is from 1 Bar to 1,5 Bar. Adjusting the carriage return (retreat and regression) pressure is from 1,5 to 2 Bars. There are two more buttons: red push button is emergency stop button and black turning button is used for target adjusting. By pushing red push button the cutting machine stops immediately. By turning black turning target button the work with or without target can be selected. The turning On/Off of the machine is on the doors behind which there are EDR 120-24 power source and DVP-14SS2 programmable logic controller with digital input/output extension unit DVP-16SP. Red On/Off turning button of the modernized cutting machine is shown in Fig.4.7.

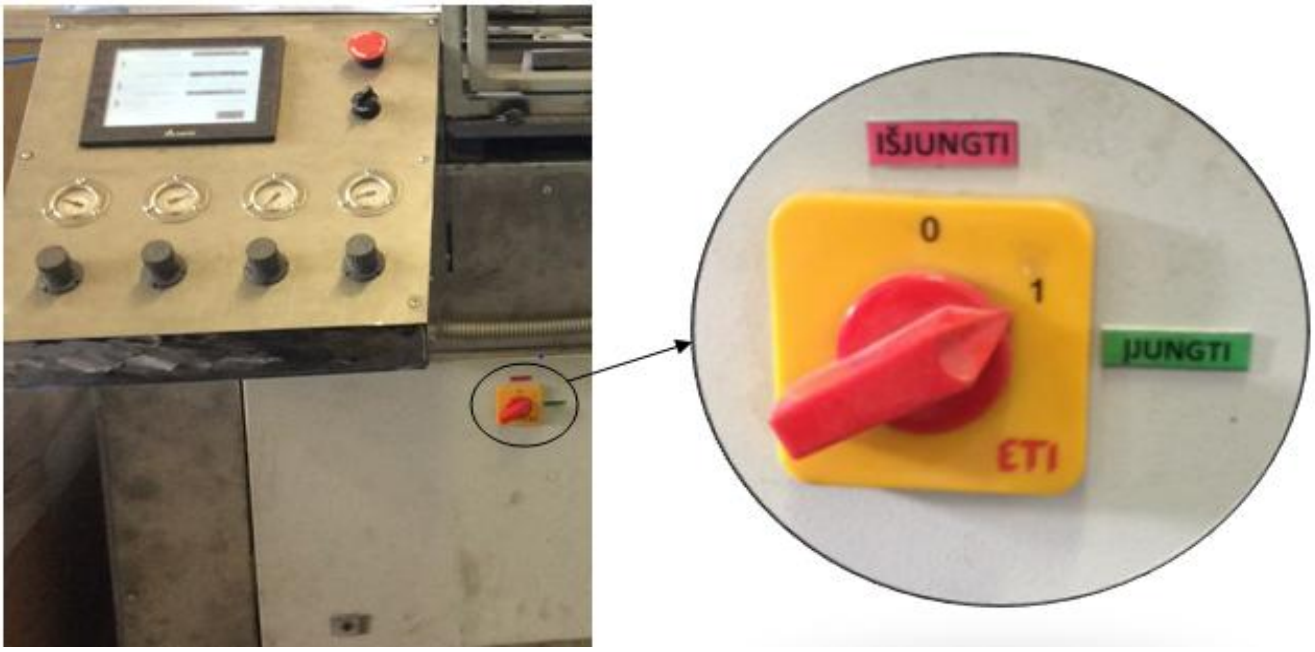


Fig.4.7. On/Off button of modernized cutting mechanism

If the button is on the position 1 (On), the machine is under voltage and is ready to work. The machine can be turned off by turning the button to the position 0 (Off).

4.2. Adjustable cutting table

An adjustable table with cutting unit will be equipped on the top of cutting case. There will be a possibility to expand or diminish the width of the table depending on the diameter of the tube by using a handle that increases or minimizes the distance between adjustable plates with assistance of trapezoidal screwed rod. Linear rail and block bearings will be used for moving cutters of the modernized cutting mechanism, because it has little friction resistance and only a small driving force is needed to move the load. Pneumatic cylinder will be attached to the base plates and cutters. At retreat and regression point of the cutters the plates with grooves will move asides and the knives will retreat and return to their start positions. The grooves on the plates are for movement of knife holders with ball bearings.

Adjustable table and its components are shown in Fig.4.8.

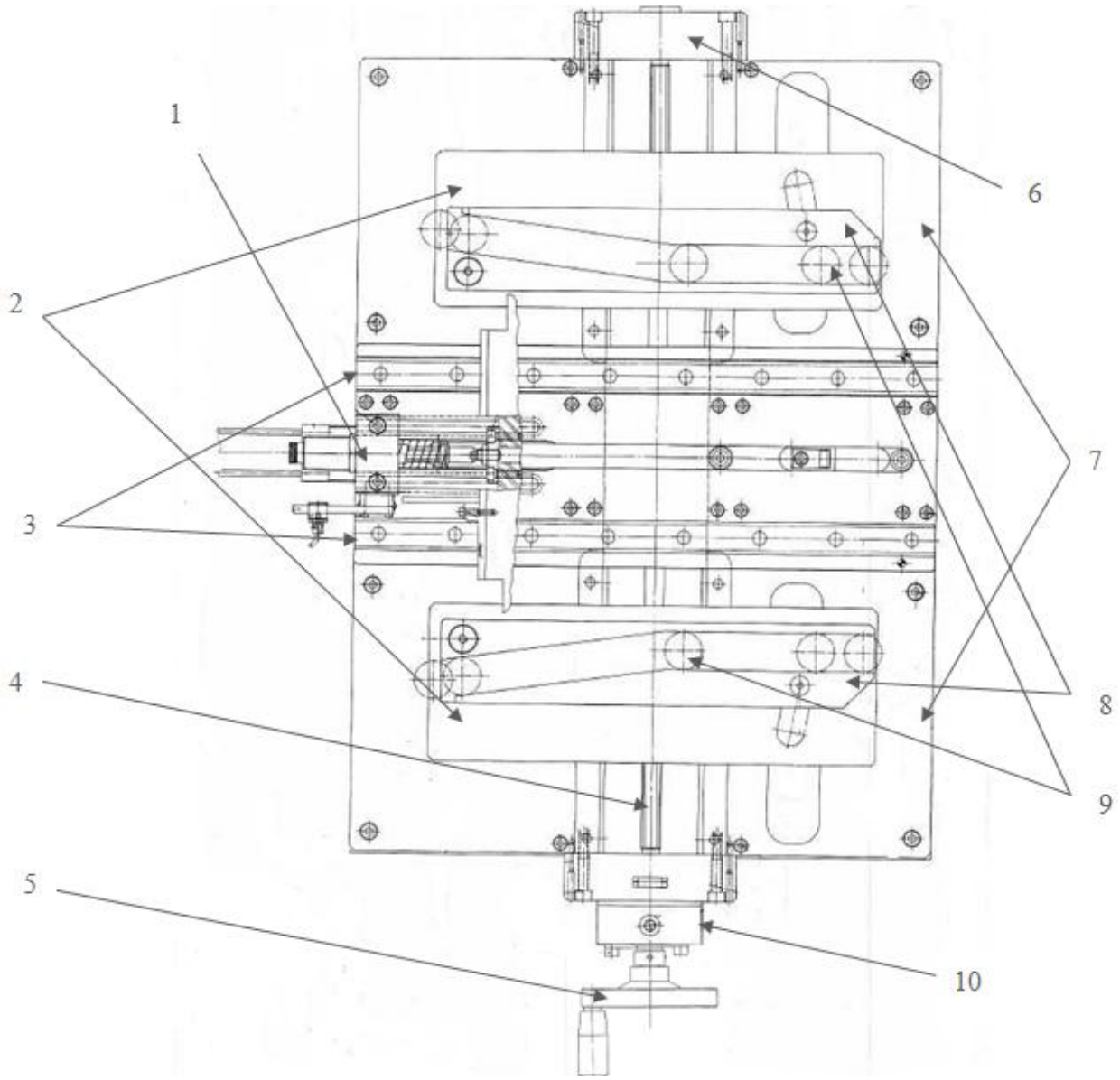


Fig.4.8. Adjustable table with air cylinder fixer *1*, two adjustable plates *2*, linear rail and block bearings *3*, trapezoidal (metric) lead screwed rod *4*, handle *5*, screw end cover *6*, two base plates *7*, plates *8*, grooves for movement of ball bearings *9* and screw entry cover *10* [26]

4.3. Protecting shield

In order to protect cutting mechanism from dusts and other environmental factors and to protect the workers from injuries according to Council Directive 89/391/EEC the protecting shield will be designed for a modernized cutting mechanism. The frame of protecting shield will be made of steel and covered with clear polystyrene sheets, because polystyrene is three times stronger than glass, light-weight, can be easily handled and has good workability when it is cut or drilled with hand tools. 3D model of protecting shield is shown in Fig.4.9.

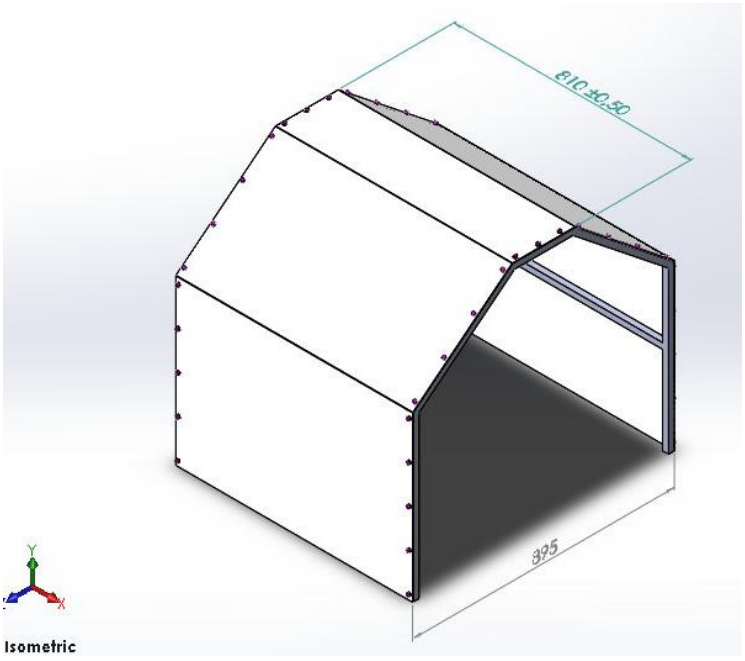


Fig.4.8. Protecting shield of cutting mechanism

The assembly drawing of protecting shield of modernized cutting mechanism is shown in Appendix-1A.

4.4. Tube holding mechanism

The glued tube will further rotate onto two rollers with axes that will be fixed onto so called combs (toothed details). Such tube holding 3D mechanism and its' main parts are shown in Fig.4.9. The assembly drawing of holding unit is shown in Appendix-2A.

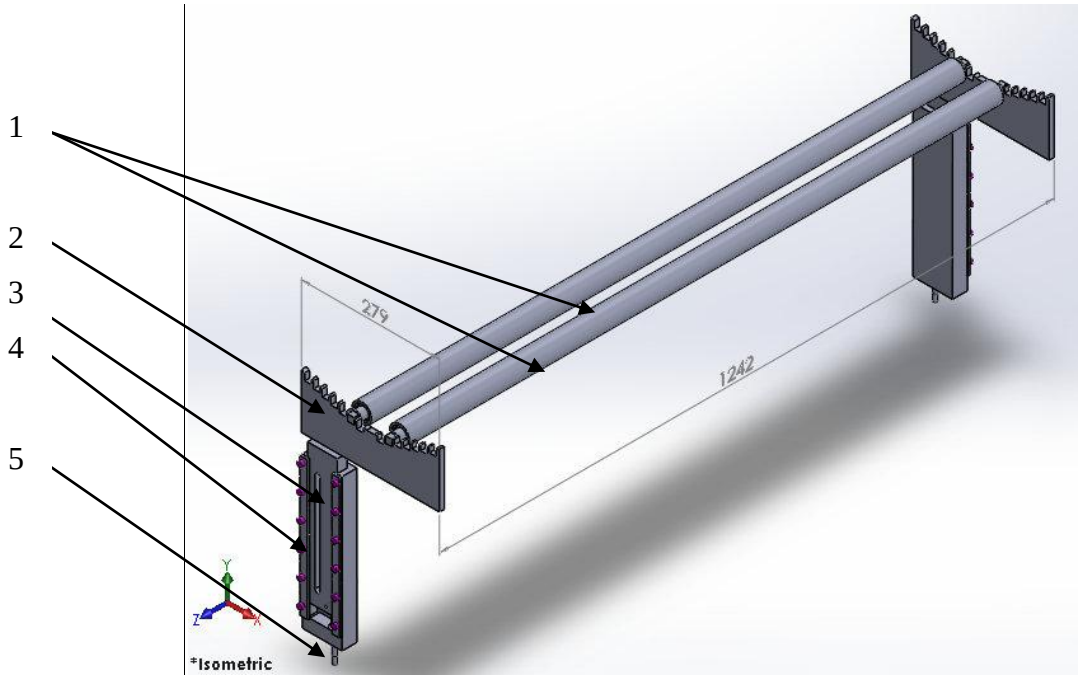


Fig.4.9. Tube holding mechanism with two rollers *1*, comb *2*, height adjuster inner plate *3*, height adjuster outer part *4* and screwed rod *5*

4.5. Knifes

The distance between rollers can be increased or decreased depending on the diameter of the tube by transferring rollers to the nearer or further tooth of the comb. The combs will be connected with the inner plate of the height adjuster. The outer part of height adjuster will hold back the inner plate. The inner plate is connected with a screwed rod. The adjustment of height of tube holding unit can be made with assistance of this screwed rod.

In order to get clear, dust- and burr-free cut, it is very important to find best solution of fixing and moving the knives. Two plain knifes were bought from CAMB Machine Knifes International company.

The knives of the cutting mechanism will be fixed with two plates from both sides and mounted onto a ball bearing in order to get free rotation and cutting motions when touching the tube. The fixation of knife and its' parts are shown in Fig.4.10.

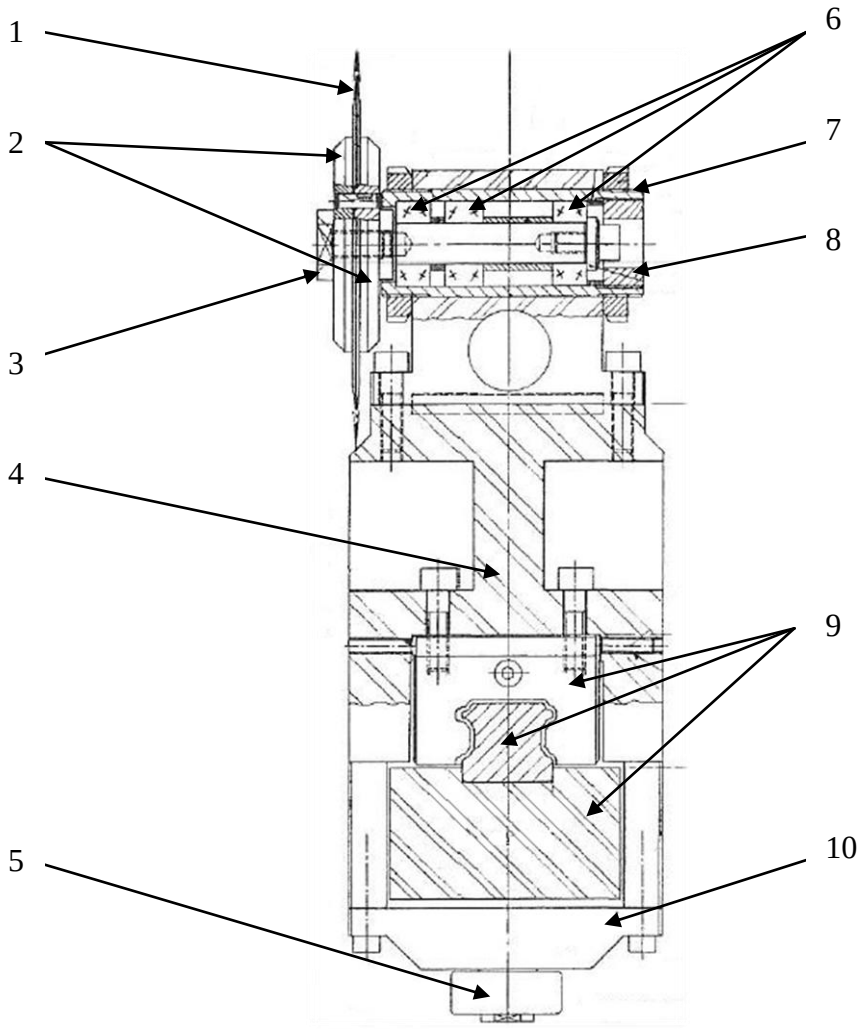


Fig.4.10. Knife fixation with plain knife *1*, two fixing plates *2*, radial bearing *3*, carrier *4*, ball bearing *5*, three ball bearings *6*, sleeve *7*, sleeve *8*, rail and block bearing *9* and cover *10* [26]

The plain knife is enshrined between two plates and mounted onto the radial bearing to facilitate the free rotation when the knives will touch surface of the tube. Together with three ball bearings, two sleeves, knife and knife plates are fixed to the carrier in order to stabilize the blade. The carrier is fixed to the linear rail and block bearing that allows the cutter to get closer and move away from the cardboard tube. The cover is directly under the linear rail and ball bearing is attached to it to move forward and back through the grooves of plates for retreating from cardboard tube and returning to the start position.

In order to adjust the height of knives it is important to know that the axis of the tube has to be slightly inferior to the axis of the knives (about 5 mm). If the axis of the cardboard tube is too much above the axis of the knives during the cutting, the tube will tend to go up and will not be cut entirely. If the axis of the tube is too much under the axis of the knives, the tube could get stuck. The axis of the tube has to be perfectly in alignment during the cutting, otherwise there would be a risk of wrong cutting (double sheared edge). The knives also have to be perfectly aligned in order to realize sheared edges without wrong cutting. Axis of knives adjustment to the axis of the tube is shown in Fig. 4.11.

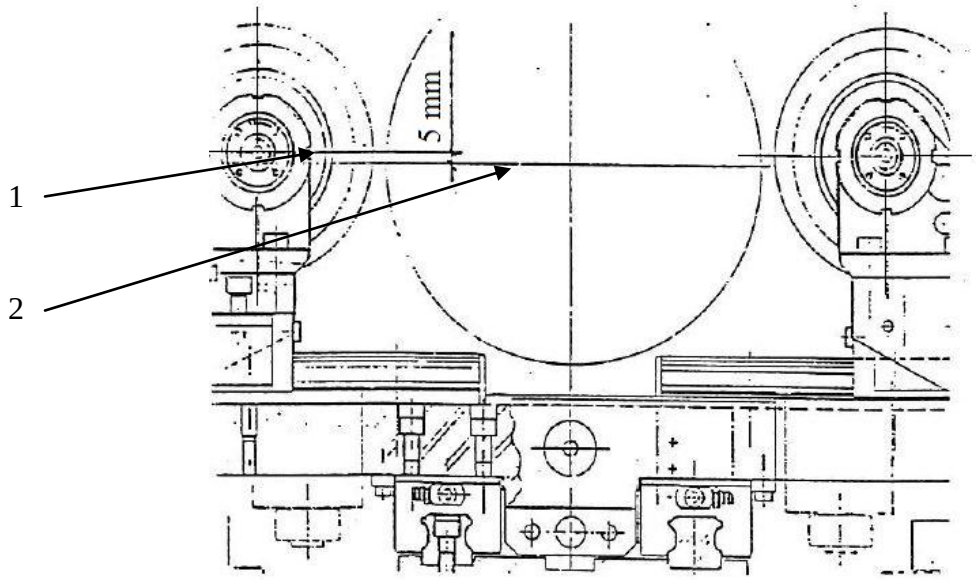


Fig.4.11. Axis of knives *1* adjustment to the axis of the tube *2* [26]

The adjustment of the distance between knifes can be done by turning the handle of the adjustable table to the right. The knives will get closer on the left and the distance between cutting mandrel will be increased. If the knives enter too much into the cutting mandrel, the cutting quality will not be perfect. The cutting mandrel will wear away prematurely; there will be a lamination of the interior band and the risk of breaking the knives.

4.6. Polyamide mandrels

The cutting mandrel of the cutting mechanism will be made out of polyamide material, because it exhibits outstanding engineering properties, such as thermal stability, dielectric strength, mechanical strength, temperature stability and chemical resistance [27]. Two different types of polyamide mandrel will be used for modernized cutting mechanism: one for tubes of smaller diameter, and another for tubes of bigger diameter. Different cutting mandrels are shown in Fig.4.12.

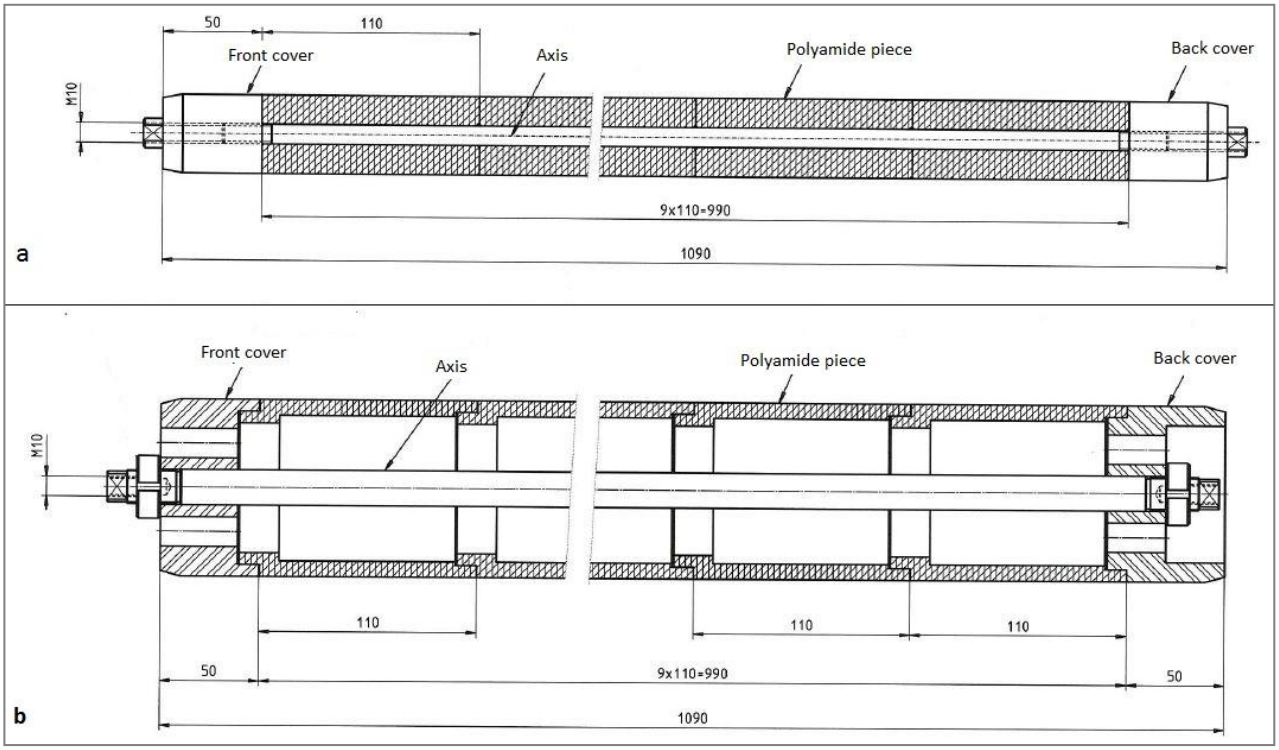


Fig.4.12. Cutting mandrel for smaller diameter tubes *a* and for bigger diameter tubes *b* [26]

Both mandrels will be composed of nine polyamide pieces that will be attached each to other (see Fig.4.12.). Both mandrels will be fixed on the same axis and both mandrels will have front and back covers. The only difference is that the covers of bigger mandrel will have holes for exiting of accumulated heat and air in order to avoid vacuum.

After some working time, the cutting mandrel will be worn away at the same location, so it should be moved few centimeters forward in order to solve this depreciation problem.

4.7. Target mechanism

The target in the modernized cutting mechanism is used for holding back of the cardboard tube and indicating when the tube is of the needed length and the cutting process can be started. The 3D model of target mechanism and its' parts are shown in Fig.4.13. The assembly drawing of target mechanism is shown in Appendix-2A.

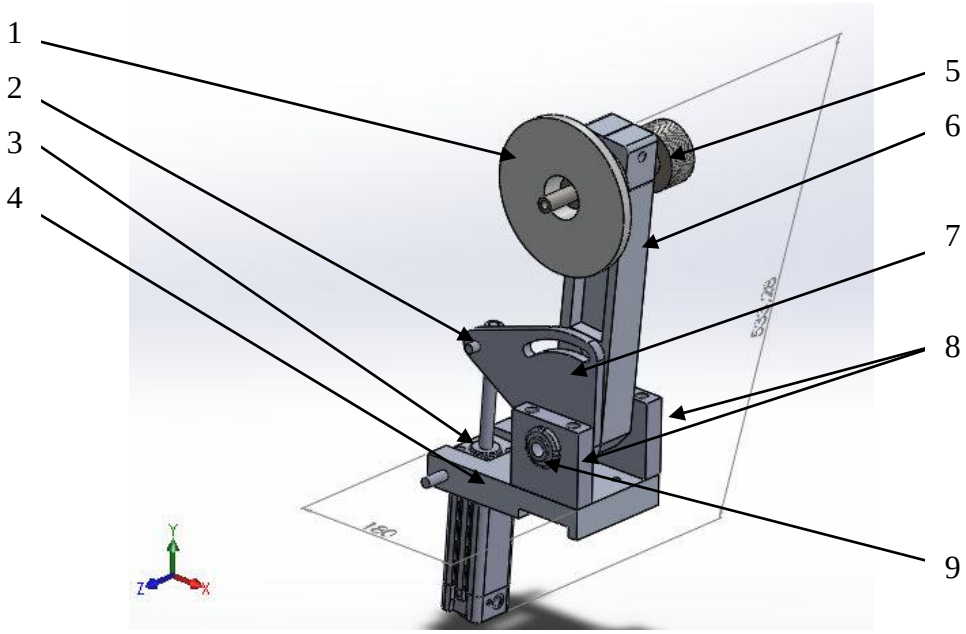


Fig.4.13. 3D model of target mechanism with pulley *1*, the joint of pneumatic cylinder and tilting plate *2*, fixation of air cylinder *3*, base *4*, axis of the target *5*, arm of the target *6*, tilting plate *7*, hinged walls *8* and sleeve of the rod *9*

The tilting plate is joined with the air cylinder, so when the cylinder pushes the tilting plate it moves the arm of the target and pulley up or down. Pulley or target is made out of polyamide material in order not to damage cardboard tube edges. This material also can stand high mechanical loads, is cheaper and lighter than the metal.

3.5. Connecting mechanism

In order to adapt the modernized cutting mechanism to the original cardboard tubes production line a location, where cutting unit could be connected with the production line and how it should be done. Whereas the tube is winded before cutting operation, it is logic to try to modernized cutting unit to the winding unit. Winding unit is shown in Fig.4.14.

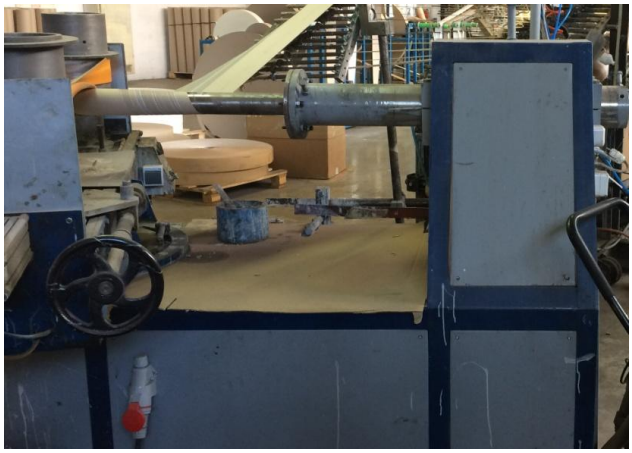


Fig.4.14. Winding unit of original cardboard tubes production line

It was conceived to create a stand with a roller that will be attached to the polyamide mandrel with the aid of cable. 3D model of such an adaptive and connecting mechanism of winding and cutting units and its' main parts are shown in Fig.4.15.

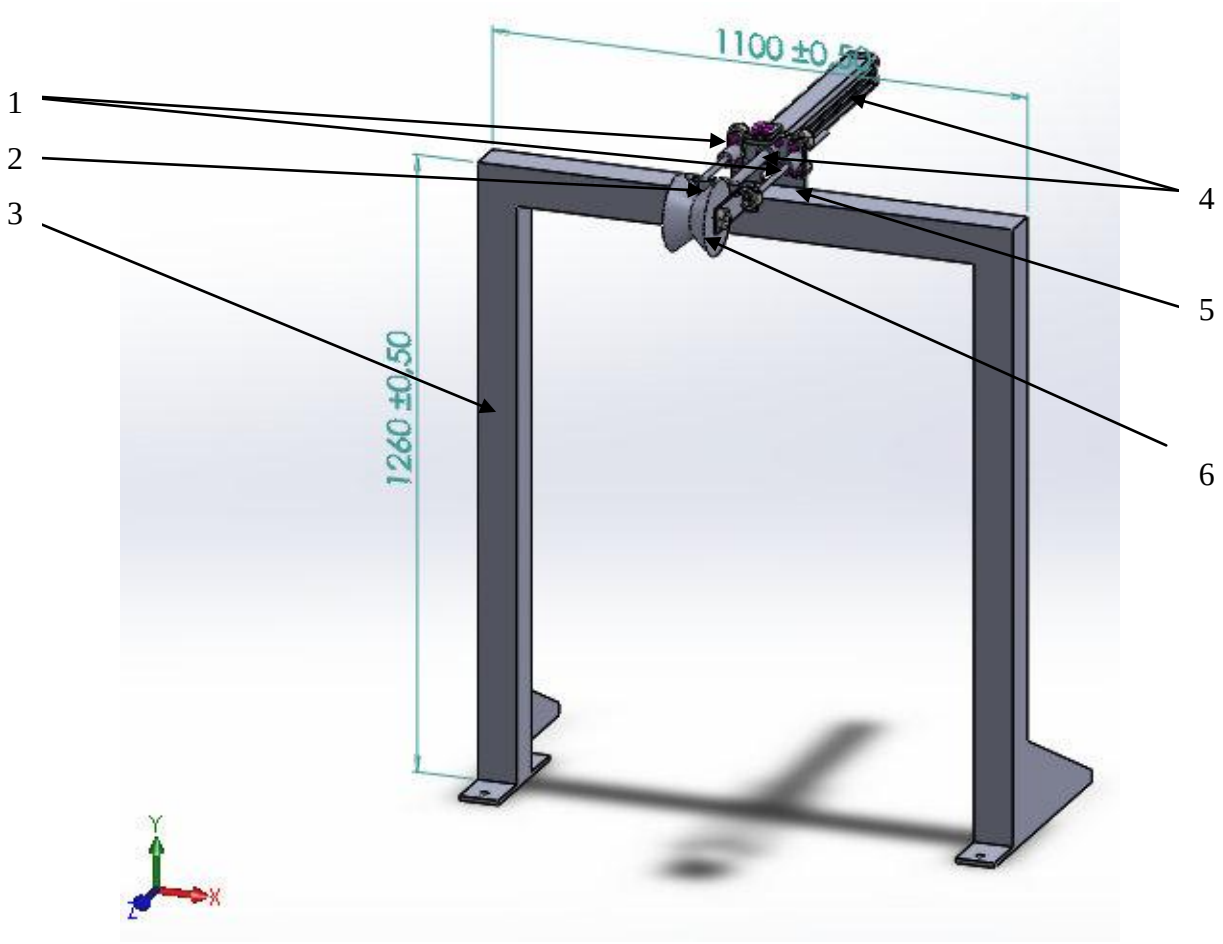


Fig.4.15. Interconnection mechanism with guiding rods *1*, guiding crossbar *2*, stand *3*, pneumatic cylinder and piston *4*, bearing and its' bed *5* and polyamide roller *6*

With the aid of air cylinder the polyamide cutting mandrel is pulled back after the cardboard tube is cut. After the cutting mandrel will wear away at the same spot, it could be manually moved few centimeters forward by pulling the cable. The assembly drawing of interconnection mechanism is shown in Appendix-4A.

5. EXPERIMENTAL ANALYSIS OF MODERNIZED CUTTING MECHANISM

After a long designing, creating and assembling process the modernized cutting mechanism was created and its' cutting abilities were tested.

5.1. Cutting quality analysis

The experiment of cutting quality with modernized cutting unit was done by turning on the machine, cutting cardboard tubes seven working hours and testing tube edges every hour. Two types of cardboard tubes were tested at the experiment. The duration of the experiment was two days. The tested tubes of the first experiment day are shown in Fig.5.1.

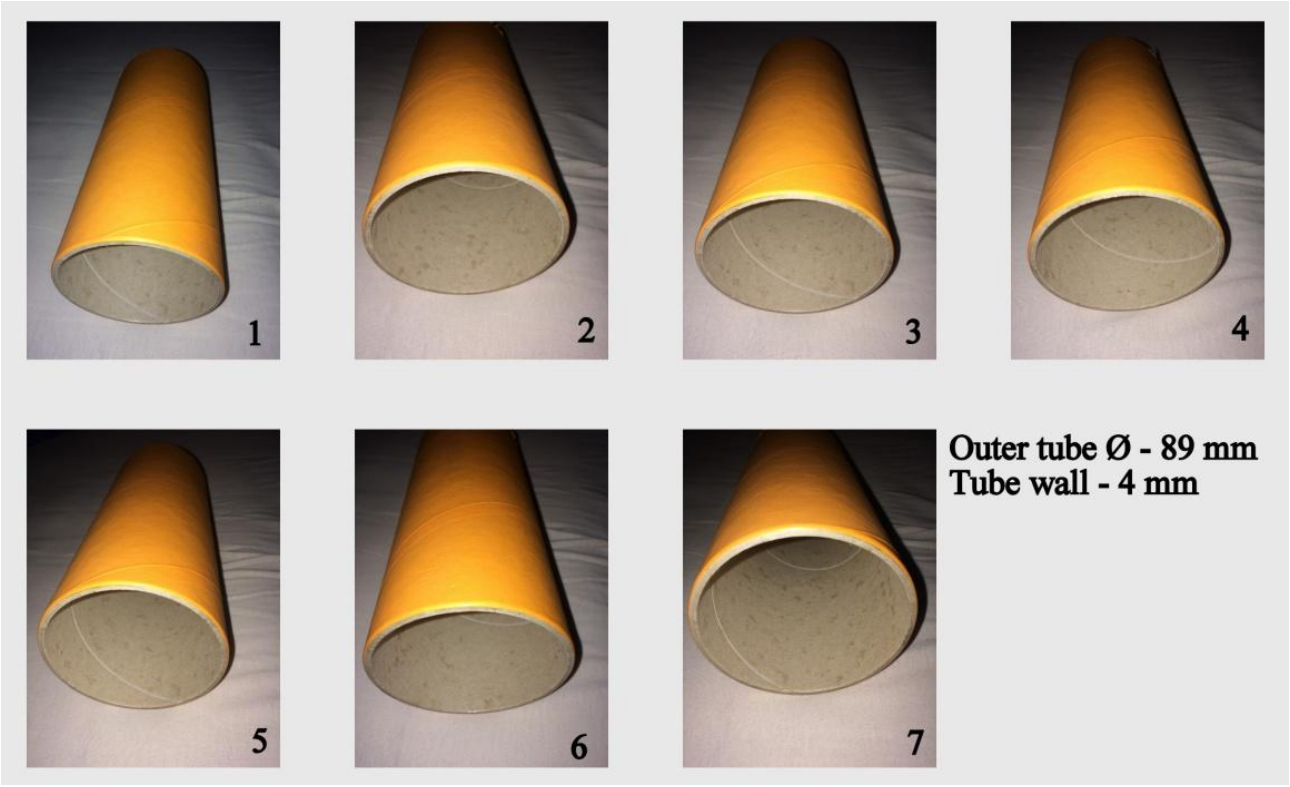


Fig.5.1. Cutting quality experiment (day 1)

The experimented tubes at the first day were specialist tubes of 89 mm diameter and the thickness of the tubes was 4 mm.The allowances of the tested tube edges were manually measured by using a caliper. The sizes of allowances of the tested tubes varied from 0 to 0,5 mm and fully met the quality and customer requirements.

The experimented tubes at the second day were specialist tubes of 86 mm diameter and the thickness of the tubes was 7 mm. The allowances of the tested tube edges were also manually measured by using a caliper. The allowances of tsted tubes were within the range from 0 to 0,5 mm and fully met the quality and customer requirements.

The tested tubes of the second experiment day are shown in Fig.5.2.

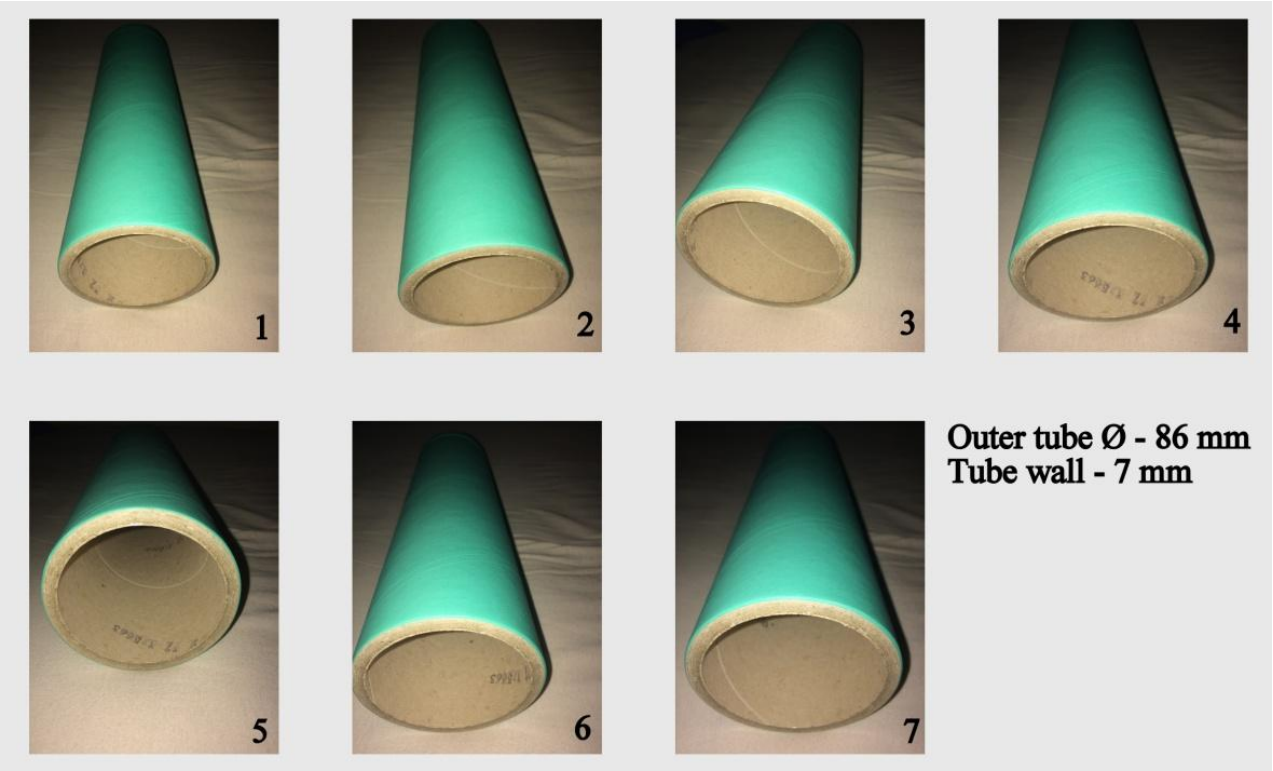


Fig.5.2. Cutting quality experiment (day 2)

The cutting quality experiment of modernized cutting unit have shown, that all the tested tubes had clean and burr-free edges of a highest cutting quality. It means, that all key requirements for cutting unit were satisfied and the cutting quality was high without damaging the cut tube edges and burr-free.

5.2. Noise analysis

Noise is largely a subjective concept, and can be defined as any unwanted sound at a given time. Noise sources are of a certain frequency and intensity oscillations, e.g. mechanical, aerodynamic, hydrodynamic and electromagnetic oscillations.

Sound waves are called acoustic vibrations that man realizes with his hearing organs. The human ear hears sounds that frequencies are from 16 to 20, 000 Hz. Sound waves of a frequency lower than 16 Hz are called infrasound, and the waves of a frequency higher than 20 000 Hz - ultrasound.

Noise at work can damage people’s hearing in permanent or disabled way. It can be gradual because of exposure to noise over time, or it can be caused by sudden, extremely loud noises. The disabled hearing damage is when the worker is not able to understand speech, to keep the conversation or to use the phone. People may not only lose the hearing, but also develop tinnitus – a disease of ringing, whistling, buzzing or humming in the ears, when the patient a feels distressing condition which can lead to disturbed sleep.

Noise at work can interfere to communicate with others, distract the attention and make warnings harder to hear. People's awareness of their surroundings and operation quality can be also affected by noise. These issues can put a worker at risk of injury or death. The Control of Noise at Work Regulations 2005 require employers to eliminate or reduce risks to health and safety from noise at work.

Sound Level Meter (SLM) was used for measuring and analyzing the noise of original cutting mechanism and modernized one. SLM is consisted of a microphone, electronic circuits and a readout display. The microphone helps to detect the small air pressure variations that are associated with sound and change them into electrical signals. These signals are further processed with the assistance of electronic circuitry of the instrument. The readout displays the sound level in decibels. The sound level meter takes the sound pressure level at one instant in a particular location [29].

The model of SLM used in this experiment is FRA-1356. It is a very accurate measurement; the measuring error is only 1.5 dB. To backlit LCD screen, users can conveniently Where View measurement results. This digital sound level meter has A and C frequency correction. A frequency filter has sensitivity to the human ear and is designed to measure ambient noise levels; C frequency filter is used to measure the noise level of mechanical equipment. This SLM complies with IEC61672-1 Class 2. It is In order to determine the noise level of cutting mechanisms the frequency weighting filter C was chosen in settings of sound level meter. The example of SLM and its parts are shown in Fig. 5.3.

Fig.5.3. Sound Level Meter FRA-1356 with transportation case *1*, manual *2*, software CD *3*, USB cable *4* and protective sponge ball *5*

Real time measuring of both cutting mechanisms was made with assistance of “Sound Level Meter” program, because the SLM has a capability to measure the noise while being attached to a computer through USB cable. The results of noise experiment of original and modernized cutting mechanisms are shown in Table.5.

Table 5.1 Original and modernized cutting mechanisms noise experiment

Record No.	SPL of Original Cutting Mechanism , dB	SPL of Modernized Cutting Mechanism , dB
1	75,20	41,3
2	75,20	71,5
3	76,10	68,4
4	78,30	67,7
5	80,30	67,7
6	77,80	66
7	73,60	66,8
8	77,40	67,6
9	76,60	67,6
10	76,50	66,2
11	76,00	67,1
12	75,60	67,1
13	75,00	62,2
14	79,10	63,6
15	79,00	63,5
16	79,00	62,9
17	75,60	58,7
18	84,50	67
19	81,60	66
20	73,20	66
21	76,30	64,3
22	77,40	61,5
23	80,10	66,1
24	76,70	64,5
25	76,30	60,8
26	82,10	65,4
27	79,70	61,9
28	79,70	63,4
29	84,10	63,4
30	79,50	66,6
31	80,40	63
32	85,80	63
Min SPL	73,20	41,30
Max SPL	85,80	71,50
Average SPL	78,24	64,34

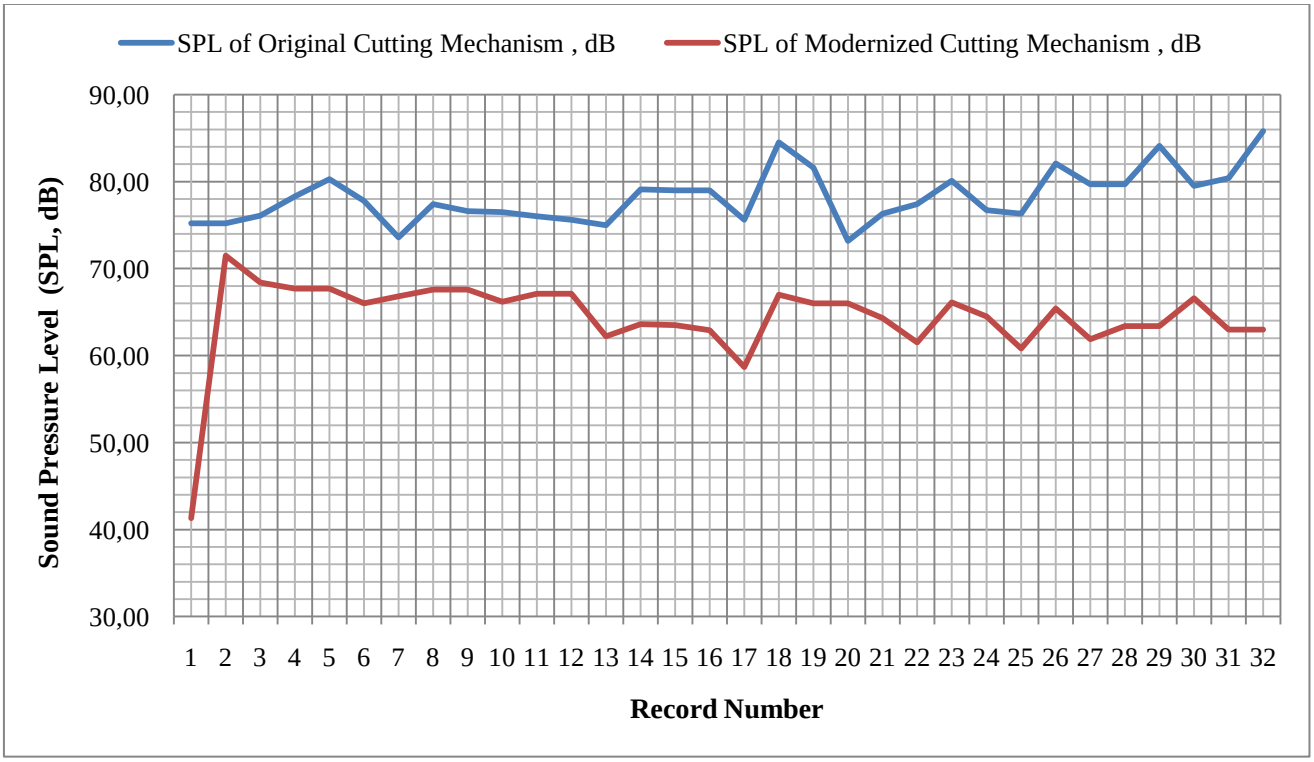
From Table 5.1 it is clear that the noise experiment with original and modernized cutting mechanisms consisted of 32 records by applying C frequency filter. The experiment lasted about 30 seconds. Both noise tests were made in order to determine which one of cutting units emits higher amount of noise while the cutting operation is done. The original table of noise experiment, made with “SoundLab” program is shown in Appendix B.

With an assistance of “Sound Level Meter” program, the records of original and modernized cutting units were analyzed and compared. The minimum and maximum noise levels of both cutting units were estimated while recording. The analysis graphs of both experiments were created.

Test has shown that the noise of original cutting machine varies from minimal 73,20 dB to maximal 85,80 dB, while noise of modernized cutting machine varies from minimal 41.30 dB to maximal 71.50 dB. The average noise of original cutting unit is 78,28 dB, while modernized cutting is 64,38 dB.

The graphical data analysis of original and modernized cutting mechanisms noise experiment is shown in Table 5.2.

Table 5.2 Graphical Data analysis of noise experiment of original and modernized cutting mechanisms



The noise experiment of original and modernized cutting units has shown that the noise level of original cutting mechanism was bigger than the noise level of modernized one. The

experiment was completed and final conclusion was made, that the noise level of cutting unit was decreased by 13,90 dB by modernizing it.

5.3. Original cutting mechanism in comparison with modernized one

In comparing original cutting unit and modernized one, these features were analyzed: exterior and design, cutting principle, cutting quality, employees working conditions related with the cutting unit; safety level of cutting unit.

The design of original cutting mechanism is quite simple and old-fashioned. Modernized cutting mechanism looks more innovative and modern. Rotating circular saw blade was changed into two plain knives, who take over the rotation from the rotating tube by touching it. The motor-produced motions at original cutting unit were changed into power source and pneumatics at modernized mechanism. The examples of original and modernized cutting units are shown in Fig.5.4.

Fig. 5.4. Comparison of: *a)* original cutting mechanism and *b*) modernized cutting mechanism

Cutting principle of original cutting unit was based on the cutting disc that is connected with the “target”. When the cardboard tube is formed, it pushes the target and the circular saw blade cuts the core. By pushing the target the inductive sensor transmit the signal to the pneumatic cylinder which moves the circular cutting disc and cuts the cardboard tube.

Cutting principle of modernized cutting mechanism was automated by using four sensors and a controller with assistance of “Delta ISPSoft” program and Delta HMI touch panel DOP-B075515. The connecting mechanism transmits the formed tube that continuously rotates on the tube holding mechanism. The target is used for holding back of the cardboard tube and indicating when the tube is of the needed length and the cutting process can be started. Then the knives of the cutting mechanism that are fixed with two plates from both sides and mounted onto a ball bearing in order to get free rotation and cutting motions will touch and cut the tube at the same

time. The cut tube will fall into the same cut tube holding construction that was used for original cutting mechanism.

Cutting quality of original cutting unit was unacceptable for the customer, with many rips, burrs and jags of 1-2 mm size. Because of poor-quality edges, inner and outer diameters of the cardboard tube are affected; these tubes cannot be further processed and are simply thrown away as a waster.

Cutting quality of modernized cutting mechanism was commendable customer-desired, the allowances of cut tube edges varied from 0 to 0,5 mm and fully met the quality and customer requirements. Such a high cutting quality was created not only by changing knives of the cutting unit, but also by changing the cutting principle from full-time rotating circular saw cutting to non-rotating knives who get free rotation by touching the rotating tube and so cutting it precisely. Such a cutting principle helps to reduce resistance forces of cutters to the tube and the cutting line stays clean and clear, without any burrs or scratches. Cutting quality of original and modernized cutting units can be visually compared in Fig. 5.5.

Fig. 5.5. Cut tube quality made with original cutting mechanism *a* and with modernized cutting mechanism *b*

Inappropriate cutting principle of original cutting unit adversely affected employees working conditions, because circular saw blade scratched the cutting line and created lots of microscopic and visual dusts. Motor together with an rotating circular saw blade created loud noises. The noise of original cutting machine varies from minimal 73,20 dB to maximal 85,80 dB, the average noise of original cutting unit is 78,28 dB.

The noise of cutting unit was decreased to average 64,38 dB by modernizing it. The minimal and maximal noise varied from 41.30 dB to 71.50 dB. The noise level of modernized cutting unit was 13,90 dB lower in comparison with original cutting unit.

The safety of workers was improper and inadequate using original cutting mechanism, because the cover of the circular saw blade was not fully protecting from sharp cutter. Blade cannot be fully covered, because it wears out quickly and paraffin wax must be manually applied onto it every hour to lubricate the blade and increase cutting quality.

Safe and south working environment was created by adding a protecting shield onto the cutting table. It protects not only from injuries, but also from dusts, because the excess of dusts to the environment is also reduced by covering cutting unit with shield. The noise from cutting unit to the environment is also reduced by adding such a protecting shield.

6. ECONOMIC COSTS AND PRICES ANALYSIS

The aim of creating of the interconnection unit was to adapt the modernized cutting mechanism to the existing cardboard tube manufacturing machine line, so that there would be the lowest possible cost for replacing the old one.

In order to assess whether the company has sufficient funds allocated to the interconnection unit it is important to calculate the cost of designed connecting mechanism.

Cost estimation of interconnection unit

Costs are certain monetary costs for the purchase of needed supplies, materials, equipment, energy resources, labor, taxes, and charges and so on. Thus, the costs can be considered as the monetary value of all goods and services for the manufacturing necessary production [30]. In assessing the engineering solutions, all costs are first divided into the fixed and variable costs.

In assessing the engineering solutions, all costs are first divided into the fixed and variable costs.

1. **Fixed costs (FC)** do not change when the production output is changing, e.g., premises rent expenses, insurance expenses, administrative expenses, interest paid on borrowed funds and etc [30]. Fixed costs in this case are as follows:

- salaries for the workers;
- premises rent expenses;
- maintenance expenses (electricity, water), insurance expenses for the workers;
- assembling expenses for assembling and installing the interconnection unit;
- programming costs for actuation and synchronization of connecting unit with production line.

2.**Variable costs (VC)** vary when the production quantities are changing, e.g., raw materials, energy consumption in the manufacturing process, the workers' wages and etc [31]. Variable costs are consisted of:

- raw material costs,
- equipment costs for assembling and installing;
- producing costs.

Raw material costs includes following cots:

- steel C 45 rods for a stand;
- two pneumatic cylinders and pistons;
- 4-5 mm width cable;
- polyamide roller.

• **General costs** are costs that company makes in producing a certain quantity of production or providing certain services. They can be calculated by summing fixed and variable costs [30]:

$$GC=FC+VC \quad (6.1)$$

when FC – fixed costs, VC – variable costs.

The average general costs (AGC) shows the expenses that company makes by producing a certain amount of products or services. They can be calculated according to formula [31]:

$$AGC= GC/Q \quad (6.2)$$

when GC - general costs, Q - the amount of produced product.

The average variable costs (AVC) show the amount of expenses for one unit being produced. They can be calculated according to formula [31]:

$$AVC= VC/Q \quad (6.3)$$

when VC – variable costs, Q- the amount of produced product.

The table 6. shows fixed, variable, general, average general and average variable costs in creating a modernized glue wiper and producing it.

Table 6. Costs to produce interconnection unit

Cost Type	Cost Identification	Price (EU)
Fixed costs (for 1 week)	Salaries for workers	3600 : 4 = 900 €
	Premises rent expenses	600 : 4 = 150 €
	Maintenance expenses (electricity, water)	290 : 4 =72,5 €
	Insurance expenses	150 : 4 = 37,5 €
	Assembling expenses	150 €
	Programming expenses	100 €
Total fixed costs	**FC= 900 + 150 + 72,5 + 37,5 + 150 + 100**	**1410 €**
Raw material costs	Steel C 45 rods for a stand	100 €
	Two pneumatic cylinders and pistons	220 €
	4-5 mm width cable	10 €
	polyamide roller	40 €

Continuation of **Table 6.**

Total raw material costs	**RC=100 + 220 + 10 + 40**	**370 €**
Variable costs	Equipment costs (equipment costs for assembling and installing of interconnection unit)	100 €
	Producing costs	300 €
Total variable costs	**VC = 370 + 100 + 300**	**770 €**
General costs	**GC= Fixed costs + Variable costs = 1410 + 770**	**2180 €**
Average general costs	**General costs/ amount of produced product AGC = 2180 : 5**	**436 €**
Average variable costs	**Variable costs/ amount of produced product AVC= 770 : 5**	**154 €**

The calculations of fixed, variable, general, average general and average variable costs were performed and the results are shown in Table 6.

After calculating the costs to produce interconnection unit the company has to decide if the needed amount of money does not exceed the company expenditure limits. If the company faces financial problems, the necessary amount of funds can be obtained from national and regional programs which provide funding in the form of grants. Since the company in this case is economically stable and reliable it itself is able to devote resources for this interconnecting unit. Then, the duration of preparation for the project and implementation of this connecting unit can be further concluded.

7. CONCLUSIONS

The aim of this master degree project was to modify and update the cutting mechanism, improve working conditions and accelerate the cutting process by adapting the modernized cutting unit to the existing cardboard tube manufacturing machine line, so that there would be the lowest possible cost for replacing the old one.

While performing the modernization of an original cutting mechanism, the recommendations and advices of cutting operators were considered. In this work the particularities of cutting mechanism, such as the material, shape, size and operating principle were analyzed in order the best results would be achieved in modernizing it.

1. The technological part of this project was about reconsidering shape and size of cutting mechanism and redesigning it in order to fulfil high quality cardboard tubes cutting requirements and improving employees working conditions related with cutting unit.

2. By modernizing the cutting unit, many experiments and analysis were done in order to find best solution of safe, dust- and noise- free, high-quality cutting principle that would implement the requirements of "Control of Noise at Work Regulations". The selected principle of modernized cutting mechanism was two opposite each to other knives who have free rotation motion and start to rotate and cut only by touching the surface of the tube. This method perfectly cuts the cardboard tube and is safer, cleaner, more modern and recent choice in comparison with the original one.

3. Tube holding mechanism and target mechanism were designed in order to adjust the modernized cutting mechanism for cutting both - small and big diameter tubes. The interconnection mechanism was designed by adapting the modernized cutting unit to the existing cardboard tube manufacturing machine line, so that there would be the lowest possible cost for replacing the old one. Together with modified cutting and operating principle the modernized cutting process with specially designed and created protecting shield created safe and south working environment for the workers. The protecting shield of modernized cutting unit was design in order to meet EU Council Directive 89/391/EEC and improve safety and health of cutting operators at work. The shield protects not only from injuries, but also from dusts and noise, because the excess of dusts and noise to the environment are also reduced by covering cutting unit with shield.

4. The experimental analysis of cutting quality with modernized cutting unit was done by turning on the machine, cutting cardboard tubes seven working hours and testing tube edges every hour. The experiment shown, that all the tested tubes had clean and burr-free edges of a highest cutting quality, so all key requirements for cutting unit were satisfied and the cutting quality was high without damaging the cut tube edges and burr-free.

5. The noise analysis of original and modernized cutting units was done by using Sound Level Meter FRA-1356. Test shown that the noise of original cutting machine varies from minimal 73,20 dB to maximal 85,80 dB, while noise of modernized cutting machine varies from minimal 41.30 dB to maximal 71.50 dB. The average noise of original cutting unit is 78,28 dB, while modernized cutting is 64,38 dB. The experiment showed that the noise level of cutting unit was decreased by 13,90 dB by modernizing it.

6. The economical part of this work was about calculating costs for producing interconnection mechanism for modernized cutting mechanism. Total fixed costs of 1410 € and total variable costs of 770 € were calculated in order to produce an interconnection unit. General costs of 2180 € were computed.

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APPENDIX A: Drawings

Appendix -1A: PROTECTING SHIELD

Appendix -2A: TUBE HOLDING MECHANISM

Appendix -3A: TARGET MECHANISM

Appendix -4A: INTERCONNECTION MECHANISM

APPENDIX B: Tables

Appendix -1B: COMPARISON OF NOISE EXPOSURE OF ORIGINAL AND MODERNIZED CUTTING UNITS

Appendix -2B: ORIGINAL AND MODERNIZED CUTTING UNIT NOISE ANALYSIS GRAPH