DAS Departamento de Automação e Sistemas
CTC Centro Tecnológico
UFSC Universidade Federal de Santa Catarina

Design, Construction and Process Control of a Conditioner for Straw Pellets

Relatório submetido à Universidade Federal de Santa Catarina

como requisito para a aprovação na disciplina

DAS 5511: Projeto de Fim de Curso

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Florianópolis, Agosto de 2013

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Esta monografia foi julgada no contexto da disciplina
DAS5511: Projeto de Fim de Curso
e aprovada na sua forma final pelo
Curso de Engenharia de Controle e Automação

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Assinatura do Orientador

Acknowledgements

First of all I am grateful to my family, especially my father, mother and brother, whose support and love were the greatest responsibles for everything that I have in life. I owe them everything.

I am grateful to God for looking upon me and my beloved ones throughout my life. I thank Him for all the blessings upon my friends, my family and me.

Warmest acknowledgements to my colleagues and friends in Blackballs Technologies. Thanks Jonas Bergert, my tutor, for all the aid and support given during my internship and for the friendship in the spare time; I would like to acknowledge Cleberson Carlos da Cunha, colleague, friend and ‘2nd tutor’, for all the invaluable teachings, help and advises; I also acknowledge Dr. -Ing. Saulo Seabra for giving me the opportunity to become part of the Blackballs team; thanks to Martin Dziambor for the friendship inside and outside Blackballs; and acknowledgments as well to Sabrina, Bugakov and Morlang for the support given during my time in BBTech.

I thank all the Automation and Systems Department (DAS) for all the knowledge taught in my 6.5 years in the university and for the opportunity to develop my PFC in Germany, in cooperation with the RWTH University. I thank especially my tutor Dr. Jean-Marie Farines, for the opportunity to study in France and do my PFC in Europe.

This project would not be possible if I weren’t a part of the ENSE3, Grenoble, France. *Merci pour tout l’aide, les enseignements et le support de l’ École, spécialement de mon tuteur Didier Georges, et des professeurs de la filière ASI, Hayate Khennouf et Ahmad Hably*.

I express my gratitude to the Brazilian government, through CAPES, for being part of the BRAFITEC program. I profoundly hope that all the experience acquired during this period help me bring development and a better future to my *“Pátria Amada”*.

Finally, I thank all the many friends that I had the pleasure to meet in my life, especially those from Automação 07.1 and Group ToP, for all the parties, sleepless nights of studies, *nabos* and crazy things we did together.

Abstract

In the last few decades, the increasing awareness regarding some environmental issues such as global warming has attracted the science community interest on the research of alternative fuel. In this context, the use of biomass for the production of energy has shown itself as a viable and interesting option. One good example of the use of biofuel are the wood pellets. Aside from that, other materials can be used for pellet production, like straw, for example.

This present project is inserted in a bigger project that aims the production of straw pellets. This report will discuss and explain the development of a conditioner for the production of straw pellets. Aspects of the mechanical construction of the machine, electrical installation and the PLC control implemented for the process are the focus of this project's report.

The final goal of the project is to automatize and increase the production of straw inside Blackballs Technologies GmbH.

Tags: Biofuel, straw pellets, conditioner, PLC control

Resumo (em português)

Hoje em dia, o problema do aquecimento global é cada vez mais um assunto de grande interesse no meio científico. O homem tem desenvolvido um grande papel nas mudanças climáticas que vêm ocorrendo nas últimas décadas: a utilização sem precedentes de combustíveis fósseis agrava o efeito estufa e, por consequência, o aquecimento global. Uma das soluções possíveis para reduzir o fator humano sobre o meio ambiente se refere à utilização de combustíveis renováveis para substituir os combustiveis fósseis. Um exemplo viável e que já é utilizado nos dias de hoje é o biocombustível, cuja matéria-prima é a biomassa. O biocombustível de interesse no presente projeto são os *pellets*.

Os pellets são geralmente feitos à partir da madeira. No entanto, um projeto realizado pela RWTH Aachen University visa analisar a viabilidade de se utilizar outros materiais para a produção de pellets. Um material que vem sendo estudado para este fim é a palha. A empresa *Blackballs Technologies GmbH (BBTech)*, onde o presente projeto foi realizado, é a responsável pela produção dos pellets de palha, enquanto a universidade RWTH está empenhada em estudar a viabilidade de se utilizar pellets de palha como combustível para o aquecimento predial.

Atualmente, a produção de pellets na BBTech é feita manualmente do começo ao fim do processo, por dois funcionários da empresa. A palha é moída, misturada com materiais adicionais e compressada em forma de pellets pelos operadores. Visa-se reduzir o tempo necessário para a produção de pellets dentro da empresa através da automação deste processo. Além disso, esses processos são bastante cansativos e representam um perigo para a saúde dos operadores, visto que a palha gerada no processo de moagem é muito fina, e gerando nesse processo um pó que fica suspenso no ar e é aspirado por quem manipula o material. Visando melhor as condições de trabalho para a produção de pellets, faz-se necessário reduzir o contato dos operadores com o processo.

A peletização pode ser dividida em três etapas: a moagem, o condicionamento (ou tratamento) do material e a compressão do material em pellets (a peletização propriamente dita). O presente projeto visa automatizar o processo de condicionamento.

O condicionamento é a etapa da produção de pelllets responsável por preparar o material para a etapa de compressão. Espera-se do condicionamento: misturar a palha triturada com materiais aditivos, adicionar água, aquecer o material, gerar uma mistura uniforme. A máquina que realiza isso chama-se condicionador.

Muitas empresas constroem condicionadores industriais. No entanto, normalmente os condicionadores industriais são máquinas grandes, voltadas para processos que produzem dezenas de toneladas de pellets por hora. Por consequência, as soluções disponíveis no mercado são muito caras. A produção de pellets na BBTech não demanda grande produçãoo, logo a solução mais viável prevista foi a de se construir in loco um condicionador menor, capaz de produzir em torno de 50-150 kg de pellets por hora.

O presente relatório apresentará o desenvolvimento do condicionador. O documento é dividido em três partes principais: a construção da estrutura mecânica, o desenvolvimento da parte elétrica e o desenvolvimento do sistema de controle. O projeto foi desenvolvido na Blackballs Technologies GmbH, Alemanha, no período de março/2013 a julho/2013.

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List of abbreviations

FB – Function block

FBD – Function block diagram

FI – Frequency inverter

GHG – Greenhouse effect gases

HMI – Human-Machine Interface

I/O – Input and output

PLC – Programmable Logic Controller

RPM – Rotations per minute

SFC – Sequential function chart

ST – Structured Text

Chapter 1: **Introduction**

1.1: Sustainable and eco-friendly energy

One of the great concerns of the 21st century is related to the increasing global warming. The last century presented a sensible rising of the average temperature worldwide. Figure 1, from the NASA Goddard Institute for Space Studies, illustrates the rising mean temperature of the planet Earth over the last 125 years.

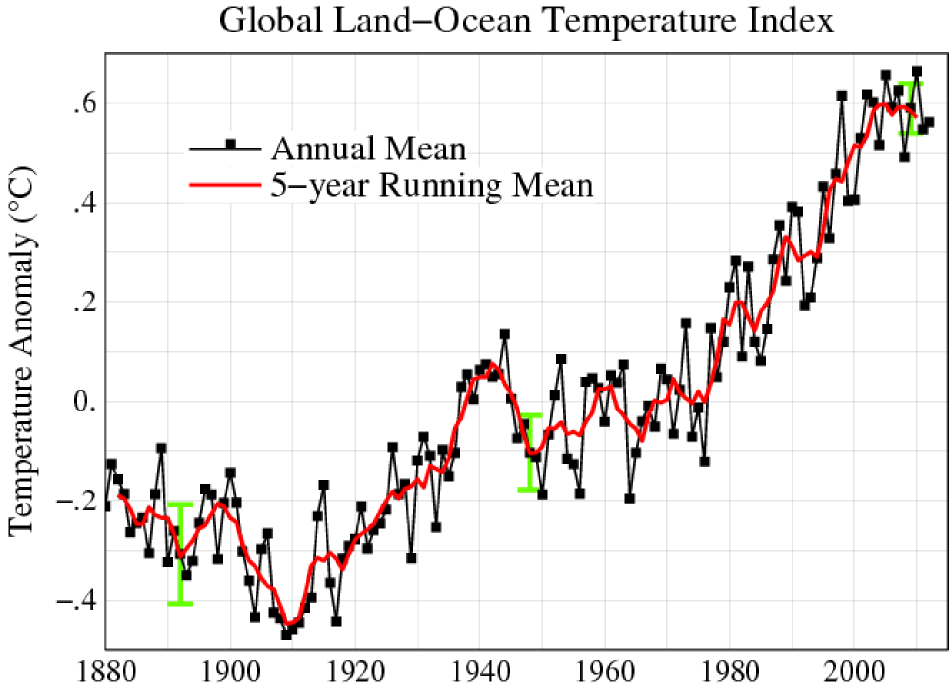

Figure 1 – Global annual mean temperature change

Many factors contribute for the global warming. Some of them are natural factors, such as the Earth's inclination and its revolution around the Sun [1]. However, the cause that concerns the world the most nowadays is the greenhouse effect.

Actually, the greenhouse effect is a process without which life would cease to exist. The planet Earth itself reflects about 30% of the radiation emitted by the Sun. If an ideal and hypothetical planet were at the same distance from the Sun as Earth is, its global mean surface temperature would be -18°C. However, the observed global mean surface temperature of our planet is 33°C higher than that. This shows us that the atmosphere absorbs more than 75% of the terrestrial radiation, thus concluding that the temperature of the planet can only be maintained at levels that can sustain life due to the greenhouse effect [2].

The problem that concerns the scientists nowadays is how humans are contributing to the increase in the greenhouse effect, which is changing the global temperature in a way that is affecting the “health of the planet”.

Since the industrial revolution, in the 18th century, due to the use of fossil fuels, such as crude oil and coal, the levels of emission of greenhouse effect gases (GHG), such as carbon dioxide, have increased at alarming rates. For example, the emission of CO_2 elevated its concentration in the atmosphere from 280 parts per million (ppm), from the preindustrial revolution, to a present level of 379 ppm, more than 70% increase in its concentration [3].

So that we can reduce the emission of GHG, and also due to the depletion of fossil fuel sources, it is of major importance that alternative fuels are developed and used. Nowadays, a lot of different alternative energy sources are used, such as wind power, solar, tidal power, biomass, etc. Figure 2 shows the consumption of different sources energy in the world.

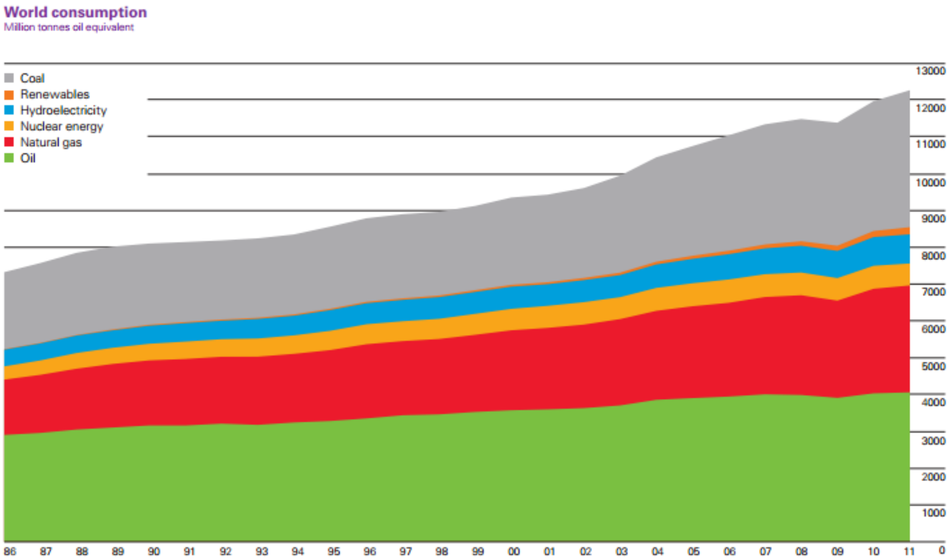

Figure 2 - World consumption of different fuels

Among the many sources of renewable and sustainable energy, the one that the present project focuses on is the biomass fuel. Also known as biofuel, this kind of energy source is derived from biomass conversion, meaning that it is a product of the biological carbon fixation, which converts inorganic carbon (CO_2) into organic compounds. Many crops, such as rice, corn and sugar cane, can be used as material to produce biofuel. When taken from sustainable plantations, biomass fuel can be a great source of renewable energy [4].

Another great role of the biomass fuel is the re-utilization of wastes – from construction sites, wood not used in papermaking, scrap lumber, municipal solid waste – which reduces the waste of material, as well as may contributes to the reduction of the use of trees for the production of the fuel [4].

1.2: Pelletizing process

1.2.1: A brief history

The history of pellets comes first of all from the history of agglomeration. The formation of a rock, where the binding mechanisms between solid particles, in the presence of temperature and pressure, form the stones, is an example of an agglomeration process that happens in the nature [5].

The history of agglomeration as a technology however is rather young. In the middle of the nineteenth century, during the industrial revolution, agglomeration was applied as a method to recover and use fine coals, which would otherwise be wasted. The study of that subject as a science is yet younger. It began in the 1950s, when the first studies started not to be only application oriented, the formal definitions of the binding mechanisms of agglomeration were first established, and so on [5]. Figure 3 illustrates the residues from machining processes (brass and aluminum) and their briquetted products.

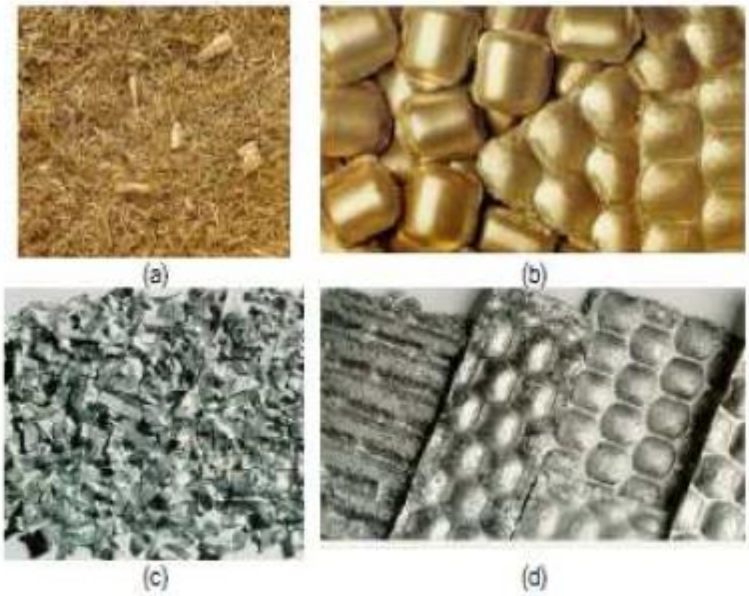

Figure 3 - Briquettes

Regarding pelletizing processes, the first patented biomass densification process was registered in the USA, in 1880. It only became a long scale process however after 1950s, when it was used mostly for its handling properties for energy production and animal feedstock. Its use grew gradually along the decades, both in the USA and in Europe, mostly for heating, as a solution for the increasing prices of fossil fuels, as well as due to the good availability of residues from sawmills and paper industry, for example. Also, policies aiming to reduce carbon dioxide emissions and general environmental consciousness became important factor as well [6].

Nowadays, the range of application of the pelleting technology includes, and is not limited to:

- Biomass Pelleting
- Recycling Industry
- Chemical Industry
- Food Industry
- Feed Industry
- Pet food

1.2.2: How it works

The process of biofuel pelletizing consists basically of five stages, as depicted in Figure 4.

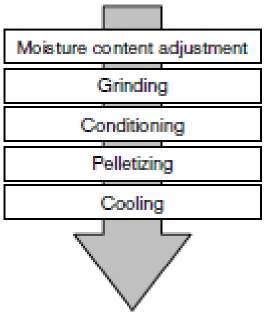

Figure 4 - Process flow at a biofuel pellet plant

First of all, the moisture content of the raw material is manipulated, since it has great influence in the quality of the final product: studies show that different materials have optimum moisture contents [6]. Then, the material goes through a grinding process, in order to reach a particle size suitable for the pelletizing. The next step is the conditioning, which prepares the material for the pelletizing, by adding moisture, heat, other binding materials (such as molasses or starch), and mixing them. After that comes the pelletizing itself, where the material prepared by the precedent steps is pressed against a profile (commonly known in the industry as die), where the pellets are produced, shown in Figure 5. Finally, so that the pellets can be stabilized, they are cooled.

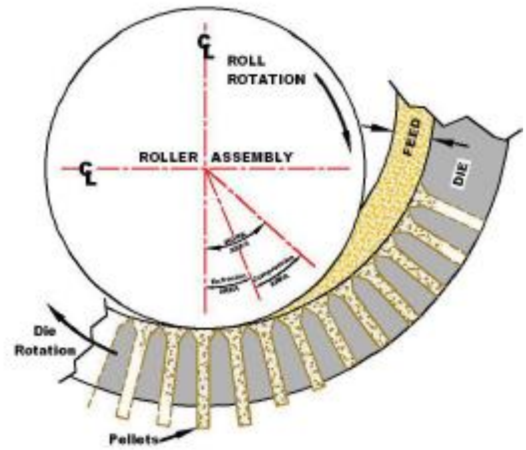

Figure 5 - The die and roller assembly

Many materials can be used to produce pellets. The material range can be divided into categories, such as forestry (different species of wood), agriculture (grains, such as wheat, soybean and rice, for example) and waste-based materials (like plywood, used in furniture) [7].

1.2.3: Process parameters

The key parameters that influence the pelletizing process the most are [8]:

- Particle size
- Pelletizing pressure
- Temperature
- Moisture content
- Biomass composition and additives

The parameters that are manipulated and thus controlled by the conditioner are the temperature, the moisture and the composition of additives. The temperature and the moisture are controlled by the addition of steam, and the additives are extra inputs of the conditioner, where they are mixed with the rest of the product.

1.2.4: Blackballs Technologies GmbH

The production of straw pellets in BBTech is part of a bigger project financed by the European Union (EU). The use of wood pellets as energy source is already greatly spread and used alternative. However, due to certain limitations of the production and use of the raw material (wood), a research project in Germany aims to analyze the viability of the use of straw pellets for heating purposes.

The project is developed in cooperation with RWTH Aachen University, which is responsible for the study of the heating properties of the pellets. BBTech is in charge of the production of the pellets for the research and for the development of the pellet recipe of straw.

1.2.5: Conditioning

The present project aims to automatize the conditioning step of the pelletizing process in Blackballs Technologies GmbH. As explained previously, the conditioning of a pelletizing process has as objectives:

- Addition of moisture to the feeding material
- Heating of the feed
- Mixing of the material with its additives

A conventional conditioner consists of a chamber with a rotating agitator that blends additives into the feed. The Figure 6 illustrates a generic conditioner.

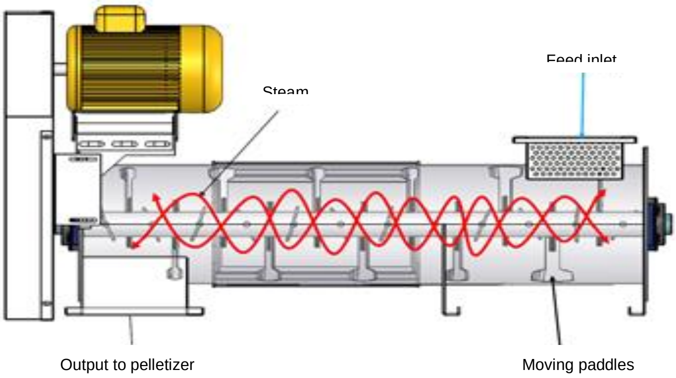

Figure 6 - Conditioner

In the Figure 6 the flow of the material is from the right to the left. The input of steam is usually on the opposite sense. Despite not shown in the picture, a conditioner must have other inputs in its structure; for a good straw pellet structure, it is of the most importance that binders are added to the product, so that the pellet acquire a good physical stability and don't brake easily.

1.3: Objectives and Improvements

The pelletizing process in BBTech is done mostly manually. Of the 5 steps seen in Figure 4 - Process flow at a biofuel pellet plant, only the first one is not performed in the company.

The grinding, conditioning and pelletizing are all done by two operators, which must be present during all the process. First of all, the operators take the straw and put it into the grinder, where the material is "cut" until it turn almost into dust. Then, the material is mixed manually with water and other substances, such as molasses and starch. That mixture is then pelletized and stored in big buckets, where they are left for cooling. Each batch of pellets is labeled considering its composition and then sent to the RWTH University for studies. This process is very dusty and dirty, being then hazardous to health, so the operators must use overalls, masks and goggles all the time.

The objective of this project is to automatize the conditioning and integrating it with the pelletizing step. The conditioner to be developed must be able to:

- Lower the contact of the operators with the process
- Control the temperature of the final product
- Control the addition of moisture
- Add different kinds of the material, such as steam
- All functionalities must work automatically
- The control of all functionalities must be centralized
- Production of about 100 kg of material per hour
- Constant output of material.

1.4: Document organization

The present document reports the activities developed during my internship in Blackballs Technologies GmbH, from February 2013 to July 2013. The report is organized in a way that each step of the development is detailed in a chapter, chronologically.

First of all, the mechanical structure of the conditioner was built specified and built (Chapter 2:). This chapter will explain each of the mechanisms used and why they were chosen for the project.

After the machine was set, all the electrical installation was made: installation of the PLC, motors, frequency inverter, safety devices and so on. Chapter 3: details the design of the electrical panel that feeds all the system and controls it, as well as the reason why the devices were used.

In Chapter 4:, the programming of the PLC is reported. Some aspects of the program will be explained more deeply, as well as a presentation of the user interface. In this chapter a quick explanation of the PLC used will also be given, as well as of the data acquisition devices.

Finally, in Chapter 5: the results obtained by the end of the project will be given, while in the following chapter a conclusion is made, along with some future development suggestions.

Chapter 2: **Mechanical Development of the conditioner**

Before the development of the new control system for the conditioner, it was first necessary to develop its mechanical structure. A possible solution would be either to construct a new conditioner or to use one from previous projects of the company. It was then decided that we would use a conditioner that was already constructed in BBTech, used in a previous project.

In this chapter we are going to discuss the mechanical development of the conditioner, since the analysis of the conditioner used, all the adaptations that were made to its structure and the addition of other features that were not contemplated in the machine previously.

It is important to have in mind that dealing with bulk materials, such as straw specially after the grinding, is not an easy task. The material has a very low density and is very dusty, which makes its handling more complicated.

2.1: The conditioner used

The conditioner resembles a big pipe, which has smaller perpendicular pipes as input and output (Figure 7 illustrates the sketch of the machine). The conditioner is built with steel and its structure is mounted with aluminum profiles. The motor coupled with the conditioner is also shown in the image.

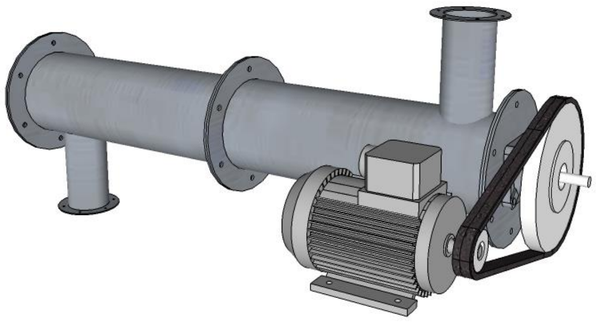

Figure 7 - Conditioner

Inside the pipe there’s a longitudinal axis with paddles. Its rotation will mix the material with its additives and move the material along the pipe, depending on the sense of the rotation of the motor. Figure 8 shows the section plane of the conditioner, thus illustrating the paddles and the axis.

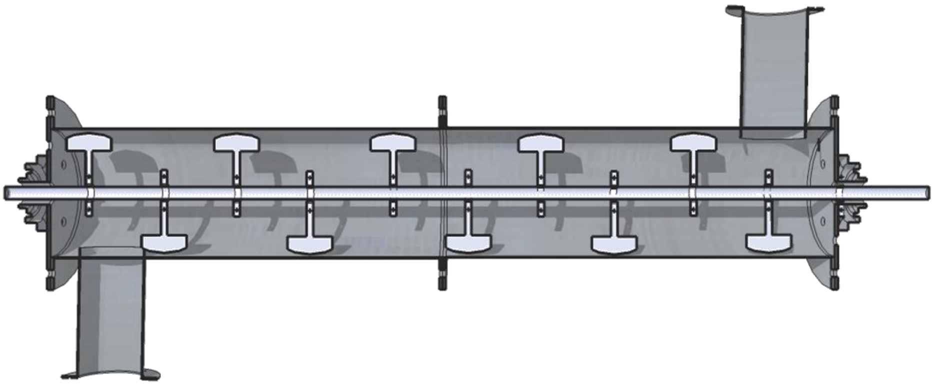

Figure 8 - Section plane of the conditioner

A steam input was installed in the end conditioner, so the steam flow against the flow of material. The current conditioner doesn’t have inputs for extra materials, like starch and molasses, so it would be necessary to make adaptations to the machine. At least one other input must be drilled to the machine, but that won’t be done for the present project.

2.1.1: Coupling of the motor

The rotation of the conditioner is done by the coupling of an asynchronous motor to the axis of the conditioner. The motor used in the project (which will be better analyzed in 3.3:) has a nominal speed of 1390 RPM. The conditioner cannot stand such a high speed, therefore it is necessary to couple it to the motor using pulleys, in a way that the speed is reduced.

The motor is controlled by a frequency inverter. The maximum frequency transmitted is 50Hz, which leads to the nominal speed of the motor. It is intended to reduce the rotational speed of the conditioner to around 300 RPM.

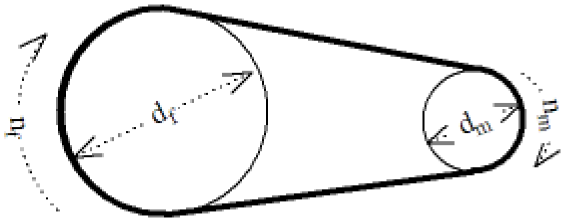

Figure 9 - Representation of the coupling of the motor and the conditioner

The relation between the speeds of two pulleys can be given by:

$$v = d_i \pi n_i$$

Where $v = \text{linear speed of the belt}$, $d_i = \text{diameter of the pulley}$ and $n_i = \text{rotational speed of the pulley}$. Since the linear speed of both pulleys must be the same, we have:

$$d_f n_f = d_m n_m$$

As specified previously, we have $n_f = 300\ RPM$ and $n_m = 1390\ RPM$. Therefore, the relation of the diameters of the pulleys must be:

$$\frac{d_f}{d_m} = 4{,}6$$

Respecting these calculations, the pulleys used in the project have diameters 6,6cm (motor pulley) and 30,2cm (conditioner pulley).

2.2: Feeder

The feeder is the mechanism responsible for the transportation of the material from one process to the other. In the present case, the feeder transports the straw from the grinding process to the conditioner. Since in BBTech the grinding is done manually, the feeding of the material into the conditioner is done also manually. It is intended to automatize this step of the process by adding an automatic feeder to the input of the system.

The input of material into the conditioner must also be dosed, so the conditioner doesn't get stuck and the mixing of the components can be better done. Therefore, it is important that the feeder is able to dose the amount of material that get into the process and in any emergency case it cease to feed material.

In pellet producing industrial plants, different methods are used as feeding mechanisms of the process. Initially some different popular feeding methods will be presented, and the chosen solution will be further discussed.

2.2.1: Feeding mechanisms

2.2.1.1: Screw feeder

Screw feeder, also known as screw conveyor, is a mechanism that uses a screw-like helical blade to transport materials when it rotates. It is widely used to move bulk material and liquids. Usually screw feeder are installed inside a hollow tube. Figure 10 illustrates a model of a screw feeder used in the industry.

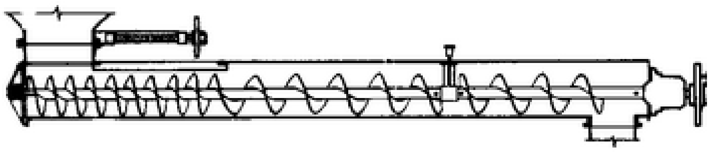

Figure 10 - Model of a screw feeder

2.2.1.2: Feeding belt

The feeding belt, or feeding conveyor, is simply a conveyor that moves the material on it. Different kinds of conveyors are available on the market, depending on the needs of the project. For example, packaging industries can use roller conveyors; for the handling of bulk materials, however, it is not possible. Belt conveyors are more suited for our application, like the one shown in Figure 11.

Figure 11 - feeding conveyor

2.2.1.3: Rotating hopper

A hopper is similar to a silo, and is commonly used for the storage of materials, specially in agriculture applications. The particular case of the rotating hopper (or rotating silo discharger) can also be used for the feeding and dosing of materials.

The bottom part of the hopper contains a hole through which the material can be discharged. The dosing of how much material falls is done by a rotating plate installed right above the bottom of the silo, which also contains hole(s). When both holes are located at the same place, the material will go through. Figure 12 shows how the mechanism works.

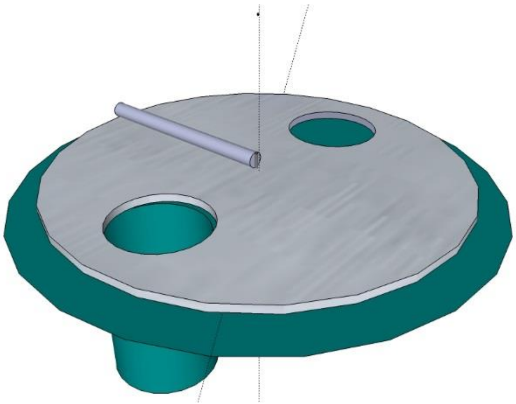

Figure 12 – Bottom of the rotating hopper

2.2.2: Use in the project

For the current project, it was necessary that the conditioner had both a storage silo and a feeding mechanism. Initially the idea was to install a screw feeder as the feeding mechanism, because it doses the discharging material more accurately. However, due to the availability of a rotational hopper in the company, it was finally decided to it for both the storage and feeding of material to be conditioned. It is installed right above the input of the conditioner and has a capacity of around 4kg of straw pellets. Tests made with the hopper have shown that it has a feeding rate of around 70kg/h, which doesn’t meet the initial specifications of the project. Nevertheless, it was decided that the hopper would be used in the project.

2.3: Steam Generator

One very important part of the machine development of the project is the steam generator. It will be the part responsible for the heating and moistening of the material.

Processes related to pellets and bulk materials are usually designed to produce tons of material every hour. However, the present project intends to produce lower quantities of material – up to 100kg/h; consequently, the steam generator must be selected accordingly. Industrial steam generators can produce great amounts of steam, in the order of tons per hour. Finding a steam generator fit for this application, that also had a good price, didn’t have many results. Most industrial steam generators were too big for this application, and very expensive. To solve this problem, it was acquired a commercial solution, used in steam baths.

The water input is connected to the tap, and is controlled by a solenoid valve. The output is also controlled by a valve, and the generated steam is connected to the conditioner. The groups of independently controlled heating elements are responsible for the boiling system. The control system developed for the steam generator adaptation to our project is better explained in chapter 3.5:.

2.4: Scale

It is important to know how much material is being fed in the process as well. There are many solutions in the market regarding in line weighing systems and force sensors. The ideal criteria for choosing a scale for the project would consider the measuring range. Since the hopper used in the project has a capacity of only 4kg, it would be desirable that the scale had a measuring range appropriate to the hopper's low capacity. However, since the company had available a regular commercial weighing scale (with measuring range up to 150kg and resolution of 0,1kg), that was the solution chosen to be installed in the system.

The scale was installed between the hopper and the conditioner, for weighing the straw that enters the process. It has cables that can be connected to the PLC, which interprets the signals and calculate the weight. The explanation about how the system calculates the weight is done in the chapter 3.6:.

Chapter 3: **Electrical development**

This chapter will explain the electrical aspects of the project, regarding the electrical installations, the electrical actuators (motors), the sensors and the data acquisition.

3.1: Electrical installation

The electrical installation was made in a structure separated from the conditioner. For that, a steel rack was built. On the rack a panel was installed, along with all the electrical connections, the PLC, the HMI touchscreen and the frequency inverter. The sketch of the rack is shown in Figure 13 - Electrical panel rack.

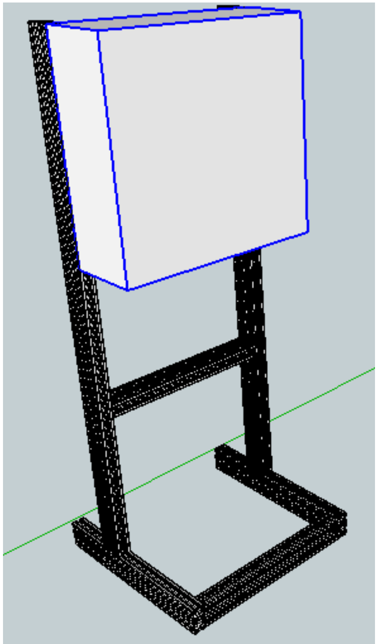

Figure 13 - Electrical panel rack

The energy supply of the whole system comes from the three-phase net. All the components are supplied by one of the phases, in a manner that the energy consumption is fairly divided for each phase and each component has a 230V supply.

The following scheme shown in Figure 14 represents the electrical scheme of the system.

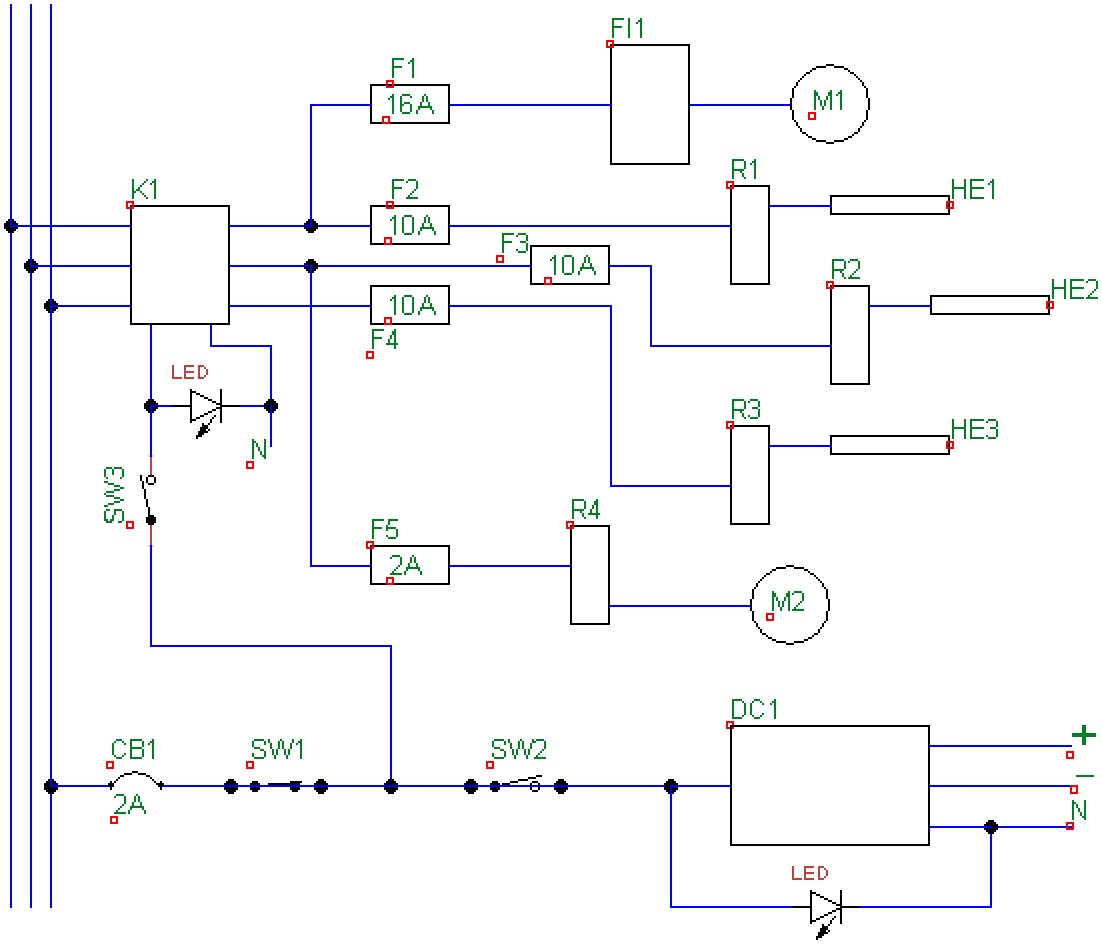

Figure 14 - Electrical scheme of the conditioner

In the scheme, the labels represent:

- K1 – contactor
- F1 to F5 – fuses
- FI1 – frequency inverter 1
- R1 to R4 – normally open relays
- M1 – conditioner motor
- M2 – silo motor
- HE1 to HE3 – heating elements from the steam generator
- SW1 – emergency button switch

- SW2 – PLC switch button
- SW3 – system switch button
- DC1 – DC supply for the PLC
- CB1 – circuit breaker

The electric panel is depicted in Figure 15.

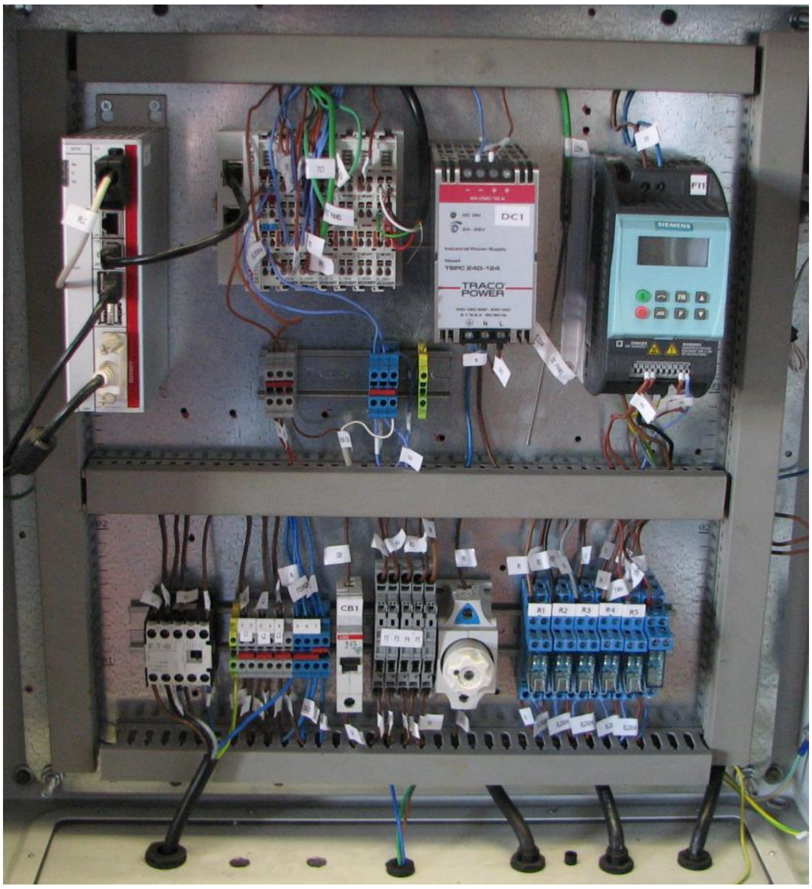

Figure 15 - Electric panel of the conditioner

A more detailed description of the elements will be given in the following chapters.

3.2: Frequency inverter

Frequency inverters, also known as frequency converters or frequency changers, are electronic devices that converts alternating current (AC) from one frequency to another. It is widely used to control the speed and the torque of AC motors through Pulse-width modulation.

3.2.1: Parameterization

One very important aspect of the frequency inverter is regarding its parameterization, which is the programming of the device for the application in question. Some of the parameters that can be manipulated are:

- Characteristics of the motor, such as power, frequency and current
- Sense of the rotation of the motor
- Ramp time of acceleration and deceleration
- Maximum and minimum frequency

The parameterization used in the project depends mostly on the specifications of the motor controlled by the frequency converter, which in this project is the conditioner asynchronous motor.

3.2.2: Use in the project

Figure 16 - Siemens G110

The frequency inverter used in the project is the Sinamics G110, manufactured by Siemens (Figure 16 - Siemens G110). It is used to control a three-phase induction motor. In order to automate the system, the frequency inverter was configured in a manner that it is operated by its digital-analog interface, thus being controlled by the PLC. In this case, parameters such as power on/power off, the speed of the motor and the sense of the rotation are sent by the PLC via digital and analog signals. The signals will be better explained in Chapter 4:.

3.3: Electric motors

In the present project, we are interested in electrical motors, which transform electricity in mechanical motion. Electrical motors can be divided in two categories: direct current motors and alternating current motors, which are divided in two sub-categories (asynchronous, also known as induction motor, and synchronous motors).

3.3.1: Use in the project

The most important motor of the project is the one that rotates the conditioner. It is important that the motor keep a steady speed despite the addition of load in the system (in this case, of feeding material). Also, the motor must be able to work in dusty environments. Finally, it is needed that the motor handle a considerable torque that is resulted by the heavy steel conditioner axis and the material that it moves. For these reasons, it was decided that we would use an AC asynchronous motor, controlled by a frequency inverter.

The motor used in the project is a 4-pole, 1.1kW, three-phase alternating current squirrel-cage rotor engine (asynchronous motor).

3.3.2: Wye and Delta connections

Motors can be connected either as a delta connection (∆) or as a wye connection (Y). In the first arrangement, each one of the three loads are connected between two phases; in the second arrangement, each of the three loads are connected between one phase and the ground. The Figure 17 depicts both arrangements.

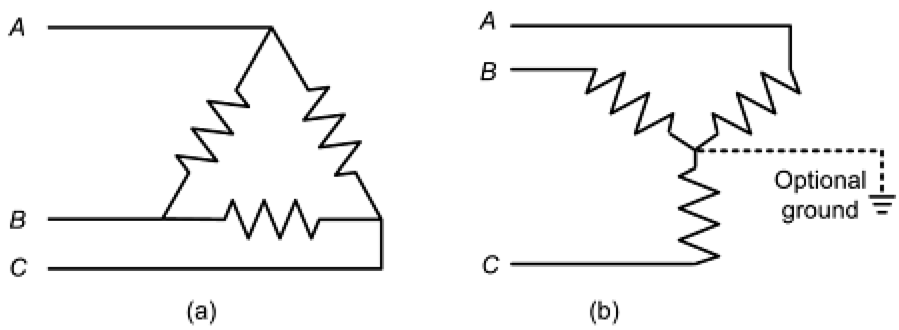

Figure 17 - (a) Delta and (b) Wye connection

Delta connections generally have better reliability, given the fact that it has a time-varying potential difference between any parts of its circuit, which protects the circuit in case any part of the circuit get accidently grounded (which would otherwise cause an outage) [9]. Wye connections, on the other hand, can use higher voltages from the same supply system. For example, let's suppose in Figure 17 - (a) Delta and (b) Wye connection the difference in points A-B (phase-to-phase, in delta) is 13.8kV. Connecting the same motor with a wye connection would convert the system to 23.9kV (which still is 13.8kV phase-to-ground), thus increasing the capacity by a factor of $\sqrt{3}$. Such change can be done merely by changing the delta connection to wye [10].

In the project, the delta connection was chosen for the motor connected to the conditioner.

3.4: Sensors

In automated systems, it is imperative that the system is able to "read" data from the environment so that the system can interpret it and actuate properly upon it. The device responsible for measuring different attributes, transforming it in electrical signals and sending this signal to the central controller is the sensor.

3.4.1: Use in the project

As mentioned in 1.2.3:, the temperature and the moisture are two of the parameters that have a great influence on the quality of the pellet.

Therefore, in order to control these parameters in the conditioner, temperature sensors and a scale were used in the project. Initially, moisture sensors were also in the project specification. However, due to the elevated prices of this kind of sensors, they are going to be used anymore.

3.4.1.1: Temperature sensors

The temperature sensors used are thermocouples. Thermocouples consist of a junction of two different metals, which when heated produce a voltage. There are a several types of thermocouples, each one of them representing different metal alloys, which have their own predictable relation between temperature and voltage. Some of the most used thermocouples are the types K, J, N and T.

The thermocouples used in the project are from the type K. It is an alloy made of chromel (90% nickel – 10% chromium) and alumel (95% nickel – 2% manganese – 1% silicon). It has a wide range of temperature, from -65°C to 300°C, though our application requires much simpler ranges, up to a little more than 100°.

Three thermocouples were installed: one in the electrical panel and two in the conditioner. The thermocouple in the panel is used to prevent the internal temperature to get too high: in case it reaches a certain value, a fan is turned on to remove the hot air inside; if the temperature continues to increase, reaching a pre-defined value, the whole system is turned off,

The other two thermocouples are installed in the conditioner, one in the input of material, and the other in the output of the process. The idea is to control the temperature of the product, and help it achieve a set-point temperature defined by the operator. The PLC will read the read the measurements of temperature and define how much steam will be generated, thus increasing or reducing the temperature of the material.

3.4.1.2: Hall Sensor

The Hall sensor is a sensor that varies its output voltage when in presence of a magnetic field. This device works on the principle called Hall Effect.

In the project it is used as a proximity switching device. The rotating silo has two magnets attached to its rotational axis. Fixed to the static structure is one hall sensor that counts the rotations of the silo and define whether it is open or closed (meaning that it is feeding material or not).

3.5: Steam generator

As explained previously in this document, one of the most important aspects to be controlled in a pelletizing plant is the temperature of the material. Our conditioner adds heat to the mixing by adding steam in the process, which also moistures the material, even though it is not controlled.

3.5.1: Use in the project

The steam generator used in the project is actually a model that is used commercially for steam baths. Therefore, this machine doesn’t have many control options, neither does it have a large range of modes of operation. This model has an intern program that controls the temperature inside a 4.5m³ room, in a range from 35°C to 55°C. For that, it uses three heating elements to boil the water and generate steam – the number of elements that work at each moment depends on the difference between the room temperature and the set-point. For the measuring of the temperature in the room, it has a probe that must be installed on the wall; however, we won’t use this sensor in our project.

For us to use that steam generator in our process, it was necessary to make a bypass-control, meaning that the internal control of the machine needed to be ignored, so that it could be controlled by the system developed for this project. For that, it is necessary that the sensors can be read by our sensor and the actuators be controlled as commanded by the PLC.

The steam generator used has three level sensors, three valves (one water input solenoid valve, one water drain valve and one steam output valve) and three heating elements. The energy supply of the steam generator can by either 230V or 380V.

First of all we need to bypass the control of the steam production, so we actuate in the heating elements. More heating elements working generate more steam. As said before, the system has three heating elements (1.5kW each). For this project, we chose to supply the system with the three-phase system, due to its lower current consumption (only 6.8A, while the single-phase supply would need 20.5A). Therefore, the bypass control was designed in a manner that each one of the heating elements is supplied by one phase of the three-phase energy source. Their control is done by normally-open relays that convert the 24V signals sent by the PLC in high voltage signals.

3.6: Scale

The scale is connected to the PLC by a 4-wire cable that sends the signals from the measurement of the scale. The scale measures the weight by the deformation of strain gauges, which varies their resistances. In order to measure the variation of the resistance, and thus the weight of the material, a Wheatstone bridge circuit is used. This circuit is made of three know resistances and one unknown one, that varies depending on the weight (deformation of the strain gauge), like shown in Figure 18 - Wheatstone Bridge.

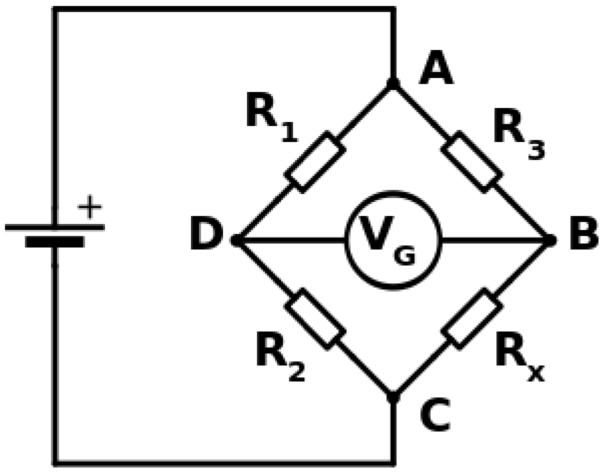

Figure 18 - Wheatstone Bridge

The scale is connected to the PLC, where its values are converted as INT values. The voltages are defined by $\mathrm{U_D = B - D}$ and $\mathrm{U_{REF} = A - C}$. The program then calculates the measurement as being a relation between the two values.

Chapter 4: **Control (PLC Programming)**

The control of the system of the project is entirely performed by a PLC (Programmable Logic Controller). The PLC is an industrial device used for controlling processes by means of a stored program (its logic function) and feedback from the process sensors and actuating devices [11].

PLCs have a central processing unit (CPU), where its internal programmable memory stores all the instructions and processes them; a input/output system (I/O system), which is the interface to field sensor and actuator devices; and a system power supply, which supplies power to the processing unit and to the I/O system [11].

There are two basic types of PLCs, the compact and the modular types. The first kind has fewer inputs and outputs that are incorporated to the CPU and is used in simpler processes and machines; the later has off-board exchangeable modules, which allows expansions and changes to the system.

4.1: The PLC used in the project

In the conditioner we used the PLC C6925, from Beckhoff (Figure 19). The great advantage of this PLC is the modularity, which allows us to add functionalities and I/O modules depending on the needs of the project. The modules used in the project will be better explained in sub-chapter 4.1:.

Figure 19 - Beckhoff C6925

The controller is able to monitor the process through its sensors. All the data acquisition of the system is received by the PLC

The communication between the PLC and the I/O modules is made by the real-time Ethernet-based fieldbus system called EtherCAT (Ethernet for Control Automation Technology). This high performance protocol was developed by Beckhoff itself. The simple configuration and flexible topology are advantages that were essential for the project.

The modules (also called terminals) used in the project are the following:

- EL1004 – digital input
- EL2004 – digital output
- EL4004 – analog output
- EL3314 – analog thermocouple input
- EL3351 – analog input for resistor bridge

4.1.1: EL1004 – digital input

Only one digital input is being used in the project so far. It is used to read the rotation of the hopper in the beginning of the process. The reading is done by a hall sensor installed under the silo, which senses a magnet installed in the rotational hopper and that can determine the rotation of the hopper.

4.1.2: EL2004 – digital output

Two EL2004 terminals were used in the project. The first of them controls the frequency inverter, hence the motor of the conditioner. It sends two signals: one to turn the frequency inverter on or off, and the other to determine the sense of the rotation of the motor.

The second digital output terminal controls the steam generator and the silo. Three signals control the heating elements of the steam generator (one for each) and the one signal turns the silo on or off, thus controlling the input of material in the conditioner.

4.1.3: EL4004 – analog output

The EL4004 analog output is a 12-bit 0-10V signal.

One signal is sent to the frequency inverter to determine the desired speed rotation (in RPM) of the conditioner. The PLC program converts the value input by the operator in a 12-bit signal that is sent in a 0-10V proportional voltage, which is then converted by the frequency inverter in a frequency of signal that is sent to the motor. The motor then rotates according to the input value given by the operator.

4.1.4: EL3314 – analog thermocouple input

This module reads the voltage sent by the three thermocouples. The conversion of the signal received into the read temperature (represented in degrees Celsius) is done by the program.

4.1.5: EL3351 – analog input for Resistor Bridge

The EL3351 terminal permits direct connection of a resistor bridge. The bridge voltage (U_D) and the supply voltage (U_{REF}) to the bridge are digitized with a 16 bit resolution, and are transmitted to the supervising automation system.

4.2: IEC61131

The IEC61131 is the international IEC (International Electrotechnical Commission) standard for programmable controllers. For the development of this project, we are especially interested in the third part of the document (IEC61131-3), which refers to the programming languages for PLCs.

The objective of the IEC61131 is to standardize the PLC programming languages, thus optimizing the programming time necessary for the set-up of the industrial PCs [12].

The standard provides six languages for writing application programs:

- IL – Instruction List
- ST – Structured Text
- SFC – Sequential Function Chart (textual version)
- SFC – Sequential Function Chart (graphical version)
- LD – Ladder Diagram
- FBD – Function Block Diagram

The first three languages are textual and the latest three are graphical.

In the scope of the project, the languages that were used the most were the ST, LD, FBD and SFC. ST is a high level textual language that is similar to, and based on, Pascal; LD is a graphical diagram where the logic is represented by relay logic of circuit diagrams; SFC is a mostly graphical language that represent processes through sequential blocks whose transitions depend on conditions (the SFC language is strongly based on GRAFCET and Petri Nets).

It is important to know that the project was developed in accordance with the standard's conventions.

4.3: Objectives of the program

- Centralize all the commands of the conditioner

    - The operator can command all the functionalities of the conditioner independently, through a single touchscreen interface
- Automatize the process
    - Routines of production of material
- Visualization of the process' sensors and actuators
- Optimize the production of material for the pellets

4.4: Structure of the program

The program was developed in modular structure that allows the future addition of new I/O terminals, sensors and actuators without the need of much changes on the code available. That is important for the project, so that future adaptations to the project can be easily made to the code.

The PLC allows concurrent computing, meaning that it is capable of executing different threads simultaneously. With that, the system can control the different parts process all at the same time. For example, it can simultaneously measure the temperature of the thermocouples and increase the production of steam by activating more heating elements.

4.4.1: The main routines

The program has three main routines: the forward-automatic, the back-forth-automatic and the manual routines.

4.4.1.1: Manual routine

The manual routine is the default of the program. In this routine all functionalities of the machine can be controlled independently by the operator. For example, the steam generator can be turned on and only two heating elements activated, regardless whether there is material being fed or not; the silo can be turned on and off and the conditioner can be activated in its different modes, in different speeds. The figure below shows the interface of the manual commanding of the conditioner.

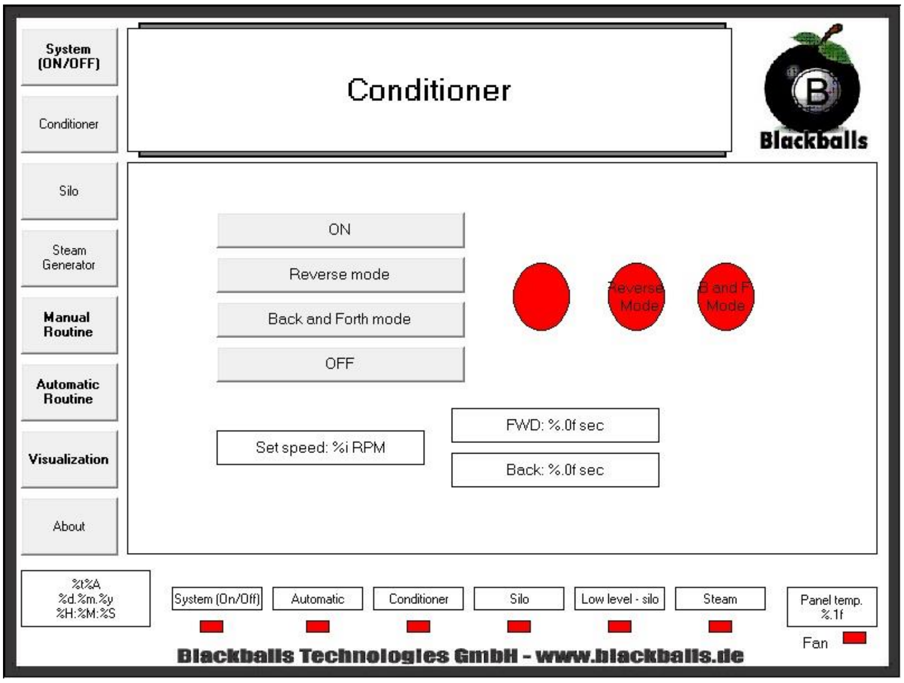

Figure 20 - Visualization of the manual control of the conditioner

4.4.1.2: Automatic routines

In the automatic routines, all different mechanisms are controlled by the own program. There are two automatic routines defined: the Only Forward and the Back-Forth. The first rotates the conditioner only in one way, continuously moving the material inside it forward. The main importance of this routine is to guarantee the continuous output of material. However, in this mode the material can't stay a long time conditioning, which affects the temperature control (the time inside the conditioner is not sufficient to heat the material to high temperatures, such as 90ºC). The later routine is better suited for the temperature control, despite the fact that it doesn't generate continuous flow of output material. In this routine the conditioner is controlled so it moves forward and back, in loops. The longer time inside the conditioner is sufficient for the conditioning to reach higher temperatures. It is up to the operator to choose what to prioritize, the temperature control or the continuous output flow.

The temperature automatic control is present only in the automatic routines: in the manual routine it is necessary that the operator command manually which heating elements are supposed to work, and for how much time (the system works in an open-loop). In the automatic routines, the thermocouple positioned in the exit of the conditioner reads the temperature of the material and compares it to a set-point defined by the operator (there's a default set-point of 80 degrees, which can be changed in the program). This value – the error – is then compared to a set of rules through which the program defines how many heating elements are supposed to work. It is important to notice that the heating system cannot be controlled analogically, meaning that steam generator, responsible for the heating of the material, can only generate steam in three different powers. The set of rules are defined as follows:

- Error = SetPoint - OutputTemperature
- Error > 7ºC → Material is too cold
- 7ºC > Error > 2ºC → Material is slightly cold
- 2ºC > Error > -2ºC → Temperature OK
- Error < -2ºC → Material is too hot

The actuators work as defined by:

- Material is too cold → 3 heating elements are turned on
- Material is slightly cold → 2 heating elements are turned on
- Temperature OK → 1 heating element is turned on
- Material is too hot → all heating elements are off

The temperature control system (controlled by the PLC program and heated by the three steam-generator heating elements) work as depicted in Figure 21.

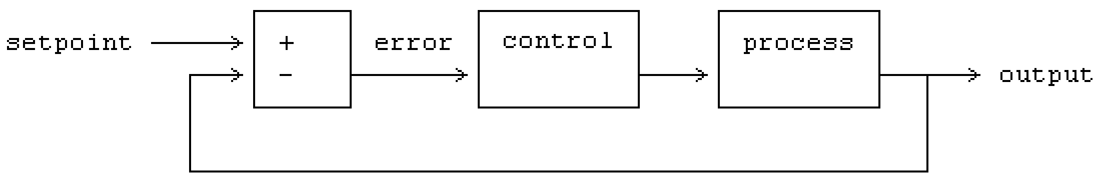

Figure 21 - Temperature control system

Figure 22 illustrates the main routines of the project, programed in SFC. Each routine is pointed by the red arrows (the first being the manual routine, the second the back-and-forth automatic one and the third the only-forward automatic mode).

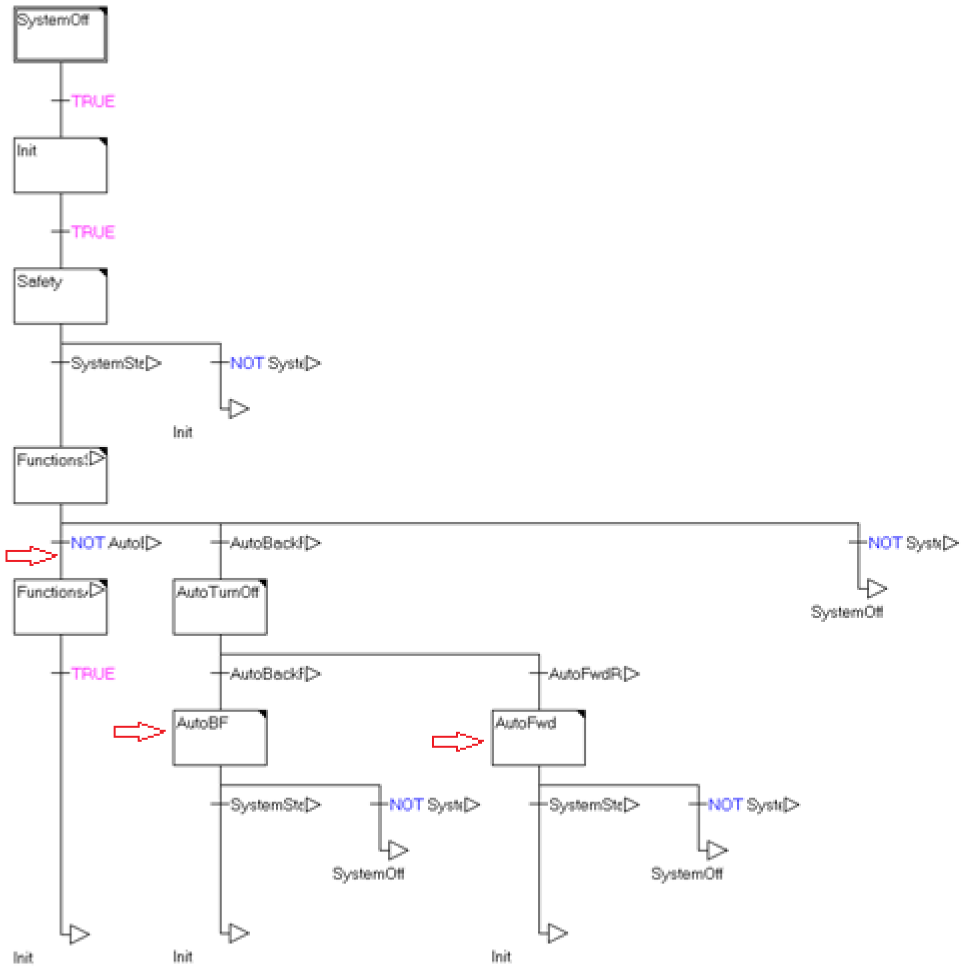

Figure 22 - MAIN routine of the program

4.4.1.3: Safety routine

Differently from the previous routines, the safety routine must always be active. In Figure 22 it is possible to see that the block *Safety* is actually part of the main loop, and not a parallel branch. That happens because the software doesn't support two parallel branches that are simultaneously active, therefore it is necessary that this block is implemented sequentially.

The safety routine is responsible for shutting the whole system off in case of overheat. One thermocouple is installed inside the electric panel and monitors constantly its temperature. In case the structure reaches a pre-defined temperature, a fan blows air outside of the box. If the temperature continues rising, the system will shut down, and the fan will still be on. The system has to be then rebooted.

4.4.2: Function blocks

Function blocks are the main building blocks for structuring PLC programs. In this project they were written mostly in ST or LD (but can also be written in SFC, in more complex functions). FBs are the complex functions with input and output variables and an internal memory that can be instantiated – each instance of the FBs are called upon in the MAIN routine, and each one of the instances act independently. They are encapsulated code that manipulate the internal variables and send the proper data – internal variables, for example – to other function blocks or the interface.

The programming of a FB can be organized in two parts, the first being the definition of the variables (inputs, output and internal ones) and second being the function itself, as shown in Figure 23 (variable definition on the left and function on the right).

```
FUNCTION_BLOCK FB_SILO
VAR_INPUT
	bSiloOnIn		:BOOL;
	bSiloOffIn		:BOOL;
END_VAR
VAR_OUTPUT
	bSiloOnOut		:BOOL;
END_VAR
VAR
	bSiloOnIntern		:BOOL		:=FALSE;
	TimerSilo		:TP;
	flag			:BOOL;
END_VAR
```

```
TimerSilo(IN:=(AutoFwdRoutine AND flag),PT:=t#8s);

IF NOT(AutoBackForthRoutine OR AutoFwdRoutine) THEN
	IF (bSiloOnIn AND NOT bSiloOffIn) THEN
		bSiloOnIntern:=TRUE;
	ELSIF (NOT bSiloOnIn AND bSiloOffIn) THEN
		bSiloOnIntern:=FALSE;
	END_IF;

	IF bSiloOnIntern THEN
		bSiloOnOut:=TRUE;
	ELSE
		bSiloOnOut:=FALSE;
	END_IF;


ELSIF AutoBackForthRoutine THEN
	IF Automatic.iAutoSpeed<140 THEN
		IF bCondPower THEN
			bSiloOnOut:=TRUE;
		ELSE
			bSiloOnOut:=FALSE;
```

Figure 23 - Function block

In the MAIN routine the instantiation of the functions is done. Figure 24 represents the FBD (Function Block Diagram) of the actuators functions of the conditioner.

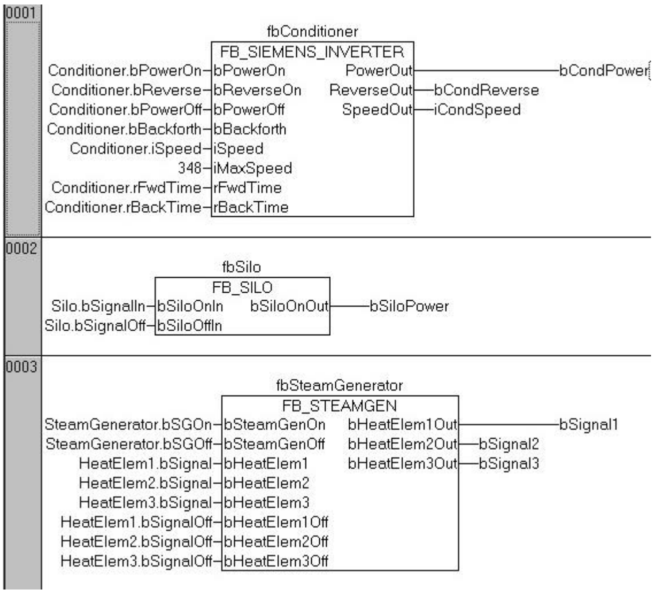

Figure 24 – FBD of the actuators in the manual routine

The FBD represents the functions as blocks where the inputs and outputs are associated with variables. Each one of the blocks are instances of the FBs. The associated variables are mostly related to instances of STRUCTs (for example, *Conditioner.iSpeed* represents the parameter *iSpeed* of the instance *Conditioner* of the struct *ST_SIEMENS_INVERTER*), but can also be integers and, as seen as outputs of the three FBs in Figure 24, physical variables – *bCondPower* is the boolean that commands the FI to turn the motor on, *iCondSpeed* is an integer that, as an analog output of the FI, is transformed to a frequency that controls the speed of the motor, and so on.

4.4.3: Other data structures

The variables from the sensors are defined as physical inputs and the variables of the actuators are set as physical outputs. The physical variables are defined as global variables (VAR_GLOBAL).

The structures of the program (STRUCT) define different types of objects and its variables. The structures are used for the creation of instances. That helps with the modularization of the code, because the addition of extra elements doesn't necessarily demand a big change on the code. For example, the Figure 25 shows the code for the structure of the FI.

```
TYPE ST_SIEMENS_INVERTER :
STRUCT
        bPowerOn        :BOOL;
        bPowerOff       :BOOL;
        bReverse        :BOOL;
        bBackforth      :BOOL;
        iSpeed          :INT        :=70;
        iSpeedRev       :INT        :=70;
        rFwdTime        :REAL       :=5;
        rBackTime       :REAL       :=4;
END_STRUCT
END_TYPE
```

Figure 25 - Example of a STRUCT

The instances of the structures are created as global variables.

```
        TCInput                         :ST_THERMOCOUPLE;
        iTempIn         AT%I*           :INT;

        TCOutput                        :ST_THERMOCOUPLE;
        iTempOut        AT%I*           :INT;
```

Figure 26 - Instances of a STRUCT

TCInput is the instance of the structure *ST_THERMOCOUPLE* that represents the thermocouple that goes in the input of the conditioner, while *TCOutput* is the one that goes in the output of the process. *iTempIn* and *iTempOut* are inputs (the I in *AT%I** defines it as input – outputs are Q), physical variables, of the type *INT*.

4.5: Implementation of the program in the PLC

As said before, the definition of physical variables as being inputs or outputs is written in the code. However, it is not necessary to set their physical address in the PLC manually. The addressing of the physical variables is done by the software System Manager, from Beckhoff (Figure 27). The programmer defines in the System Manager which channel of the terminals the variables are supposed to be addressed to and the software uploads the program to the PLC.

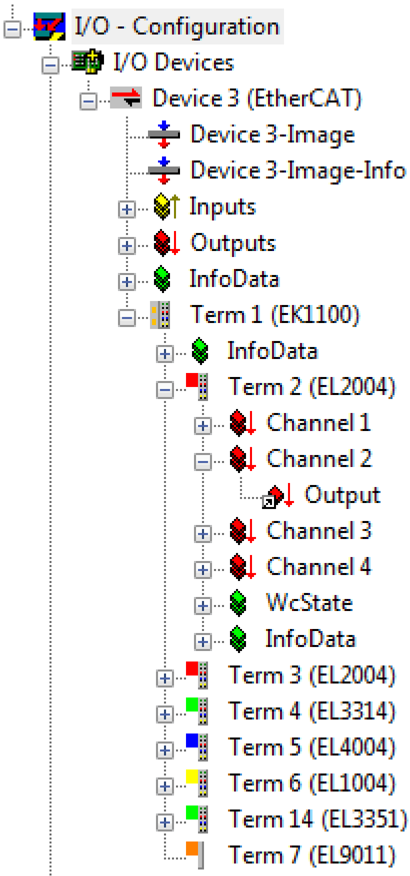

Figure 27 - Setting the variables to the PLC's terminals

4.6: Supervisory system

Supervisory systems are used for monitoring and control industrial processes. It gets all the data from sensors, actuators and alarms, and can show them in the screen. The data is presented in a HMI and can be manipulated by the operator, all in real-time. In other words, supervisory systems are a simple and useful tool for centralizing the visualization of the whole process.

A HMI was developed for the present project for the control of the process. Different screens were developed for the monitoring of each area of the conditioning. It was developed using the same program as the PLC program, from Beckhoff. Figure 28 shows as an example the screen of the program developed for the scale calibration.

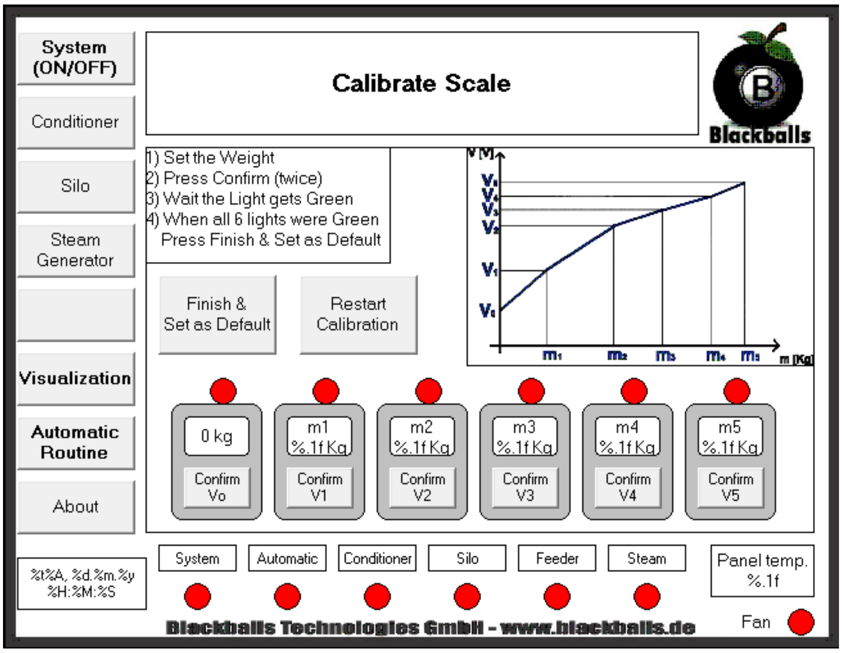

Figure 28 - Screen of the scale calibration

All the functionalities of the conditioner are controlled through the screen, by the operator. Each of the routines (automatic and manual) have a visualization that centralizes all the important data for the operator. For example, in the Automatic Screen (Figure 29) it is shown the values of the temperatures, how many and which of the heating elements are on, the speed and the mode of operation of the conditioner, the amount of material in the silo, as well as the timer of production. All the data is updated automatically and in real-time by the program.

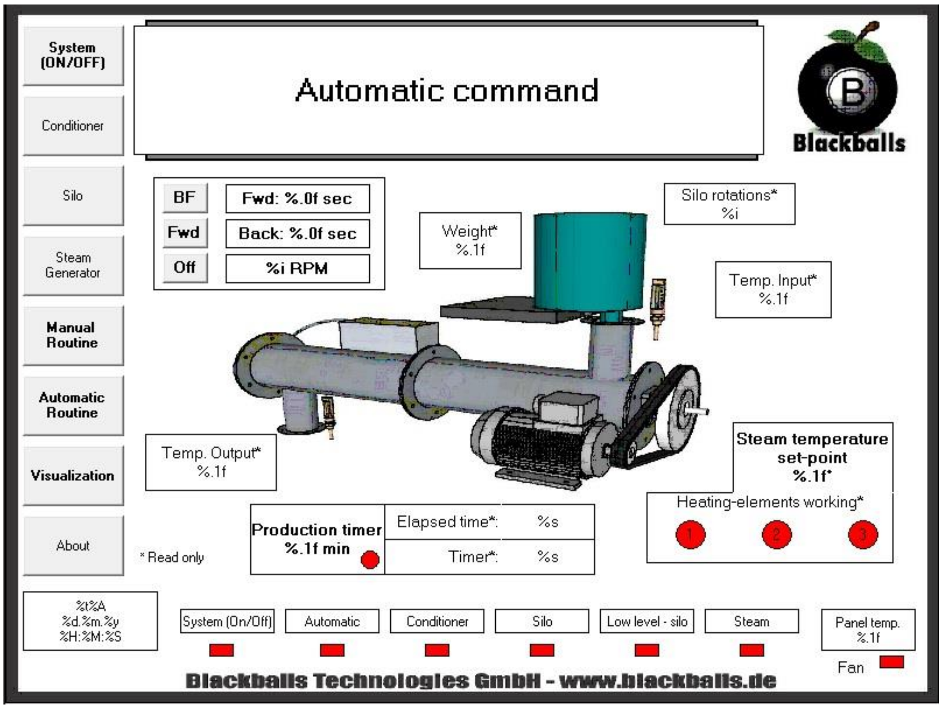

Figure 29 - Automatic command screen

Chapter 5: **Results**

The current document reported the development of a conditioner for a straw pelletization process. The model of the conditioner designed and built in the project is shown in the picture below.

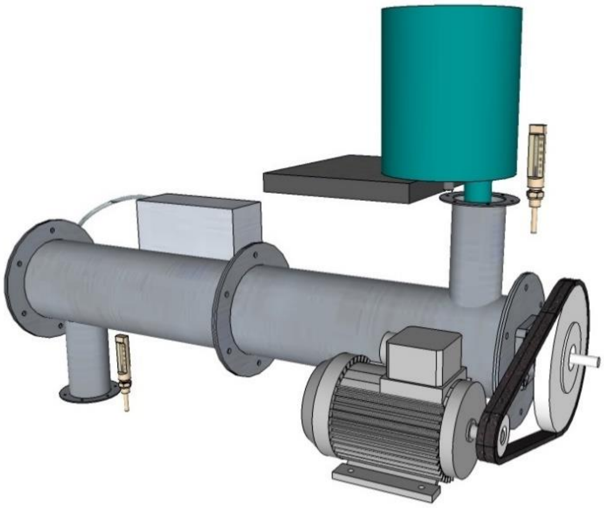

Figure 30 - Model of the conditioner

The conditioner can operate both in the manual and in the automatic modes. In the manual routine all the functionalities of the machine are independently commanded by an operator via the touchscreen interface. On the other hand, in the automatic routine the operator just have to set the production parameters desired and the program will run everything automatically.

The initial specifications by which the whole project was guided were:

- Lower the contact of the operators with the process
- Control the temperature of the final product
- Control the addition of moisture
- Add different kinds of the material, such as steam
- All functionalities must work automatically
- The control of all functionalities must be centralized

- Production of about 100 kg of material per hour.

Now, with the usage of the conditioner, the contact of the operators with the conditioning process is lower than it was before, limited to the setup of the program parameters, to the addition of material to the hopper and to the collection of the material output. The centralized command through the user interface simplifies the use of the conditioner. Also, now that the process is automated, the operators can focus on other activities (for example, the pelletizing step), thus optimizing the time of production.

Another good result of the project is that now it is possible for the process to heat the material for the pelletization, which wasn't possible before the project. That is only possible due to the addition of steam into the conditioner, which wasn't possible when the conditioning of the material was done manually. Some tests performed on the machine show that the system can reach the set-point defined, using the following parameters:

- Temperature set-point: 80ºC
- Routine: Automatic, back-and-forth
- Conditioner speed: 200 RPM
- Time to reach set-point ± 2ºC (from room temperature): 7min30s
- Material output: not constant

However, using the other automatic routine the temperature control results weren't as satisfying:

- Temperature set-point: 80ºC
- Routine: Automatic, only-forward
- Conditioner speed: 150 RPM
- Temperature reached (after 7min): 49,8ºC
- Material output: constant

This result shows us that some modifications must be made to the conditioner in order to implement a better temperature control. The more time the material spends being conditioned, the faster it heats. It is clear after the tests that, in the only forward routine, the time of conditioning isn't sufficient for the material to heat properly.

However, in the other routine, the not-continuous flow of material may compromise the steps that follow the conditioning, even with the proper conditioning. It is necessary that a bigger conditioner is used (thus taking longer for the material to exit the process), or that a more powerful steam is used, to heat the material faster.

Some other specifications couldn't be met by the project as well. The control of moisture cannot be done, since there is no measuring of the moisture of the material by the system. Different moisture sensors were researched for this project, but due to the price for this device it was decided to ignore the moisture aspect of the product.

Other important specification that couldn't be achieved by the project is regarding the production rate. It was expected that the system would be able to produce around 100kg/h. However, the low feeding rate of the hopper, and the short size of the conditioner, have shown that it is not possible to produce more than 70kg/h without the changing in these mechanisms.

Figure 31 pictures the prototype developed by this project and used for the tests.

Figure 31 - The conditioning system

Chapter 6: **Conclusion and future development**

The increasing need for alternative sources of energy is a matter of great importance nowadays. Fossil fuels, such as petrol, coal and gas, are both non-renewable and have a great pollutant potential. The use of biomass as fuel is a viable solution to this problem, and the use of pellets as the source of biomass is something worth studying and researching.

The machine developed during this project is not new in the pelletizing industry, many companies already produce conditioners worldwide. However, due to their high costs, the development of a conditioner inside the company was necessary. Also, the project was able to lower the time of conditioning of the material, process is done completely manually in the company.

The automation of the conditioning process have shown some interesting results. Many of the tasks that needed to be done manually by the operators are now done automatically: it is possible now to weight the material, mix it with water and heat it without the operator. All those tasks were before done manually, and the material wasn't even heated, due to the complicated handling of steam, which greatly affected the quality of the material produced. All the functionalities implemented so far have been independently tested and approved.

Nevertheless, much can still be implemented. A proper conditioning requires the addition of materials called *binders*, which have the property of binding the pellets more strongly, making them more dense and stable. The input of binders is not yet implemented: it is necessary to drill the input in the conditioner, install a motor to transport the binder to the conditioner, and to dose that input somehow.

It must also be noted that, in order to achieve the specifications made in the project, more investment must be made to it. One aspect of the project that must be enhanced is the measuring of the quality of the product produced, due to the need of some sensors, such as moisture sensor. What is currently done is a visual inspect of the product. Therefore, it is important that some automated method for product quality inspection is designed and implemented.

Although some tests were made using the whole system, it is important that more tests are made. The heating of material is done by an on/off control, which takes in account only the temperature of the output material. The mathematical modeling of the system, and consequently the design of a better control system, with the addition of a solenoid valve for controlling the amount of steam input, would be a nice continuation to this project.

The development of this project was of great importance for the conclusion of the Control and Automation Engineering course. The practical applicability of concepts learned in class, such as PLC programming, was a very interesting and important experience for the last steps taken out of the academic world into the industrial and business world. Moreover, the learning and application of knowledge not deeply studied in the Control and Automation curriculum, such as electrical and PLC installation were maybe the greatest contribution that the project gave to my experience in Blackballs.

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