DEVELOPMENT OF A SCADA CONTROL SYSTEM FOR A WEIGHING AND BAGGING MACHINE

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DEVELOPMENT OF A SCADA CONTROL SYSTEM FOR WEIGHING AND BAGGING MACHINE

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ABSTRACT

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In this thesis study, a prototype is designed in order to improve the weighing accuracy of the weighing and packaging machine that used in sugar factories. The unavoidable factory conditions cause weighing and packaging machine to do weighing errors. In order to correct these errors, the prototype produced in this study was designed as a quality control unit which will take the excess sugar and fill the deficient sugar in the sacks. Because of being small and having an easy installation, the application of the prototype was done considering 1-kilogram bags rather than available 50-kilogram ones.

So as to correct the faulty weighing, sugar extraction and filling processes are provided from a bunker which is designed on the basis of data obtained by statistical analysis. For suction, vacuum is used and filling is realized by a ball valve. Upwards and downwards movement of the bunker is carried out with a pneumatic cylinder. Weighing information is received via a load cell and an indicator. Control of all these devices is provided by PLC hardware and SCADA interface.

Key words: weighing, bagging, sugar, PLC, SCADA

ÖZ

TARTIM VE PAKETLEME MAKİNASI İÇİN BİR SCADA KONTROL SİSTEMİNİN GELİŞTİRİLMESİ

Aykaç, E. Sinem
Yüksek Lisans, Makina Mühendisliği Bölümü
Tez Yöneticisi: Prof. Dr. Tuna Balkan

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Bu tez çalışmasında, şeker fabrikalarında kullanılan tartım ve paketleme makinasının tartım doğruluğunu iyileştirmek için bir prototip tasarlanmıştır. Bazı önlenemeyen fabrika koşulları tartım ve paketleme makinasının hatalı tartım yapmasına neden olmaktadır. Bu çalışmada üretilen prototip ise bu hataları düzeltmek üzere bir kalite kontrol ünitesi gibi çalışarak çuvallardaki fazla şekeri alacak eksik şekeri ise dolduracak şekilde tasarlanmıştır. Montaj kolaylığı ve küçük olması açısından prototip uygulaması mevcut 50 kilogramlık çuvallar yerine 1 kilogramlık çuvallar düşünülerek yapılmıştır.

Hatalı tartımı düzeltmek üzere şeker çekme ve doldurma işlemleri, istatistiksel analiz ile elde edilen verilere dayanılarak tasarlanan bir hazneden sağlanmaktadır. Emiş için vakum kullanılmıştır, dolum ise bir küresel ventil ile gerçekleştirilmektedir. Haznenin yukarı ve aşağı hareketini pnömatik bir silindir sağlamaktadır. Tartım bilgileri bir yük hücresi ve indikatör aracılığı ile alınmıştır. Tüm bu cihazların kontrolü ise PLC donanımı ve SCADA ara yüzü ile yapılmıştır.

Anahtar Kelimeler: Tartım, paketleme, şeker, PLC, SCADA

To my loving family and to the memory of my dear friend Neslihan Akşin

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TSE : Türk Standartları Enstitüsü (Turkish Standards Institute)

F_s : suction force

ΔP : pressure difference

d : dimension of the suction hole

m_i : values in statistical analysis

f_i : frequency of values

μ : mean value

F_a : thrust

F_{re} : return force

P : working pressure

D : bore diameter

A : cross sectional area

D_0 : diameter of piston shaft

F_r : friction force

n : partition value

x : variable used in set up program

k : variable used in set up program

e : division range

Max : maximum capacity of load cell

y : upper limit of indicator

CHAPTER 1

INTRODUCTION

Every human being is affected by weights and measures in some way in a part of his/her life. Throughout our daily lives, weighing and measuring are an important and often vital part of our existence. Our bodies, the food we eat and all the products we use as an integral part of modern living have all been weighed and measured at some stage in their development.

The first weighing activity began in ancient Egypt. Many changes have taken place since man first developed a system of weights and measures. It developed day after day and from the late 1940s mechanical weighing began to combine with electronics. However, it was not until the device called a load cell was invented. Load cells, or transducers, now lie at the heart of every electronic machine. Precision load cells convert weight into electronic signals for measuring accurate values [1]. Weighing accuracy is an important subject. Remaining of weighing and packaging within the correct values and allowed standards must be one of the priority issues for a facility. It is apparent that error made in the weighting causes damage to both consumer and the manufacturer.

Nowadays weighing systems perform accurately by choosing components suited to the application and by taking steps to control environmental and other forces acting on the system. A component in a system plays a big role to achieve the weighing accuracy. A controller is a significant factor that affects the quality and the system's performance. Lately PLC hardware and SCADA interface are widely used for controlling the simple or complicated systems.

Improvement in electronics introduced us PLC (Programmable Logic Control) hardware in the late 1960’s. The primary reason for designing such a device was eliminating the large cost involved in replacing the complicated relay based machine control systems [2]. However, nowadays it is the most widely used product in the industrial automation business. Also, SCADA interface (supervisory control and data acquisition) has been around as long as there have been unmanned control systems. SCADA interface provides real-time monitoring and control of the facilities. Its fundamental purpose is to remotely monitor a range of processes, collect real-time data and then perform analysis on the accumulated data. The foundation of SCADA interface can be researched back to the 1960's, when simple input and output devices were used to remotely monitor operations in industrial applications. Due to technology advancements, SCADA interface systems have now been developed using advanced software, high performance microprocessors and wireless technology. Additionally, SCADA interface systems deliver productivity and operational efficiencies by improving the reliability and stability of the system. These devices are widely used in plants, factories and power generating facilities.

Like all factories that product something, sugar production factories are a chain of systems and processes. In this operation, several machines, equipments, measurement devices, test equipments, chemicals, electronic or electrical devices are used. As in each of the advanced manufacturing sector in sugar production automation is an important issue also. As well as the production quality matters automation is inevitable for producing cheaper. Automation is desirable as there are increasing difficulties with the manual procedures in food production such as increasing hygiene demands and skilled labor requirements. Non automated systems are slower, more costly and has a higher risk of contamination. That's why automation was made in a lot of facilities in the sugar factories and critical controls have been removed from human initiative.

1.1. TŞFAŞ and EMAF

Being the owner of the 25 factories; TŞFAŞ (Turkey Sugar Factories Inc.) is a state-owned economic enterprise. It produces sugar from sugar beet and has approximately 70% share in this sector.

Electromechanical Devices Factory; namely EMAF was established to meet the growing need for measurement and control devices with our country's resources, for TŞFAŞ. Purposes of this establishment are also the development of existing systems and devices in sugar factories and provide maintenance and repair for the working systems. The weighing and bagging machine that will be improved by the prototype which is designed and produced in this thesis study is also a design of EMAF and it is planned and designed by Koruk (1994).

1.2. Summary of sugar production

Sugar, one of an important food for centuries, was produced only from sugar cane until the end of the 18th century. Sugar beet farming and sugar production from sugar beet was begun in the 19th century. World's 75 percent of sugar need meets with sugar cane, while the rest is compensated largely with sugar beet and other species [3]. In our country we use sugar beet to produce crystal sugar. Sugar is very valuable nutrient in our tables and also sugar beet agriculture provides the development of crop and animal production and contributes to improve the physical structure of soil and the ecological balance.

Sugar beet is collected from the fields and carried out to the factories after the harvest. Processing the sugar beets to make the crystal sugar generally lasts 4 – 5 months from September to February. A beet contains 10 – 15 percent sugar in it and the aim is to draw out this sugar from the beet [3].

First, the washed beet is sliced and the sugar extracted with hot water in a 'diffuser'. Diffuser enables to produce a sugary juice. This juice then goes through several filtration (impurities are precipitated with an alkaline solution "milk of lime" and carbon dioxide from the lime kiln), purification and concentration stages to isolate the sugar from juice. The juice is then boiled. After boiling, evaporation is provided to increase the concentration of the juice. The syrupy juice is then sent through a centrifuge to separate the crystals from the syrup. The sugar crystals are removed by a centrifuge and the liquid recycled in the crystallizer stages. The white crystals must then be packaged. Figure 1.1 summarizes the process briefly. After the process ends, there exists a liquid form and no more sugar can be economically removed from this liquid. This liquid is called as molasses and used in cattle food and alcohol production.

Sugar has a spectacular superiority in terms of foreign market value among the alternative products that base on agriculture. Therefore, during the packaging of this valuable product, weighing should not be allowed to be performed incorrect.

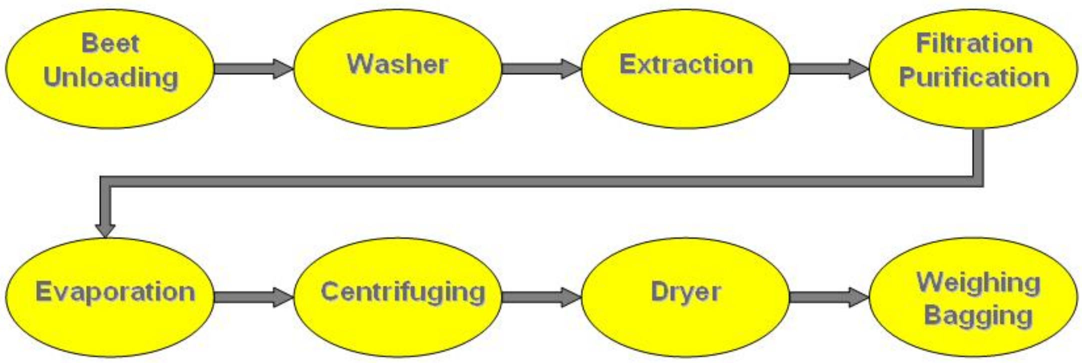


Figure 1.1: Fundamental process of sugar production

1.3. Weighing and bagging machine

The bagging, storage and loading of sugar has traditionally been a considerate and time consuming operation. In early days of the sugar factories mechanical weighing machines are used to weigh the crystal sugar but approximately sixteen years electronic weighing machines take the place of mechanical ones. Electronic weighing and bagging machines are faster and more accurate compared to mechanical weighing and bagging machines. The name of the weighing and bagging machine used in the sugar factories is KNT 93A Electronic Weighing Machine and it is intended for quick measurement and dumping of consecutive weights. It is suitable for measuring bulk materials. It has four main parts and these parts are showed in Figure 1.2. Four parts are:

- Feeder
- Weigh hopper
- Bagging hopper
- Bag clamp

Weighing cycle starts after giving necessary feedings to the system with a command signal that comes from air pressure and sugar level sensors. The cycle begins with coarse weighing after then fine adjustment starts for accurate weighing. Bagging hopper operates with the command signal from bag clamp which senses the bag. After sugar flows from bagging hopper, weigh hopper closes itself and gets ready for a new weighing cycle. The same operation repeats with a command signal showing existence of bag at bag clampers.

It can be seen from the Figure 1.3 that when 50 kilograms of sugar is weighed and packed, bag is conveyed to a platform scale that is used to weigh the bag statically. Purpose of this operation is to control the bag whether it is filled in correct amount or not. This platform scale works as a verification unit for the accuracy of the weighing and bagging machine. A worker checks the deviation of the weighing and provides the bag remain in desired limits. If the bag weight exceeds the upper limit he takes the excess sugar from the sack. He also completes the sack in case the bag weight is under the allowed limits. After these corrections are completed the bag comes to the desired conditions and it is send to the sewing machine to be closed.

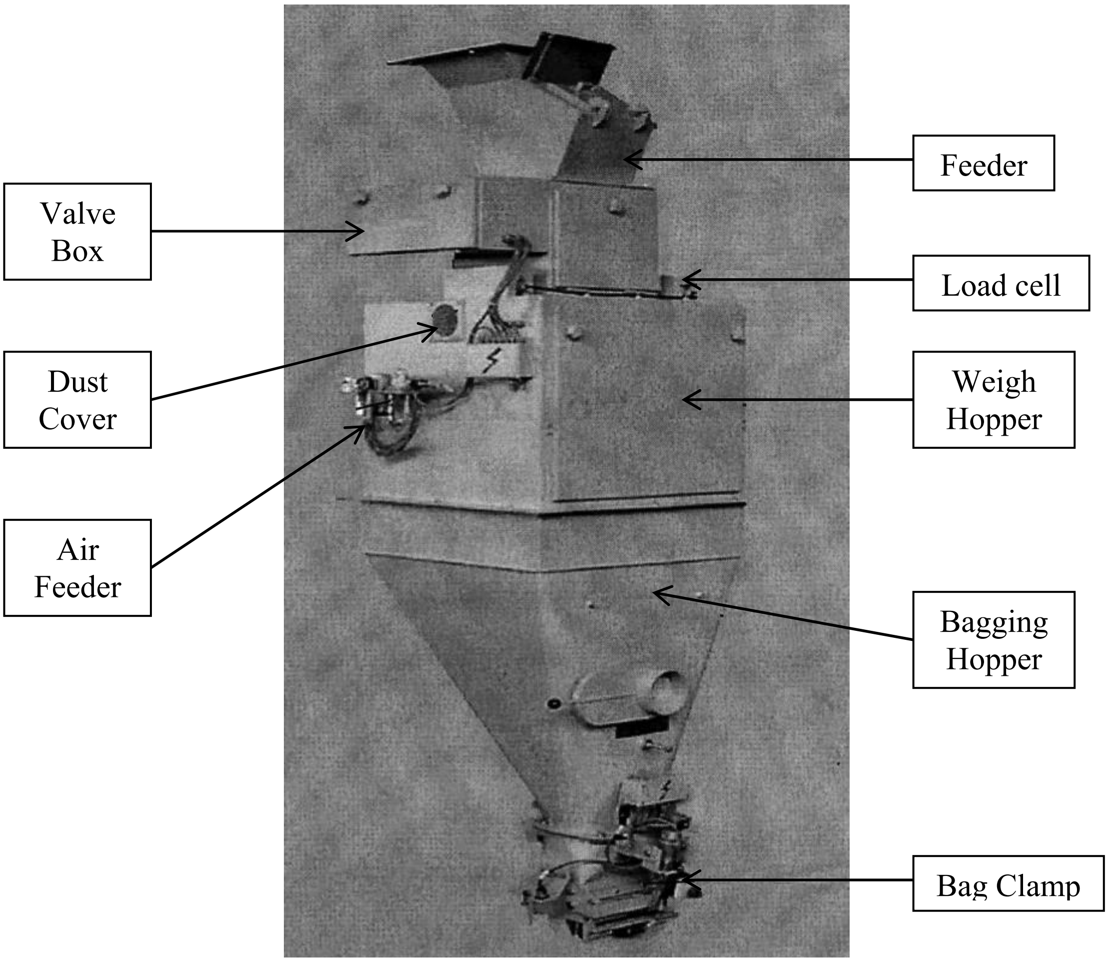


Figure 1.2: EKNT 93A Electronic Weighing Machine

At this stage, it seems that a worker is needed all the time to correct the faulty weighing. This situation prevents the realization of the correction at desired speeds as well as it is contrary to the hygiene application at all the stages of production. In order to be one step closer to the fully automated weighing and packing systems correction should be made without a human interference.

Figure 1.3: Weighing and bagging operation

CHAPTER 2

LITERATURE SURVEY

2.1. Introduction

Until recently –before private sugar factories were put into operation– sugar production has been a monopoly long time in public enterprises owned by TŞFAŞ. The need of all equipment, machinery, measurement tools and system automation was executed by machine factories and EMAF that works within the structure of the sugar factories. That is to say; sugar factories are Turkey's biggest producer of sugar technology itself for a long time. In this sense, sugar factories tried to follow the latest technologies and have been signed to original designs within the facilities. Weighing and packaging machine is one of the most successful works produced in the structure of sugar factories.

Koruk (1994) designed a micro controller based electronic weighing and bagging machine that works fast and makes accurate measurement and also packs consecutive weights. It was suitable for granular materials. This system could take the tare weight of the weight hopper automatically; its software system was written in such a way that, some difficult conditions of the sugar factories were taken into account and it was easy to understand. System was user friendly and gives the required alarms. The calibration of the electronic boards can be made easily. These advantages can be extended, but briefly this system has been used in all sugar factories since it was designed.

A disadvantage of the system underlies to this thesis study. This system cannot compensate the deviations from the target weight automatically. Target weight is checked by a platform scale that is located after weighing and bagging machine. For fixing the deviations a human interference is needed.

In this thesis study a prototype is designed to eliminate the weighing deviations of the weighing and bagging machine by correcting the errors automatically with a system that is independent of human effect. Automatic controlling is provided by PLC hardware, at the same time SCADA software has been added to control the system remotely. This prototype is based on taking away the excess sugar from the sugar bag and completing the deficient sugar. Accordingly, prototype was planned to process the 1 kg of sugar bags instead of 50-kilogram sugar bags because of the simplicity of the assembly and the ease of testing. As regards to the design; a moving small bunker takes the sugar from the bag with vacuuming if the sugar bag has the excess sugar and also when the sugar bag has inadequate sugar in it this bunker provides the filling of the deficient sugar to reach the standard values that was designated by Ministry of Industry and TSE. This whole process was planned to put in practice at the platform scale that follows the weighing and bagging machine.

To achieve the mentioned above various devices were used in the construction of the prototype. For the filling operation a ball valve is used. It is a very common and simple device for directing the way of a flowing substance. Vacuum process was performed by a vacuum generator (venturi ejector). These devices are very practical and functional for generating vacuum. For ensuring the continuity of the vacuum the pressure should be measured. This is provided by the pressure transmitter. Pressure transmitter helps us to see the existence of vacuum and it is useful for checking the value of the vacuum to examine whether the vacuum generator is working properly or not. Controlling the direction of the compressed air is another issue for this study and this is figured out by using different kind of valves such as solenoid valve, directional control valves. As stated before a moving bunker is considered for containing a little amount of sugar to realizing the filling process while it should have a space for the vacuuming process. This bunker’s moving action is provided by the assistance of a pneumatic cylinder. Pneumatic cylinder accomplishes the up and down motion of the bunker. Lastly, weighing procedure remains to be explained.

Weighing and its display are carried out with two devices. Load cell sends the data of weighing and the indicator helps us to see it on the screen. As it is seen, some of these devices are controlled electrically as some of are controlled pneumatically. Directors of all these devices are the PLC hardware and SCADA interface.

From the literature survey it has become clear that there is no such a study that was made like this one, but there are studies about conveying food with vacuum pressure or gripping technology that works with vacuum also PLC hardware and SCADA interface controlling has been used in all kind of industrial applications.

Granulated sugar or sugar-like substances in the structure, has been moved by help of the vacuum from one location to another with air transport that is also known as pneumatic conveying. Pneumatic conveying systems are basically quite simple and are eminently suitable for the transport of powdered and granular materials in factory, site and plant situations. With vacuum systems, materials can be picked up from open storage or stockpiles to another. A vast range of food products from flour to sugar and tea to coffee are conveyed pneumatically in numerous manufacturing processes [4]. A simple scheme is given in Figure 2.1 to explain the logic of pneumatic conveying. This system resembles structurally to the vacuum suction part of this study.

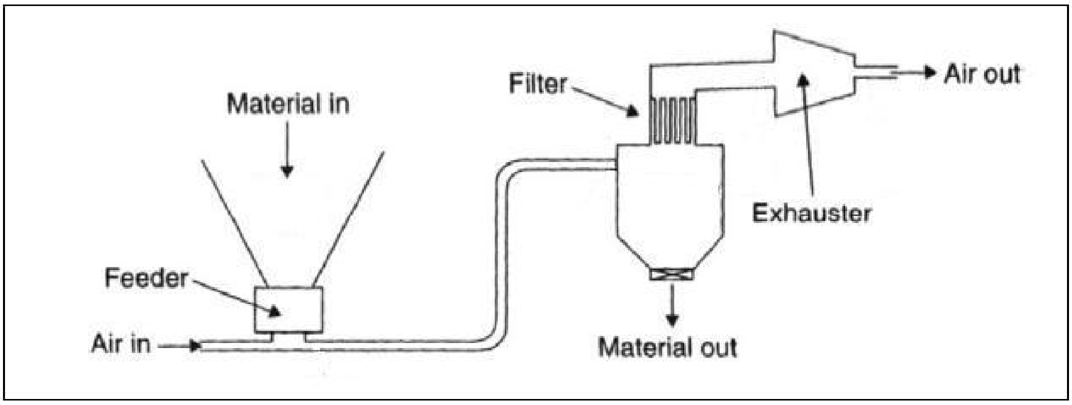


Figure 2.1: A simple pneumatic conveying scheme [4]

Besides pneumatic conveying, vacuum technology has been used in handling food products and lots of studies are still being carried on about it. Usually vacuum is used in handling with grippers in robot arms. A method to select gripper principles for the handling of substances according to material properties was presented in [5]. In this study also suction forces were given for different situations and general planning procedure for process planning and system design is explained.

Y. Qiao, H. Bu [6] gave a critical formula to determine the suction force without considering the influence of air viscosity. They made a study to find the optimum suction force to hold fragile material; microprocessor. Although this formula is given to calculate the suction force on vacuum pumps it is used in this study.

Ludwig [7] describes the vacuum ejectors and enumerates the advantages of using these types of low pressure generators for producing economical vacuum conditions. Ejectors can handle wet, dry, or corrosive vapor or air mixtures and develop any reasonable vacuum needed for industrial operations. All sizes are available to match any small or large capacity requirements and their efficiencies are reasonable to good. They have no moving parts, hence, maintenance is low. They operate quietly and installation costs are relatively low when compared to mechanical vacuum pumps. Space requirements are small and also their simplicity is an advantage. As a venturi device, ejectors are said to offer a cheap and simple alternative to a vacuum pump [8].

As stated before all the devices that used in this study is controlled by PLC hardware and SCADA interface. They are the heart of an automation system and automation plays a big role in industrial applications. It is an engineering approach which is a source of advancing production and increasing efficiency. Companies always want to product the output in a serial manner with minimum error and without human touch. One of the reasons of automation usage in food industry is human health. Some of the driving influences encouraging the development automation in food production stem from human contact with the product (Khodabandehloo and Clarke, 1993). According to Trickett (1992), every year thousands of people suffer from food poisoning as a result of eating food that may look, taste and smell perfectly normal but is in fact contaminated with large numbers of harmful bacteria. In order to reduce this number, people should be removed from the food preparation and handling environment [9].

2.2. Standards about bagging

TSE 861 [10] is a national standard about white sugar (crystal, cube and powder). It includes the classification of white sugar, sampling, inspection, testing and placing on the market. At the same time as a subtitle it declares the packaging and gives the details of packaging of white sugar.

According to TSE 861, crystal sugar should be supplied to the market in a certain weight. If the weight is less than or equal to 5 kilograms, the amount of deviation must be ±0.5% and if it is greater than 5 kilograms, the amount must be ±0.1%. For 50-kilogram bags it can be seen clearly that the deviation should be ±50 grams. However if we glance at the regulations of Ministry of Industry [11], it can be seen that allowed deviation for X class weighing machines should be ±0.053% for keeping CE sign. This corresponds to approximately 27 grams for 50-kilogram sugar bags.

Although it has been mentioned in TSE 861, deviation is arranged about ± 30 grams per 50-kilogram bags at the weighing and bagging machines in sugar factories to keep in view the regulations of Ministry of Industry. In this thesis study, all the calculations are done considering the deviation about 30 grams per 50-kilogram sugar bags.

2.3. Objective of the Study

The main purpose of this thesis is to design a prototype for improving the weighing accuracy of the weighing and bagging machine that used in sugar factories. Figure 2.2 represents the prototype.

Any weighing application's accuracy increases as the consistency of the production factors and the product flow rate increases. However, product flow rate cannot be constant sometimes. To explain; granulated sugar products are basically masses of single sugar crystals and are differentiated by the size distribution of the crystals. The sugar refining process produces these crystals to be free-flowing by conditioning the sugar to remove almost all the free moisture [12]. In the sugar factories sugar is produced at a rate of 0.2% moist. However, sometimes some disruptions in the production line prevent producing regularly and then moisture increases. Rising of the moisture obstructs the weighing accuracy. Also changing density of the material or not obeying to the user guides of the machine affects the speed and accuracy performance of the machine and faulty weighing can be seen. If the flow rate or the density of the material changes, a new adjustment is needed. Changing the target weight setting is a much more complicated and tedious operation and it takes a lot of time. Not obeying the using guides of machine can cause it break down and an experienced technician is needed for finding the failure in a short time [13].

Weighing equipment does not make the packaging beyond the desired range all the time. When several factors come together as inconstant conditions of the factory and misbehavior of employees, weighing and bagging machine losses its accuracy and begins to fill the bags with excessive or less quantities. This prototype bases on fixing the incorrect weighing of weighing and packing machine because of aforesaid factors. It will work as a kind of quality control unit for weighing.

Before actual product or mass production, production of the prototype was executed to achieve the best performance according to elements such as ease of installation, economy, quality, durability, and aesthetics. Moreover, it is designed such that modifying could be done easily. After the installation the system’s performance is easily monitored and the results are clearly revealed.

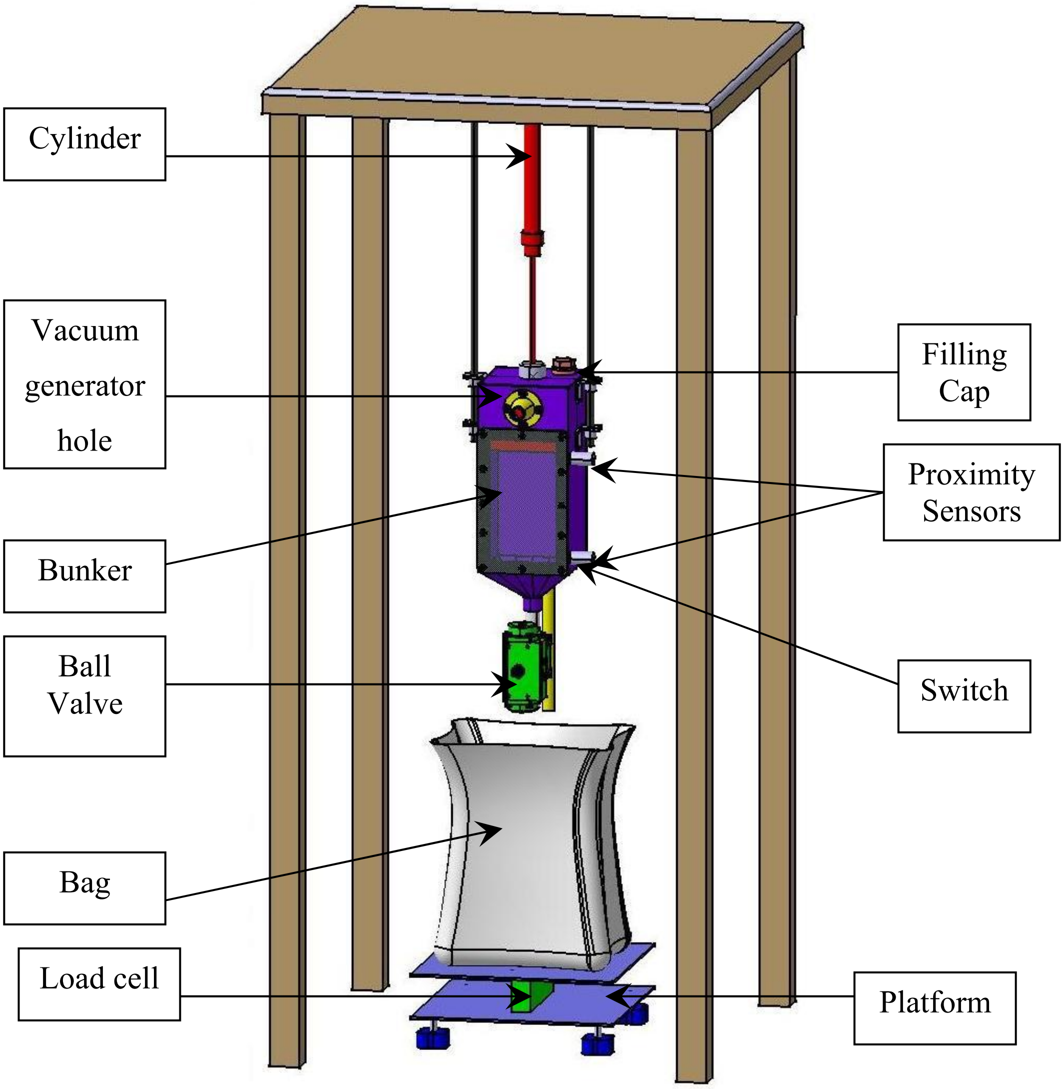


Figure 2.2: Prototype for weighing and bagging machine

CHAPTER 3

MECHANICAL and ELECTRICAL COMPONENTS

3.1. Requirements of the Prototype

Shortly to explain, prototype is made for improving the weighing accuracy of the weighing and bagging machine. It takes the excess sugar from the bag also it fills the deficient bags. Extraction and filling process is provided by a small bunker that is designed with data obtained from statistical analysis. The vacuum suction is provided for extraction, while a ball valve is used for filling. Moving down and upward of the bunker is ensured with the help of a pneumatic cylinder and finally weighing information is obtained from a load cell. An indicator is used to display the weighing value that comes from load cell. All opening and closing, taking measurements or motion control of these devices has been made with PLC hardware and SCADA interface.

Although it can operate at a speed of 12 bags per minute, suggested weighing speed for weighing and bagging machine is 8 bags per minute. Accordingly, this prototype should complete the operation in 8 seconds. Operation cycle starts with downward motion of the bunker, it is followed by extraction or filling of 1-kilogram bag. At this moment weighing should be completed and finally upward motion accomplishes the cycle.

This prototype should be usable to the greatest extent possible by every worker, regardless of their ability and duty in the factory. Briefly it should be user friendly. However, changing of the software part must be avoided. For this, software must be encrypted, except the basic usage sections.

System should not go into shutdown without completing any measurement and verification. Also, system should give necessary alarms. It could be stopped in case of emergency situations.

For ensuring the continuity of the vacuum, the pressure should be measured and reflected to the screen. Checking the value of the vacuum pressure is useful for controlling the existence of vacuum. In an emergency case, like electricity or air cut off, system should be able to return to the starting position.

3.2. Design process

To clearly understand the aim of this study, background of the sugar weighing and packing system is explained in Chapter 1. The main purpose of making a study like this one is fixing the faulty weighing of weighing and bagging machine that used in twenty five sugar factories all around Turkey. For starting simply; input and output relations of the prototype and the composition of process is given in Figure 3.1.

Before starting to design this system, it is decided exactly what will be made and then appropriate action for this request is intended. The definitively aim of this study could be expressed as ***‘to achieve as possible as zero error rate by correcting the incorrect weighing according to the standards’***. Shown above in Figure 3.1 series of a simple process is intended then appropriate device selection for processes is realized. As described in the literature survey such a system has not been designed for this type of operation previously, devices that are irrelevant to the subject are taken into account. However, the details will be explained.

First, two important questions arise about the system’s mechanical design. The first one is how to add the deficient sugar to the sack; the second one is how to move away the excess sugar from bag. Begin with; the first question is brought up to discussion. Frequently used in industry for filling operations valves are considered to be ideal elements for opening and closing.

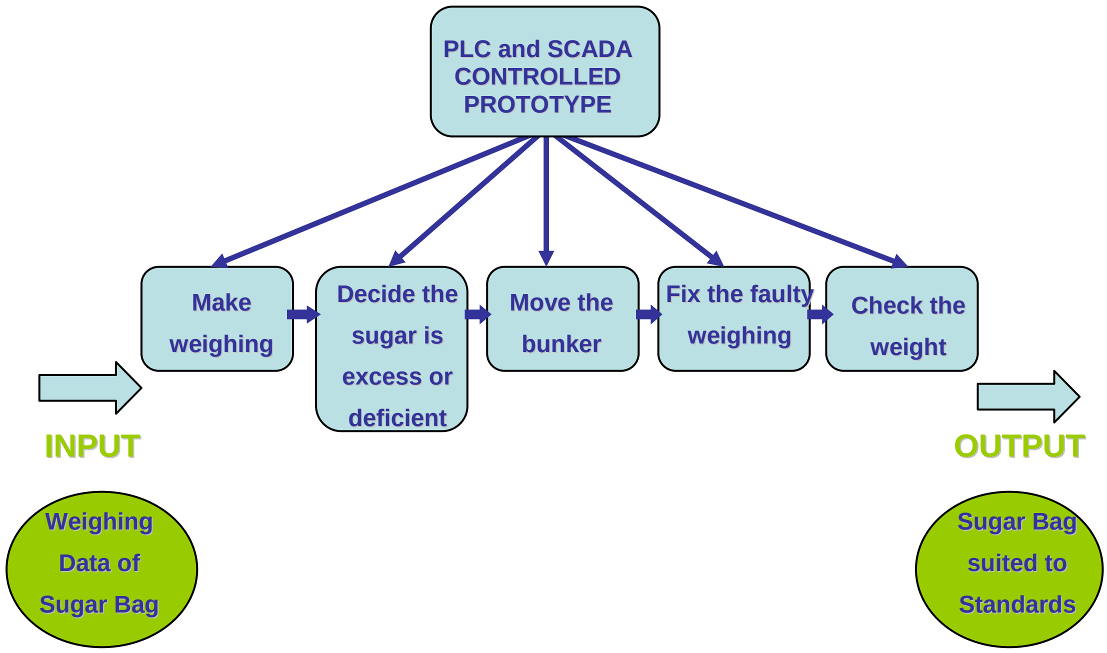


Figure 3.1: Composition of the process and input and output relations

Literature survey shows that some types of valves will not be suitable for this work. For example; a very popular device for this type of operations is a butterfly valve. However, it cannot get enough power to actualize the opening and closing action when used with small actuators. Whereas it is thought to be necessary to use small parts because the prototype is also small. A survey on available valves in the market shows that, the most appropriate device for this study is ball valve, then carrying sugar crystals with this type of valve is discussed with valve manufacturers and ball valves appear convenient for this type of materials and it is also appropriate using with small actuators.

The solution to the above-mentioned second question is more complex and more challenging. Taking the excess material in a container is realized usually through spirals. In fact, spirals are generally used for conveying materials. Many examples of this are available on the market.

Figure 3.2 shows an application of a spiral conveying of raisins from bottom to top. However, in the working logic of spiral, spiral should dive into the material that will be removed from field. So; if the excess sugar in the bag is to be taken with a spiral, spiral would dive into the sack to lift the sugar and it would apply an amount of weight to the bag. This weight could be compensated with various adjustments but cost of engine to run the spiral would raise the first investment and also maintenance costs for an engine would be higher, so another solution is needed.

Figure 3.2: An application of a spiral conveying

Pneumatic conveying issue has been examined which is generally used for transporting large amount of powder and it is understood that pneumatic conveying can be applied for this study. As stated in literature survey; granulated sugar or sugar-like substances in the structure, has been moved by help of the vacuum from one location to another with air transport and that is known as pneumatic conveying. Same vacuum logic is used in this study. To take the excess sugar it is decided to use vacuum. However, separating the vacuumed air from sugar appears as a problem here. So, other mechanisms that use vacuum or work with vacuum are investigated.

Although being a radical example, required answer is found after examining milk pumps used by women who give birth. That application does not seem relevant to the subject but these devices separate milk and vacuumed air from each other. A simple wall which behaves like a filter passes the air but not milk. This gives an idea of placing a wall to the bunker like in milk pumps. The problem has been eliminated by placing a thin metal plate attached to serve as a wall in the bunker. Considering all this explained issues the components to be used and various computer programs has been decided as shown in the Figure 3.3.

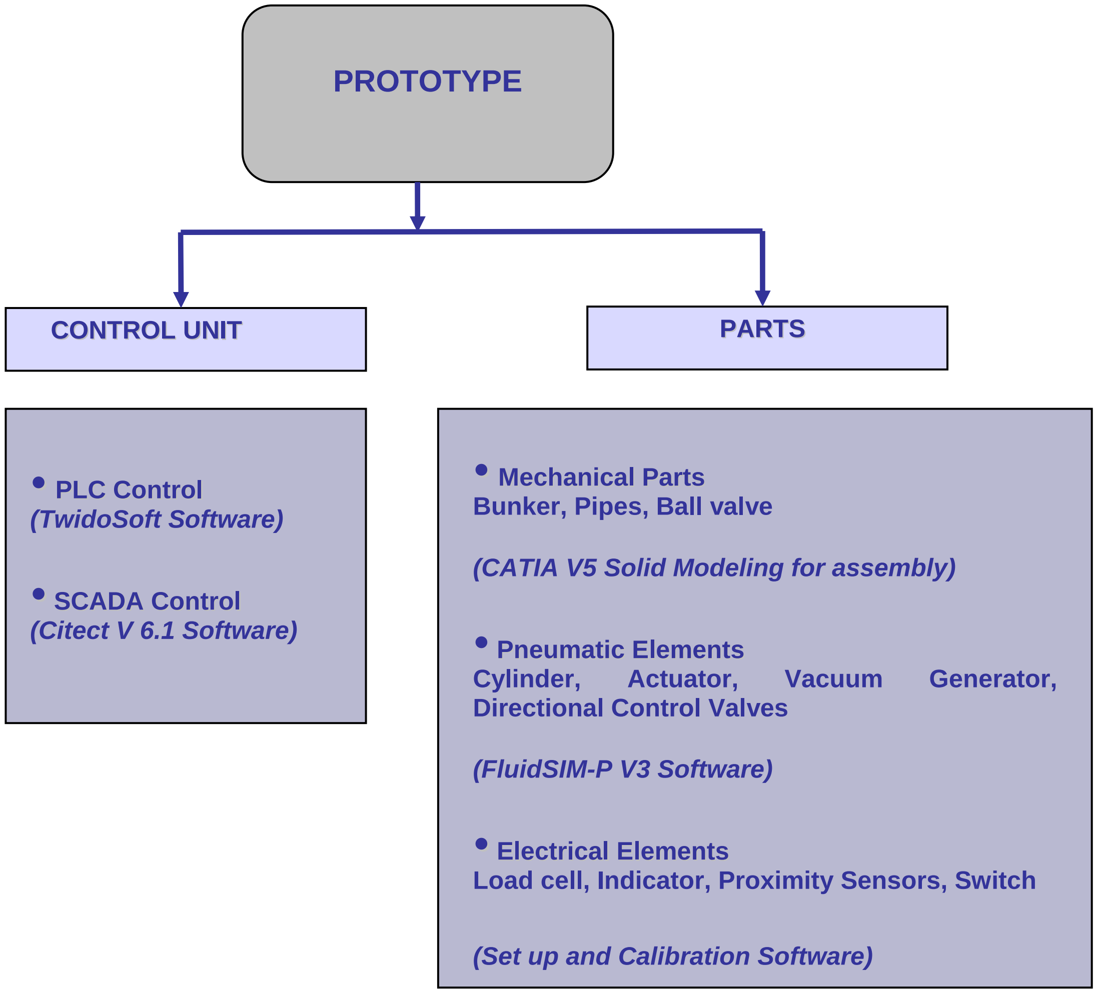


Figure 3.3: Components of the prototype and software used

It can be understood from the Figure 3.3 given above that, PLC hardware and SCADA interface is found appropriate for the control unit. Frequently used in industrial areas, this twosome is the method for controlling the system without human intervention.

In this study, the device is not developed only for the research purposes, but also it is planned to use as an active machine in twenty-five sugar factories. Therefore beside the main purpose, achieving as possible as zero error rate, some other approaches are thought. Following Table 3.1 shows the other design objectives. The scope of the next subject will be devices those meet the requirements for design goals.

Table 3.1: Design Goals

List of Design Goals
Accuracy
Resolution
Computer interface
Ease of use
Easy maintenance

3.2. Statistical analysis for the design of the bunker

Dimensions of the moving bunker that belongs to prototype are designed after the statistical analysis. There hasn't been any information about the amount of incorrect packing of weighing and bagging machine. No body knows the amount of excess sugar or amount of deficient sugar. However, this information is needed for designing the bunker that makes the process of extraction and filling.

Again to remind briefly, the duty of the bunker is taking excess sugar and completing the deficient one if necessary. Thus, a certain amount of free space should be provided to maintain the sugar sucked from the bag. Besides, in the task of completing the deficient sugar, bunker should keep the sufficient amount of sugar. The blank space that the bunker should have, analyzed by sacks that packed with excessive quantities. At the same time, bunker's required space that should be filled with sugar has been calculated by taking into consideration of incomplete sacks.

During the campaign periods sugar factories works 24-hour continuously. Job of collecting the necessary information has been started with considering no interference to the bunker along two hours. This means that; four interventions will be done during the 8 hours shift. This time can be increased or decreased by making the bunker bigger or smaller.

As stated before, weighing and bagging machine is able to pack 0 – 12 bags per minute. Under consideration of optimum conditions the machine is assumed to make package 8 bags per minute. In this case, it reveals that 960 sugar bags are filled within 2 hours. This study contains weighing measurements that were recorded 8 times along 2 hour shifts to expand the database. This means that 7680 bag is examined.

It is impossible to consider each data individually so statistical analysis is used to deal with these piles of number. Also statistical analysis helps us to see patterns. So, necessary information is written down over 7680 sacks during 16 hours. The statistical analysis is performed according to above 16 hours weighing and bagging information. The purpose is to make the raw information easier to understand. Packaging information is provided for the 7680 sack is given below on Table 3.2.

After these results are taken the following two graphics are created. According to these charts in positive difference 32 grams, in negative difference 8 grams are the most repeated values. Although these two values have a high percentage of iteration the calculated average values appears to be very different.

Table 3.2: Packaging information for 7680 sacks

# of bags that remains within the allowable limits ± 30 grams	**# of bags that remains above the allowable limit + 30 grams**		**# of bags that remains below the allowable limit -30 grams**	
2166 bags	8 grams	1600 bags	2 grams	69 bags
	18 grams	486 bags	12 grams	61 bags
	28 grams	335 bags	22 grams	51 bags
	38 grams	227 bags	32 grams	421 bags
	48 grams	249 bags	42 grams	56 bags
	58 grams	762 bags	52 grams	32 bags
	68 grams	156 bags	62 grams	23 bags
	78 grams	57 bags	72 grams	12 bags
	88 grams	98 bags	82 grams	85 bags
	98 grams	194 bags	92 grams	15 bags
	108 grams	516 bags	102 grams	9 bags
Sum		4680 bags		834 bags
TOTAL # OF BAGS = 7680				

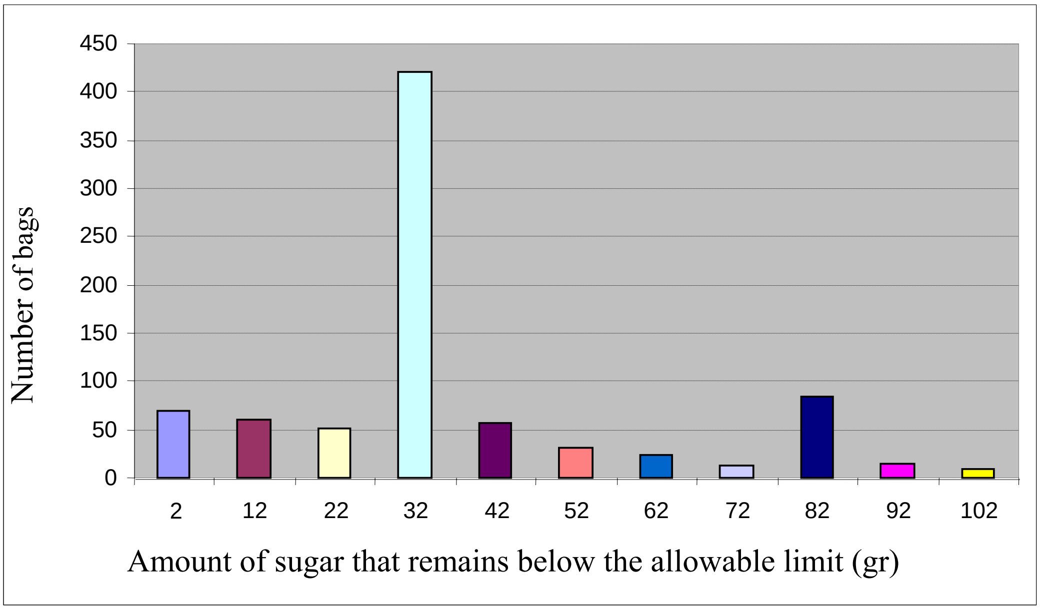


Figure 3.4: Graph of negative difference

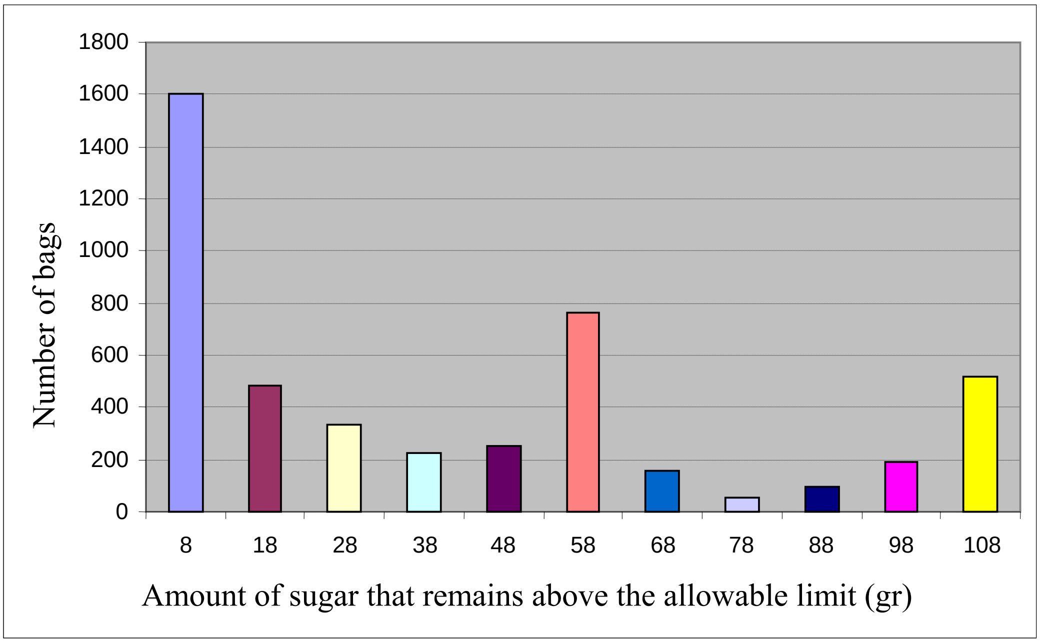


Figure 3.5: Graph of positive difference

Before describing how the calculations were done, sacks that are used for packing the sugar are thought to be necessary to mention. It is obligatory to take into account of the weight of the sugar bag in calculations. Sacks that used for packing the sugar are made of polypropylene and they are manufactured within the allowed weights. Weight limits of the bags are determined by the specifications of the sugar factories. If these specifications are examined it can be seen that the allowable limit for the weight of sacks changes between 115 – 108 grams. Sacks that have a weight outside of this limit is rejected and not used. For this study, the average weight of the bags is taken as 112 grams.

To explain Table 3.2 it must be told what was done before creating this table. After weighing and packing machine, bags are referred to the platform scale. From this platform scale the weight data of the sugar is read and noted. It is known that these values represent the sum of bag and sugar weight. Assumed average weight of bag 112 grams is subtracted from the read value. This value gives us the information of the explicit weight of the sugar in the bag. Calculations are made to understand how much this explicit weight differs from the allowed limits. The number of sacks and their difference from +30 grams are given in the second column of the Table 3.2, and the number of sacks and their difference from -30 grams are given in the third column of the Table 3.2. Lastly, the first column represents the number of bags that stays in the limits.

To give an example, let's assume that the weight of a sack at the platform scale has been read as 50200 grams. The weight difference is 200 grams here. If the weight of the bag 112 gram is subtracted from this value 88 grams is obtained. This is the explicit amount of sugar that is excess in the bag. According to the allowed limits; deviation from the +30 grams is 58 grams. Likewise, for one of the negative values, if necessary, for example, let's assume that the weight of a sack of platform scale has been read as 50000 grams. This indicates that the excess sugar is zero. If the sack weight is subtracted from zero, -112 gram is revealed. This is the explicit amount of deficient sugar in the bag. According to the allowed limits; deviation from the -30 grams is 92 grams. If the second and third column of the Table 3.2 is examined these values can be read.

Table C.1 and Table C.2 in Appendix C is created by performing calculations for the bags that remain above +30 grams limit. Arithmetic average method is used when the calculations are made. For the negative difference and for the positive difference the same method is performed. The bags that remain above and below the allowed limits are evaluated in their selves and a reasonable average value has been found.

From Table C.1 and Table C.2 it can be seen that mean value is about 41 grams and standard deviation is about 34 grams. These two values will be used for calculating the blank space of the bunker.

In practice, generally data is assumed to come from a main mass that shows approximately a normal distribution. According to the central limit theorem, the sum of quite a few random variables that are independent from each other and have a same distribution tend to a normal distribution on the limit. If this assumption is valid, as shown in Figure 3.6, 68.2 % of likely values are located between the points plus and minus one standard deviation from the average [14]. This means that the correct value will be in the range of 7 grams and 75 grams with the probability of 68.2%. For making more assuring assumption 75 grams of exceeding is taken as a result. At this stage, the blank space of the bunker could be calculated.

If the worst-case scenario is considered -namely every packing is made faulty during 2 hours with exceeding values-the calculation should be done by multiplying the bag number in 2 hours with 75 grams. Result of this product is 72000 grams. However, this calculation is only valid for 50-kilogram sugar bags. In this study prototype is made for 1-kilogram bags. If the result is divided by 50 the blank space that should be available in the bunker is calculated as 1440 grams. The density of crystallized sugar is 1.586 kg/m^3 at 20 C° [3]. Finally the volume of the blank space appears to be approximately 908 milliliters.

Same calculations should be done to for the bags that remain below -30 grams limit. As mentioned before, arithmetical mean method is used. Table C.3 and Table C.4 in Appendix C shows the number of bags (frequency column) that differs from the limit of -30 grams and their amount of difference (values column).

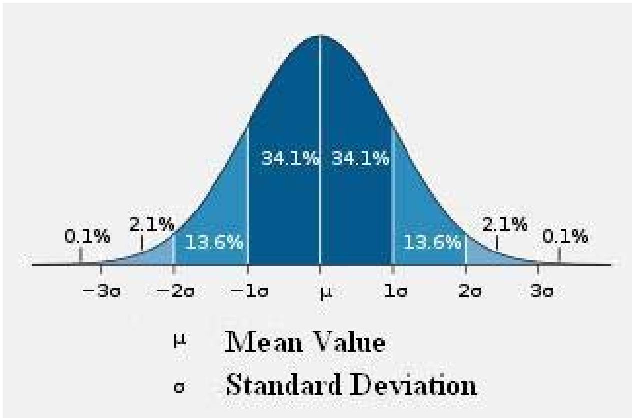


Figure 3.6: Normal distribution of data

Table C.3 and Table C.4 show that the mean value is about 37 grams and standard deviation is about 23 gram. With the probability of 68.2% the values would change in the range of (mean value – standard deviation) and (mean value + standard deviation). This means that the correct value will be in the range of 14 grams and 60 grams. For making more assuring assumption 60 grams of difference is taken as a result. Now the sugar volume which the bunker should have in it can be calculated.

As done before, if the worst-case scenario is considered -namely every packing is made faulty during 2 hours with negative exceeding values-the calculation should be done by multiplying the bag number in 2 hours with 60 grams. Result of this product is 57600 grams. If these numbers are adapted for 1-kilogram bags, result appears as 1152 grams. Density is 1.586 kg /m3 at 20 C° so the volume of the sugar mass is approximately 726 milliliters.

3.3. Mechanical and electrical components that forms the prototype

3.3.1. Bunker

Calculations in the statistical analysis show that total volume should be 1634 milliliters for the bunker. However, for the safety, 20% of the volume is added to total volume. This makes the volume of the bunker approximately 2000 milliliters. Photograph, construction and the dimensions of the prototype, drawing of the assembly are given on the Figure A.5 and Figure A.6 and Figure A.13 at Appendix A. The plate that is explained in the design process part can also be seen from these drawings. To remember; a thin metal plate is attached to serve as a wall in the bunker to separate the sugar and vacuumed air. Photograph of the bunker is shown in Figure 3.7.

Figure 3.7: Photograph of the bunker

3.3.2. Suction

Until the mid-17th Century, the existence of a vacuum in nature had been a philosophical question, revolving around ancient arguments, which regarded a vacuum as; "abhorrent to nature". A contemporary of Galileo, Evangelista Torricelli (1608 – 1647), is recognized as the first man to create a sustained vacuum with his invention of the barometer. The development of the vacuum pump, however, resulted from work done in hydraulics and pneumatics, notably by Blaise Pascal (1623 – 1662), the inventor of the hydraulic press. Following these early advances, the basic design of the vacuum pump hardly changed for 200 years, until the early 19th Century Oil flooded rotary vane vacuum pumps were developed in 1913. Latterly, we have seen further developments in vacuum production [8].

The production of vacuum pressure implies exhaustion of a given vessel by suitable pumping action. The machines used for producing vacuum pressures are known as vacuum pumps. Types of vacuum pumps are:

- Radial blowers
- Side channel
- Rotary lobe (Roots)
- Claw pumps
- Dry running screw pumps
- Rotary piston pumps
- Ejectors (venturi devices)
- Liquid ring pumps

The working pressure to be produced or maintained in the system determines the type of pump required and also the pump-down time has to be considered when deciding on a suitable pump size and balanced against other operational factors such as the work cycle. Other criteria for selecting the type of the pump are; running costs (electricity, compressed air, steam), cooling; sealing fluids/lubricants, waste disposal and effluent treatment, capital cost of the equipment, reliability, environmental impact and finally available space. Understanding the process itself is also a key aspect of supplying vacuum systems.

In this study compressed air is used to generate vacuum using a venturi; in other words ejectors are chosen to produce vacuum. Venturi devices are referred as a few names; ejectors, vacuum generators, ejector vacuum pumps, venture-style vacuum pump and compressed air ejectors. These devices are reliable, compact, lightweight and quiet. They have no moving parts and can be mounted directly on production machinery. Their maintenance requirements are minimal. They are widely used in industry. Packaging applications, material-handling systems, pick-and-place operations are some examples of the applications. Their simplicity and reliability makes them the favored method for many automation applications.

Vacuum generators produce vacuum by passing high-velocity compressed air through a venturi or nozzle. As shown in Figure 3.8, compressed air A is blown through nozzle D and this causes a depression at C then air flows C to the atmosphere at B. Simply this is working principle of vacuum generators. As it is understood compressed air is needed to work with venturi devices.

Performance depends on the nozzle’s shape and size, compressed air pressure and flow, and the desired vacuum level. Steam, vapor, water and other liquids can be used as a motive fluid, too. Vacuum generators should be mounted in close proximity to the point-of-use, with supply tubing connecting the vacuum device to a central compressed air system, to prevent the pressure loss and reduce the volume of piping to be evacuated.

In this study BOSCH REXROTH EBS series vacuum generator is used. It can be seen in Figure 3.9. Its control is provided pneumatically and it has a silencer at the exhaust part. The graphs of the vacuum generator (Vacuum value depending on working pressure, suction capacity q_s depending on working pressure, air consumption q_v depending on working pressure, evacuation time t_E depending on vacuum for 1 liter volume) are given in Appendix A with Figure A.1, Figure A.2, Figure A.3 and Figure A.4. The term ‘air consumption’ refers to the compressed air the vacuum generator requires. ‘Maximum suction capacity’ describes the amount of air that will be sucked from the suction part at optimum working pressure.

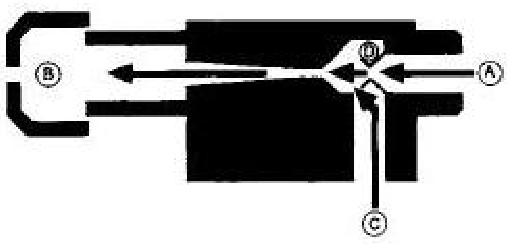


Figure 3.8: Vacuum generator scheme

Here are some technical data about this vacuum generator:

Nozzle diameter	: Ø 2 mm
Maximum vacuum level at optimum pressure	: %85
Maximum suction capacity	: 123 l/min
Air consumption at optimum pressure	: 208 l/min

White sugar composes of many granules. The size of the granules changes in a range of 200 – 500 microns. Values under this magnitude are referred as sugar powder [3]. Accumulation of powder can block any small hole. Nozzles that located in vacuum generators are also small holes and produced very delicately. Thus, necessary care must be given to nozzle holes. Blockage of this sensitive part means that it can’t be possible to use the device again.

Figure 3.9: Vacuum generator

Pollutant particles are measured in microns and the filter sensitivity is given in a similar way. Here, a 5-micron fabric filter fitted to the mouth of the suction port to protect the device from sugar powders. A special slot is made for replacing the filter easily when it is clogged.

Two important reasons for choosing this type of generator are that nozzle's diameter is relatively larger size than the others and comparatively less evacuation time. Despite the filter usage, nozzle diameter may be chosen beyond the needs. However, this selection results with the rise of the suction force and unfortunately increase of the air consumption. Evacuation time is also important because for completing the whole operation in a short time is required such as 8 seconds.

A simple way to estimate the suction force is to use the following equation:

$$F_s = \Delta P * \pi * \frac{d^2}{4} \quad 3.1$$

where F_s is the suction force without considering the influence of air viscosity, ΔP is the pressure difference, and d is the diameter of the suction hole [6].

The vacuum pressure measurements performed in EMAF's measurement control workshop. At those measurements, absolute pressure in Ankara emerged as 914 mbar. Meantime, pressure transmitter is placed in the ending of the suction hole of the vacuum generator. As shown in Figure A.1 at Appendix A, at the working pressure of 4.5 – 5 bars, it creates 150 mbar vacuum pressures. Pressure transmitter confirmed this value. These pressure values are necessary to find the pressure difference. Dimension of the suction hole is needed also to calculate the formula given above. It is the diameter of the suction part of the vacuum generator and it is 8 mm. After all the values replaced the suction force appears to be 3.875 N. It is clear that with this force 395 grams can be lifted.

3.3.3. Vacuum Measurement

Vacuum technology includes all systems utilizing a pressure less than atmospheric. Vacuum systems operate with pressures below atmospheric pressure. There are three distinct ways in which pressure is measured. Some pressure transducers or transmitters measure the pressure difference between two input ports. This is known as ‘differential pressure’. In some transmitters low pressure input port is open to atmosphere, so the pressure transmitter indicates pressure above atmospheric pressure. This is known as ‘gauge pressure’, and is usually denoted by a ‘g’ suffix. The pressure transmitter measuring pressure with respect to a vacuum is known as absolute pressure transmitter [15]. In this study this type of pressure transmitter is used.

Alternatively, vacuum is quoted as a percentage of atmospheric pressure, in which case the percentage is numerically equal to the vacuum pressure in kPa. Thus 85% vacuum is equal to a pressure of 150 mbar. The common metric unit for vacuum measurement is the mbar.

To check the continuity of the suction pressure which is necessary for the taking the excess sugar, pressure measurement must be done. In this study APLISENS Smart Pressure Transmitter Type APC-2000 ALW is used for vacuum measurement. It measures the absolute pressure as defined above and its photograph is shown in Figure 3.10.

Some technical data about the pressure transmitter is given as follows:

Nominal measuring range	: 0 – 1 bar (0 – 100 kPa)
Output signal	: 4 – 20 mA
Power supply	: 12 – 55 V DC
Accuracy	: ≤ ± 0.075% of the calibrated range

Figure 3.10: Pressure transmitter

3.3.4. Solenoid Valve

Solenoid valves are used in fluid power pneumatic and hydraulic systems, to control cylinders, fluid power motors or larger industrial valves. Solenoid valves offer fast and safe switching, high reliability, long service life, low control power and compact design.

In this study, the solenoid valve is used to control the air that provides to activate the vacuum generator. Vacuum generator is able to continue vacuuming as long as compressed air is provided. To stop the generator cutting of the compressed air is required. Image of which shown below in Figure 3.11, solenoid valve opens when it is energized and close when the energy is cut off. Some technical data about the solenoid valve used is given below:

Orifice size	: 5mm
Pressure min/max	: 0 – 7 bar
Standard voltage	: 24 V DC

Figure 3.11: Solenoid valve

Solenoid valves consist of two parts; solenoid that provides movement and valve that performs movement. Working principle is quite understandable. There is a diaphragm available in valve. Closed diaphragm means fluid cannot pass through the section, contrarily open diaphragm designates the free flow of the fluid through the valve. The thing that provides the diaphragm to be switched on and off is a spring mechanism.

'Normally closed' valves are automatic valves that do not allow air to flow unless external influences cause the valve to open. If the type of the valve is 'normally closed' then spring will enables a pin to close a path which supplies a way to the fluid to reach the diaphragm. Because of this, valve remains closed. When solenoid is energized, spring moves backwards and allows the path filled with fluid. Fluid pushes back the diaphragm so the valve becomes an open state.

3.3.5. Ball Valve

Ball valves are valves that control air by using a ball that rotated through a hole in the middle of it. The fluid flows freely through the valve when the hole is aligned and when the ball rotates and the hole is not aligned the fluid flow is stopped. It is named for the ball that rotates. They are used in many areas due to their ease of repair and ability to withstand pressure and temperature. The ball valve, along with the butterfly valve and plug valve, are part of the family of quarter turn valves. This means that a ball valve requires only a quarter turn to open and to close. Some ball valves are equipped with an actuator that may be pneumatically or motor operated.

Figure 3.12: Ball valve with pneumatic actuator

There are both strengths and weaknesses of one valve type against another when comparing designs and their intended application but ball valves are excellent choice for shutoff applications and also they do not tend to develop problems if they are not used for long periods of time. Also they are cheap and easily obtainable.

In this study SMS – TORK T – KV903 Serial Stainless Steel Body ball valve is used with T-RPA 32 DA type pneumatic actuator. Actuator's air is supplied with a 5/2 directional control valve. PLC control unit ensures the opening and closure of the ball valve through this 5/2 directional control valve.

Ball valve is threaded and it is dimension is 1/2". It works with 4 – 8 bar pressure.

Pneumatic actuator is double-acting type. It consumes 0.09 – 0.16 cm^3 air and opening and closure time is 0.22 – 0.26 seconds. Directional control valve is 1/4"-5/2 single solenoid and 24 V DC.

In addition to the one described above, the most important reason for choosing this type of valve in this study is that ball valve complies concordantly with the prototype design. Under the conditions of small produced prototype and loosing of balance with the excess weight, using of a light-weighted type valve is necessary. In this respect, the selection of ball valve has been very suitable. Otherwise, dimensions of the actuator should be taken into account. Its weight also should be light. Ball valve actuators are mounted close to the top of the valve and the stroking runs parallel to the piping. Compared to other valves this height difference makes an advantage in weight and also in image. Furthermore, to begin the movement, valves like butterfly valve require more torque, while this value is small for ball valves. Therefore, a smaller actuator can be used. Also prototype should complete the operation in 8 seconds in this study. If a really fast closing time is required, a ball valve with only a quarter of a turn to close is the fastest.

In developed countries food production is now being performed using only stainless steel. In order that flow of the sugar in the bunker will be provided through this valve, stainless steel is chosen as the valve material.

3.3.6. Pneumatic Cylinder

Pneumatic cylinders are elements that convert compressed air energy into linear pushing or pulling motion. A pneumatic cylinder is composed of front and back cover, cylinder tube, piston rod and seal. Although very different types of cylinder are available on the market due to the motion type, most commonly used ones are single-acting and double-acting cylinders. Compressed air is effective in one direction in single-acting cylinders. In other words, there exists one hole for air inlet and outlet. In double acting cylinder, resulting force that depends on the air pressure and surface area of the piston moves the piston in either direction.

When selecting a pneumatic cylinder, the most important points that should be considered are its stroke, surface area of the piston face, known as "bore size", pressure and type of connection. Calculations used for the selection of cylinder are given.

Cylinder Force Calculations:

The theoretical thrust of pneumatic cylinders depends on the bore diameter, friction force, seal, and the working pressure no matter the cylinder is single or double acting.

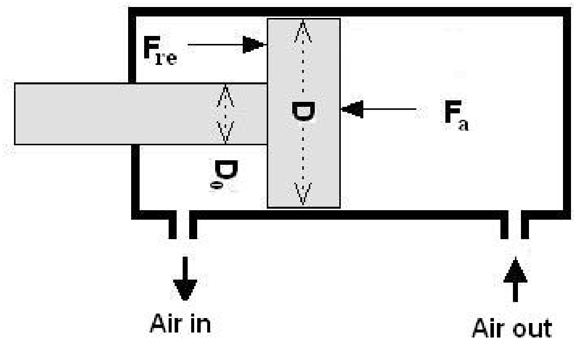


Figure 3.13: Double-acting pneumatic cylinder

The produced bunker and devices that fixed on the bunker weighs about 6.005 kilograms. Also the weight of the sugar that will be filled in (2.615 kilograms) should be added to find the total weight. If it is included, cylinder should carry about 8.620 kilograms. It nearly equals to 85 N. For choosing the cylinder type, bore diameter should be found. If these values are replaced in Equation 3.2 diameter can be found.

Advance Stroke

$$F_a = P \times A - F_r \qquad 3.2$$

where F_a is the thrust**,** P is the working pressure**,** F_r is the friction force, A is the cross sectional area ($A = \pi \times \frac{D^2}{4}$) and D is the bore diameter. However friction force is neglected. So $F_r = 0$

If the numerical values are replaced in Formula 3.2 (P = 5 bar = 5 x 105 Pa, F = 85 N), bore diameter can be found as 14.71 mm. A cylinder which has the dimensions closest to this diameter can be selected.

Return Stroke

Reduction of the force because of the decrement of the piston area due to piston shaft should be taken into account when the cylinder returns. Return force should be examined to find out the sufficiency. 6 mm piston shaft diameter corresponds to 16 mm bore diameter. When cylinder returns:

$$F_{re} = P \times \pi \times \frac{D^2 - D_0^2}{4} \qquad 3.3$$

where, F_{re} is the return force, D_0 is the diameter of bore shaft. From this equation return force can be calculated as 86 N. It seems sufficient for lifting all the weight even if the cylinder returns. However any device can be added to the bunker in the future and also friction force is a factor that should be kept in mind. Because of this reasons bore diameter is chosen as 20 mm.

In this study, FESTO type DSNU-20-160-PPV-A cylinder is used. It is double-acting and pneumatic cushioning is available and adjustable at both ends. Bore diameter is 20 mm, piston shaft diameter is 8 mm, stroke value is 160 mm and it is made of steel as seen in Figure 3.14.

Figure 3.14: Pneumatic cylinder and directional control valve

Directional control valve, ORIGA PA 10312-0033 is used for actuating the cylinder. It is a 5/2 directional control valve with an operating pressure of 2 – 8 bar, its type of actuation is electrical and spring return and it has a standard nominal flow rate of 300 l/min. In industrial applications increasing the number of inputs and outputs is a frequently encountered problem. In this study, in order to minimize the number of inputs and outputs directional control valves are chosen spring returned and appropriate program software of the system formed.

Cylinder Assembly on to the Bunker

As described above, a single cylinder is used in this study. Double cylinder could have been used attached to right and left side of the bunker. However, using single-cylinder should be evaluated as a step in reducing costs. Even in advanced stages it is advantageous in terms of maintenance and repair costs. However, not in the cost issue, but as mechanical perspective it can be observed that single cylinder has some disadvantages.

Although the bunker has a homogeneous distribution at weight, various parts that are attached to the bunker changes the center of gravity. Especially ball valve mounted to filling pipe at the bottom of the bunker is larger and heavier than other parts. This the gravity is required with taking into account the own characteristics (material properties, actual dimensions, etc.) and the weights of the bunker and each piece mounted on the bunker. So the assembly point of the cylinder could be determined.

The foregoing calculations are performed by solid modeling of the bunker and every part that is mounted on it. Solid modeling is realized by CATIA Software V5.R10. As shown in Figure 3.15, an image that shows the center of the gravity is taken from the software. This calculation gives an idea for the location of center of gravity and it has been enlightening for the assembly of cylinder. Owing to this software, difference from origin on three axes has been seen and an appropriate corrective action has been completed to merge the cylinder and the bunker.

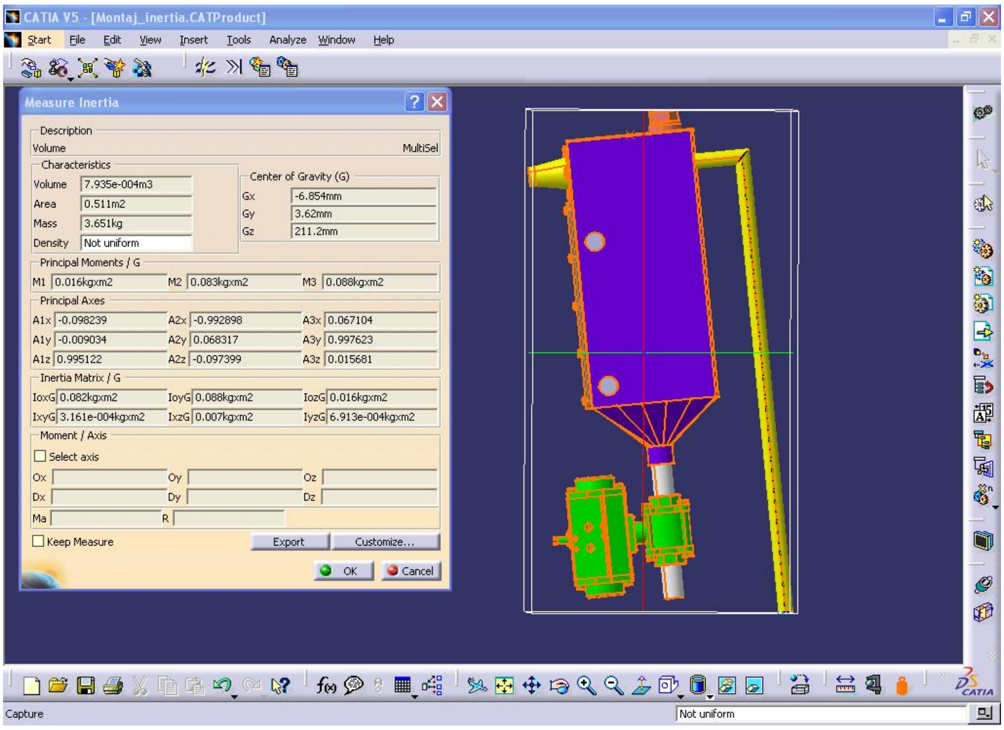


Figure 3.15: Calculation of center of gravity for cylinder assembly

After the assembly of the cylinder is obtained, manufacturing of moving parts is completed. In Figure 3.16 the cylinder, bunker and the parts that compose the bunker can be observed in detail.

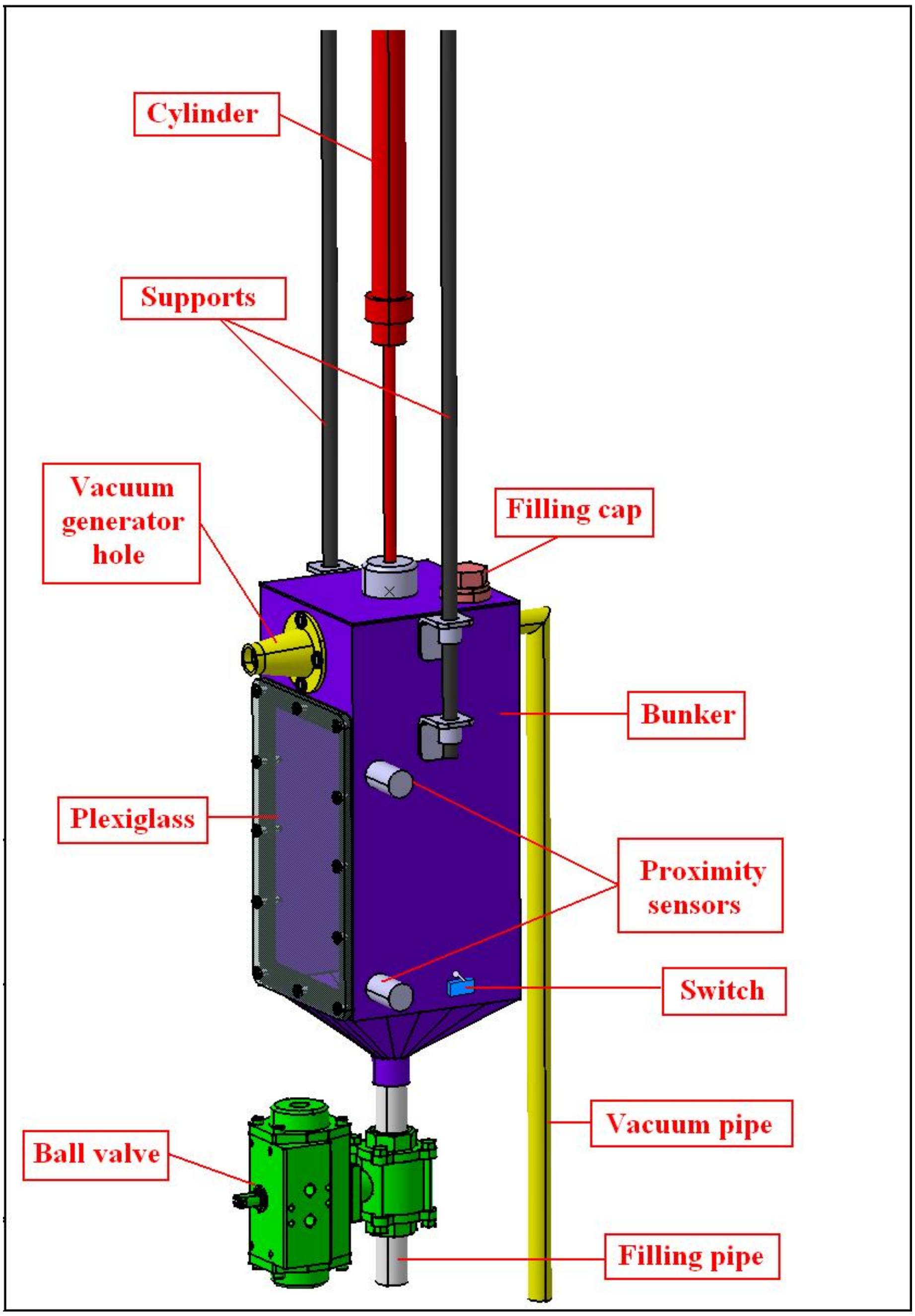


Figure 3.16: Cylinder, bunker and the parts attached to bunker

3.3.7. Pneumatic Circuit Diagram

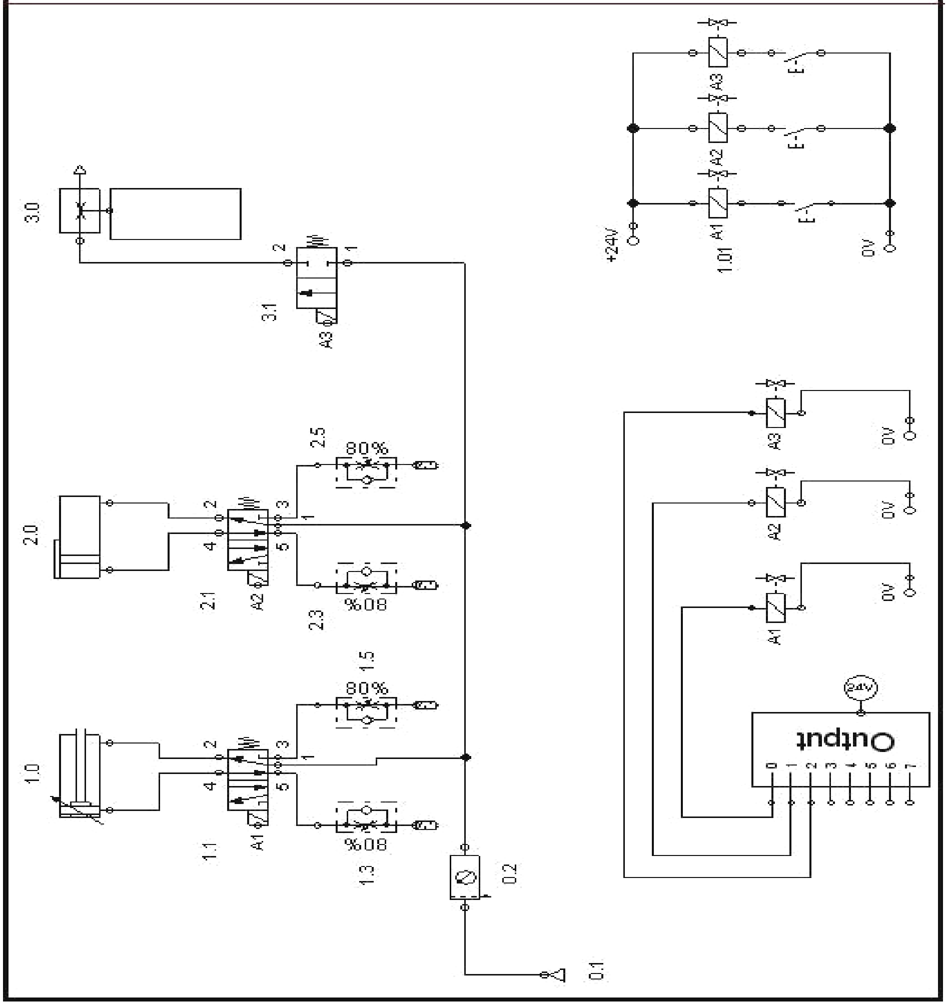
Before the pneumatic components are installed, pneumatic part of the system is examined by using the circuit simulation program FESTO FluidSIM-P. After running the circuit simulation and realizing that no problem occurs in the working of the system, mounting started. To draw the circuit, control chains are generated.

Working element and the corresponding power control unit forms a control chain. A project could consist of many control chains. These chains should be placed side by side and must be marked with a sequence number. In DIN 34 347 how to encode the components and the connections are shown with a sample circuit diagram [16].

Power supply unit cannot be included to any control chain because it feeds the various control chains so it is always marked with the sequence number 0. Control chains are marked as one, two and three respectively. Working elements (e.g. cylinders) are enumerated as 1.0, 2.0 etc while the final control elements (e.g. direction control valve) are enumerated as 1.1, 2.2 etc and the elements affecting the forward movement of the working elements are enumerated as 1.2, 2.4 etc (with even numbers), lastly the elements affecting the reverse movement of the working elements are enumerated as 1.3, 2.3 etc (with odd numbers). Advantage of this numerated system is that; machine maintenance worker can easily determine which signal affects where according to the element number. Figure 3.17 shows the image of the circuit diagram.

3.3.8. Load cell

A load cell (also called a load sensor or transducer) is a piece of machined metal that bends with the load's mechanical force and converts the mechanical force into an electrical signal. The bend doesn't exceed the metal's elasticity and is measured by strain gauges bonded at points on the cell. As long as the load is applied to the proper spot on the load cell, the strain gauges provide a proportional electrical signal [17]. Briefly, load cell is a transducer which converts force into a measurable electrical output.



Sign	Names of the element
1.0	Double acting cylinder
0.1	Compressed air supply
1.1	5/n-Directional control valve
	Voltage Supply (0V)
0.2	Conditioner, simplified demonstration
1.3	One way flow control valve
1.5	One way flow control valve
3.0	Vacuum generator
3.1	2/n-Directional control valve
	Voltage Supply (0V)
	DDE-Outlet
	Voltage Supply (24V)
A1	Valve solenoid
	Voltage Supply (0V)
	Voltage Supply (24V)
	Normally open switch
A2	Valve solenoid
	Voltage Supply (0V)
	Voltage Supply (24V)
	Normally open switch
2.1	5/n-Yön Directional control valve
2.3	One way flow control valve
2.5	One way flow control valve
2.0	Pneumatic linear element(actuator)
A3	Valve solenoid
	Voltage Supply (0V)
	Voltage Supply (24V)
	Normally open switch

Figure 3.17: Pneumatic circuit diagram

Load cells are divided into several types according to their measurement principle:

- Strain gage load cells
- Bending beam load cells
- Shear beam load cells
- Compression load cells
- Ring torsion load cells

In this study 'bending beam' type load cell is used. The strain gauges are bonded on the flat upper and lower sections of the load cell at points of maximum strain. This load cell type is used for low capacities because bending beams offer high strain levels at relatively low forces and it performs with good linearity.

Bending beams have relatively high strain levels with greater deflection compared to other measuring principles. This in turn means that although the cell is subjected to greater static overload, mechanical stops are more feasible. The dynamic overload capabilities are excellent because of the typical high deflection [18].

REVERE 642 C type single point load cell is chosen in this study. Its accuracy class is C3. Accuracy class specifies an error envelope for certain parameters, such as linearity, hysteresis, temperature effects, creep, etc. Technical data about load cell used is as follows:

Excitation voltage	: 5 – 15 V
Combined error	: ≤ ± 0.02 (The total error allowed for a load cell as the limiting factor)
Maximum Platform Size	: 400x400 mm

The maximum platform sizes given are those recommended to ensure that the system meets weights and measures requirements and damage is not done to the load cell through excess load. Platforms dimensions are 270 x 270 x 3 mm. It is made of stainless steel to prevent the over bending of platform. Materials like aluminum bend such an excessively that platform contacts with load cell. However, contacting of load cell with platform is not a desired situation, they shouldn't touch each other. At the same time, screwing is more difficult in respectively less hard materials such as aluminum. Screws can become loose as the time goes by and this causes faulty measurement. The load cell and the platform can be seen in Figure 3.18 and Figure 3.19.

Figure 3.18: Load cell

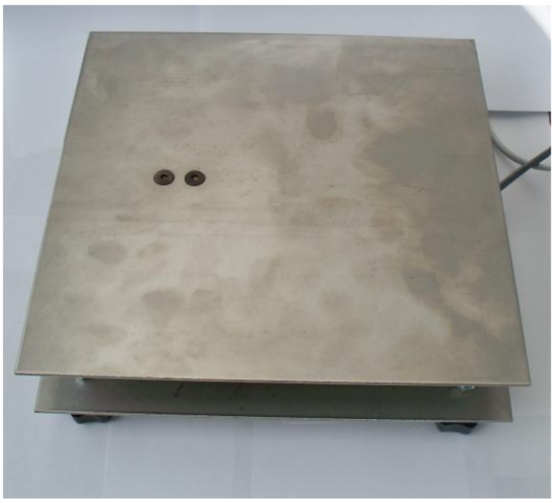


Figure 3.19: The platform

A load cell is a device that is very sensitive to external influences. Environmental forces such as wind loading, shock loading, vibration, large temperature changes, and pressure differentials, can produce errors in the load cell signal. So, the place should be carefully chosen. In the weighing and packing facilities of sugar factories, above-mentioned factors are not available.

3.3.9. Indicator

Load cells work with the principle of strain gages as mentioned before. The resistance strain gage is an electrical sensing device that varies its resistance as a linear function of the strain that occurs because of the applied force. It can be bonded to a surface in such a way that any subsequent deformation of the surface produces a like deformation of the gages.

A linear relationship can be achieved between the applied force and the sensed strain. The Wheatstone bridge circuit shown below in Figure 3.20 is almost universally used in load cells. The Wheatstone bridge circuit is ideal for measuring the resistance changes that occur in strain gages. Wheatstone bridge is a circuit consisting of four resistances. The fundamental concept of the Wheatstone bridge is two voltage dividers, both fed by the same input, as shown in Figure 3.19 the circuit output is taken from both voltage divider outputs. In the figure, E is the representation of excitation voltage in both (+) and (−) terminals. Excitation voltage can be either AC or DC, and is usually limited by heating considerations to a maximum of 10 volts for 120-ohm bridges and 20 volts for 350-ohm bridges. O/P denotes the output signal in both (+) and (−) terminals.

If load cell is not loaded, the strain and the voltage would not change and circuit remains in balance situation. This means no current flows in either direction or no voltage difference exists. Its balance equation is

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \qquad 3.4$$

where R1, R2, R3 and R4 are the bridge resistances. One of them is strain gage, others are stable resistances. If load cell is loaded then the gage would be deformed, eventually its electrical resistance changes and the balance situation fails. Meanwhile a voltage difference occurs in mV range at the O/P terminals in a direct proportion to the force. This voltage difference is an analog signal. O/P terminals are the input of the indicator.

Indicator used in this study is put into the system because of the fact that it processes the data received in the form of mV into the form of mA. Input or output data to the PLC hardware should be in a form of mA for this prototype. By using the indicator screening the weight data on the LED Display or on the PC or on the external display is provided

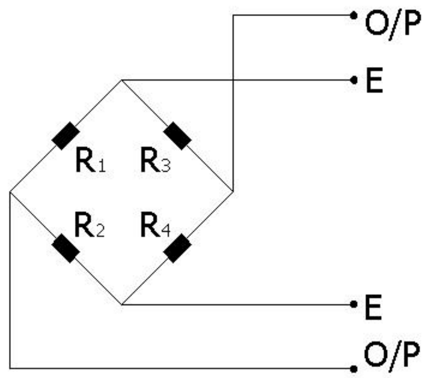


Figure 3.20: Wheatstone bridge

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In this study EMAF ET 01 D type indicator is used to read the weight data. This indicator is suitable for using load cells that have accuracy class III and IV. Here are some technical data about the indicator:

Source voltage : 220 V AC

Load cell excitation voltage : 10 V

Output signal : 4 – 20 mA

With a high resolution such as 16 bits, ADC is available in the indicator. Connection scheme of the indicator is given in Figure A.8. at Appendix A.

3.3.10. Load cell and Indicator Testing

Installation and calibration of load cell and indicator should be provided before their usage. In this study set up and calibration procedures were carried out by two software whose interfaces are shown in Figure 3.21 and Figure 3.22. Calculation methods have been done according to TS EN 45501 [19].

If the load cell and indicator are required to operate together, indicator should know the working principle of the weighing system which it is connected to. Introducing of maximum measuring weight, measurement range, weighing unit and a variety of such information to indicators is essential for an accurate weighing.

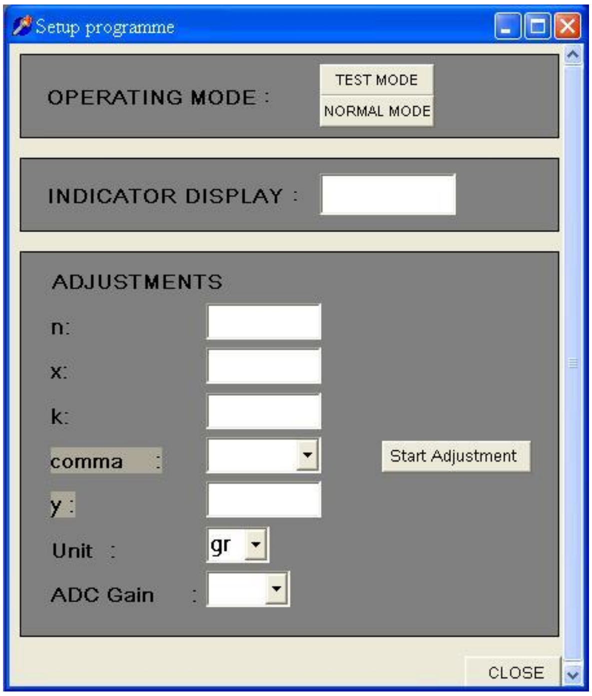

Figure 3.21: Interface of the setup program

To perform the set up procedure a program is used that is called as ‘Setup Program’. Software, interface of which is shown below in Figure 3.21, has two operating modes. ‘Test Mode’ reads the raw data that is send by ADC. In other words, tare, calibration coefficient and a variety of such data is not included yet in weighting information. 'Normal Mode' reads processed information of the weight. To read this information some calculations must be clarified first.

Variables; shown in the part of the program ‘adjustments’, such as n, x and k should be calculated and entered to their places in the program. According to TS EN 45501 [19] and as specified in the program 'x and k' represents constant numbers. x can only take ‘1, 2 and 5’ values while k is a negative, zero or any positive integer. However they should verify the formula below;

$$e = x \times 10^{k} \qquad 3.5$$

where ‘e’ is the division range. In other words ‘e’ is selected according to the desired amount of increase or decrease in the weighing. In this study, making precision measurement is demanded so 1 gram of division range has been decided. x variable is chosen as 1 and according to Formula 3.5 variable k is calculated as 0. A value which appears in the program is 'n' and it represents the partition value. With the help of the following formula it is calculated.

$$n = \frac{Max}{e} \qquad 3.6$$

where ‘Max’ is the maximum capacity of load cell. As stated previously, in this study the load cell is selected as 5000 grams. That is to say; because of Max value is 5000 grams and e value is 1 partition value n appears to be 5000.

Finally, it remains the ‘y’ value that should be calculated in the program. y represents the upper limit of indicator. The weighing data that exceeds the maximum capacity and will be shown by the indicator should be introduced to indicator. This value is calculated by Formula 3.7 according to TS EN 45501 [19].

$$y = 9 \times e \qquad 3.7$$

In this case, y value for this study should be 9. In other words indicator could not show the weights over 5009 grams. The value over the 5009 grams disappears as a line.

Making calculations according to the kind of used device before entering the variables into the program is essential for an accurate weighing. After determining the values they are entered to the program and adjustments of the device is started and then the appropriate operation is actualized before the set up process was completed. After that, indicator is calibrated with the calibration program shown in Figure 3.21. For this, 5-kilogram, 1-kilogram, 500-gram, 100-gram, 50-gram, 10-gram and 1-gram etalon weights are used that stored in a special box.

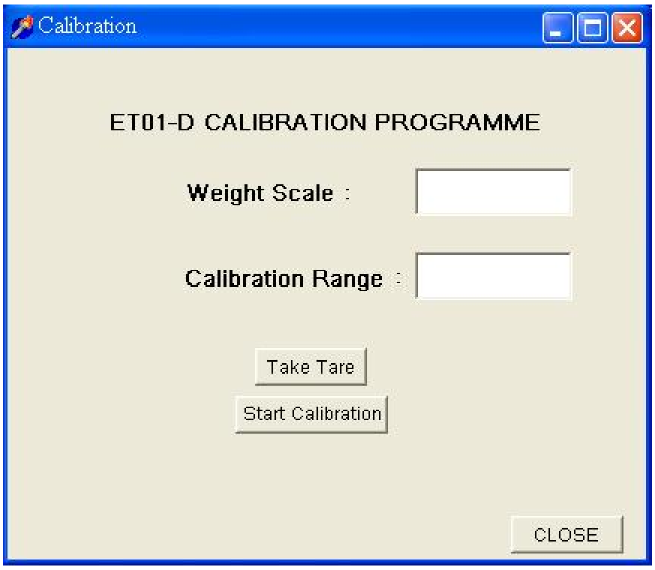

Figure 3.22: Interface of the calibration program

3.3.11. Proximity Sensors

Bunker that has a duty of taking the excess sugar and filling the deficient sugar is previously described. One thing that should be taken into consideration is that sugar level will constantly increase or decrease as long as the taking and filling processes go on. How can the operator who runs this system should realize the sugar level in the bunker? Going and looking to the system once in a while may be an option. However, the system is claimed to operate independently from human. So this process should be followed and necessary warnings must be given by control unit. For this; a sensor is mounted on the bottom of the bunker to give the information of 'bunker is empty' and similarly a sensor is attached to the top of the bunker to understand whether the bunker is full of sugar or not. The type of this sensor is proximity sensor.

Proximity sensor is a device that can sense the objects closer to itself without any physical contact. A proximity sensor often emits an electromagnetic or electrostatic field and waits for the change on the field so it can detect the coming substance. There are kinds of proximity sensors used for different applications. In this study the capacitive type sensor is chosen. Because this device is very suitable for detecting metallic or non-metallic materials like sugar, plastic, paper or wood [20].

Capacitive proximity sensors contain 4 main components: plate, oscillator, detection circuit and solid state switch. When the power is turned on, the oscillator detects the amount of capacitance between the external target and the metal plate in the sensor. As the target approaches, the capacitance increases. When the capacitance reaches a certain point, the oscillator begins to operate. Once the oscillation reaches a preset point, the detection circuit senses this, and signals the switch to change state. This is the working principle of the sensor. In this study MEFA Sensor, type MK 10-S18-PA is used and its photograph is given in Figure 3.23. Technical data about the capacitive sensor is as follows:

Sensing distance : 8 mm

Connection type : PNP

Working voltage : 10 – 60 V DC

Switching current : 400 mA

Figure 3.23: Photograph of the capacitive proximity sensor

3.3.12. Micro Switch

Switches are the devices that send the contact data of a contact to the system. They are actuated by a very little physical force. As seen in Figure 3.24 when spindle on the switch is pushed, contact closes and current can flow through the circuit. Micro switches have very common usage due to their low cost and long life.

In this study, micro switch is used for recognizing the position of the cylinder. It is mounted on the lower side of the bunker. When cylinder is in the up position namely when it is closed one of the supports push the spindle and sends the data of 'closed cylinder'. Its position can be seen in Figure 3.16.

Figure 3.24: Micro switch

Technical data about the micro switch is given as follows:

Mechanical Life : 10000000 operations

Electrical Life : 100000 operations

Operating Voltage : 250 V AC

Operating Current : 10 A

CHAPTER 4

CONTROL UNITS

4.1. PLC

PLC hardware is widely used in all sectors of the industrial automation as a control unit. Because it can easily control and run many machines at the same time and also correcting an error is much simpler than the other systems. PLC hardware is effective, productive and low cost system and these entire makes it demanded components for the automation processes.

PLC hardware – being acronym of the 'programmable logic control' – is often defined as miniature industrial computer that contain hardware and software that is used to perform control functions. It is also defined in detail by Bliesenger in [21].

"A digitally operating electronic system, designed for use in an industrial environment, which uses a programmable memory for the internal storage of user-oriented instructions for implementing specific functions such as logic, sequencing, timing, counting and arithmetic, to control, through digital or analogue inputs and outputs, various types of machines or processes".

PLC hardware consists of two basic sections: the central processing unit (CPU) and the input/output interface system. The CPU, which controls all PLC hardware activity, can be broken down into the processor and memory system. The input/output system is physically connected to field devices (switches, sensors, etc.) and provides the interface between the CPU and the information providers (inputs) and controllable devices (outputs). An input module converts the incoming signals into signals, which can be processed by the PLC hardware, and to pass these to the control unit. On the other hand the output module converts the PLC hardware signal into signals suitable for the actuators.

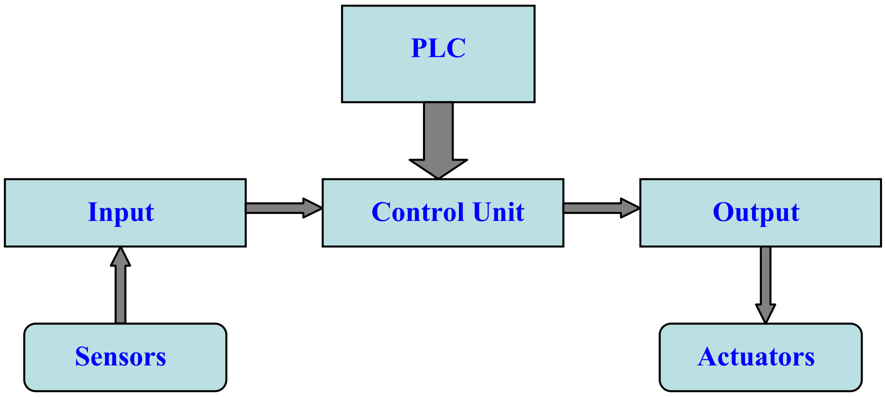

Figure 4.1: Simple scheme of PLC hardware

In this study, Telemecanique Twido Moduler; Model:TWDLMDA20DRT type PLC hardware is used to control the system. The reason for choosing a modular PLC hardware is that modular PLC hardware can be configured individually according to the needs of the system. Originally the main unit of this PLC hardware has a processor, a memory, 12 digital inputs and 8 digital outputs in it. To run PLC hardware a power source is needed and also a module is demanded to be able to communicate. Therefore, some additional parts are required; one of them is used to energize the PLC hardware that is power supply and the other one is used for communication, this one is called as communication module. This communication has been achieved with the help of an Ethernet network connection. Besides these two, according to the designed the system an analog input module is added for the analog data coming from the field. Analog input or output modules are not an obligation for the systems, the usage of analog input or output module is only up to the designed system but a devices such as a power source is an indispensable part for PLC hardware. The system that is designed for this study is shown in Figure 4.2.

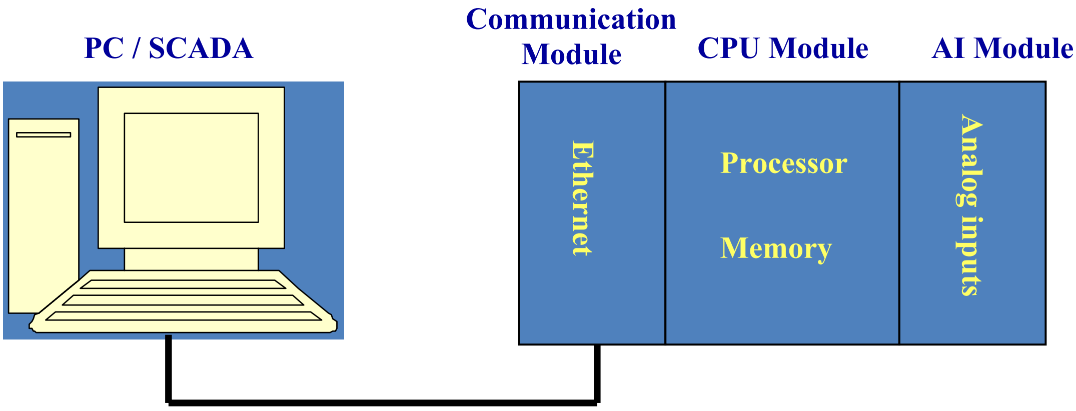

Figure 4.2: Configuration of control units

In computers, digital inputs and outputs are in the form of digital data and analog inputs and outputs are in the form of analog data. The word analog denotes a phenomenon that is continuously variable (force measurement, speed setting etc). The word digital, on the other hand, implies a discrete, exactly countable value that can be represented as a series of digits (numbers). Virtually all modern computers depend on the manipulation of discrete signals in one of two states denoted by the numbers 1 and 0. Whether the 1 indicates the presence of an electrical charge, a voltage level, a magnetic state, a pulse of light, or some other phenomenon, at a given point there is either "something" (1) or "nothing" (0). This is the most natural way to represent a series of such states [22]. Here the inputs and outputs of the system are given:

3 digital inputs

- High level data of the bunker
- Low level data of the bunker
- Cylinder up data

2 analog inputs

- Indicator weighing data
- Pressure transmitter vacuum pressure data

4 digital outputs

- Ball valve on/off data
- Solenoid valve on/off data
- Cylinder on/off data
- Alarm

No analog output

The analog module that is mentioned above has two inputs available in it for taking the data sent from pressure transmitter and indicator (weighing data and vacuum data).

4.1.1. A summary for the process

Before looking through the program, it could be beneficial to examine the itemized information about how the system will operate. This will evidently makes the program more understandable.

After being weighed and packed with weighing and packing machine, sugar bags are sent to platform scale for weight control. Including the platform scale, job of the prototype begins after this process. Operations carried out by the prototype can be listed as follows:

Bag comes to platform scale.

Weighing information is sent to the system through indicator.

Sugar level of the bunker is checked before the operations have been started. Level control is achieved through two capacitive proximity sensor placed on the body of the bunker. One of them shows the low level the other one shows the high level.

If the level is appropriate, system starts to work. If the level is low, system waits for 5 seconds, gives alarm and does not work. If the bunker contains sugar that passes the high level limit, system again waits for 5 seconds, gives alarm and will not work. In case of these two conditions, system waits for the level drawn into allowable limits and the alarm to reset status. Once these are provided system is ready for operation.

System waits for the weighing information to be stabilized during three seconds.

The system should decide whether there is a bag or not on the platform scale.

If a weight that is heavier than a certain weight value is placed to the scale then system understands the information of ‘there is a bag on the scale’.

This certain weight value has been previously entered to the system by the operator.

If the existence of the bag on the scale data becomes certain, system should determine whether the weight of the bag is in the allowable range or not, according to data received from indicator.

This determination will take place after a variety of calculations have been completed. Calculations are provided according to the ‘allowable limits’ and ‘bag weight’ data that are previously entered into the system. In light of this information, the system calculates the negative and positive difference.

If the bag weight that received from indicator remains in the calculated limits, system sends a message that indicates ‘bag is in limits’.

If the system determines that the bag weight is above the allowable limit +30 grams, it starts a number of processes to take the sugar from the sack.

First, the system calculates how much sugar is over and it lifts down the cylinder in the meantime.

With the movement of the cylinder to downwards, bunker lifts down and vacuum starts and the vacuum pipe dives into the sugar bag. Because of this contact, pipe applies pressure on the sugar bag and there would be some changes in the weight of the sack. System makes various calculations to eliminate this change and takes the required amount of sugar from the bag.

After taking the excess sugar, process ends and cylinder moves upwards but vacuum continue to work for a while. This is necessary to prevent the flowing of the sugar that remains in the vacuum pipe and to prevent the ruining of the adjustment of the bag weight.

The cylinder moves upwards, in the meantime system weighs the bag again and if the bag remains in the allowable limits it sends a message that indicates 'the bag is in limits'.

Application of the system is explained when an excess sugar bag is detected. However, the amount of sugar in the bag may be less than the allowable limit. If such a situation is determined, system starts a number of processes to fill the deficient sugar to the bag.

First, the system calculates how much sugar is deficient

Cylinder does not move in this operation and bunker stays stable. Then ball valve opens and deficient amount is filled to the bag.

After the filling process is completed the ball valve is closed.

System weighs the bag again and if the bag remains in the allowable limits it sends a message that indicates 'bag is in limits'.

During all these operations, system continuously checks for alarms. System gives alarms when the system, vacuum, cylinder and valve cannot be started. Also, as stated before high limit and low limit of the bunker is controlled continuously.

For detecting the working of the vacuum generator, vacuum data is used. This data is received from pressure transmitter. The system knows whether vacuum is occurred or not through a vacuum comparison value that has already entered the system by the operator.

For detecting the working of the cylinder, system uses the data that received from a switch. This switch is attached to the bottom of the bunker and can bee seen in Figure 3.16. It sends a signal when one of the supports of the bunker touches it so the system knows that cylinder moves to downwards.

Finally, for detecting the working of the ball valve, system uses the weighing data. If the ball valve appears to be open and weighing value does not changes then system realizes that the ball valve is not working and required alarm is given.

In the meantime, all this operations can be monitored by the SCADA interface via the computer screen. In fact, the system can be turn to manual position and controls can be done by the operator. Operator can open and close the cylinder, ball valve and vacuum generator manually through the SCADA window. Also starting, stopping and resetting of the system are possible.

4.1.2. Flowchart of the process

A flow chart is a working map of the final product. It is an easy way of working for providing a graphical representation of actions to be taken. A flow chart makes the process understandable even for the complicated and detailed ones. Figure 4.3 simply shows the flowchart of the process that is designed in this study.

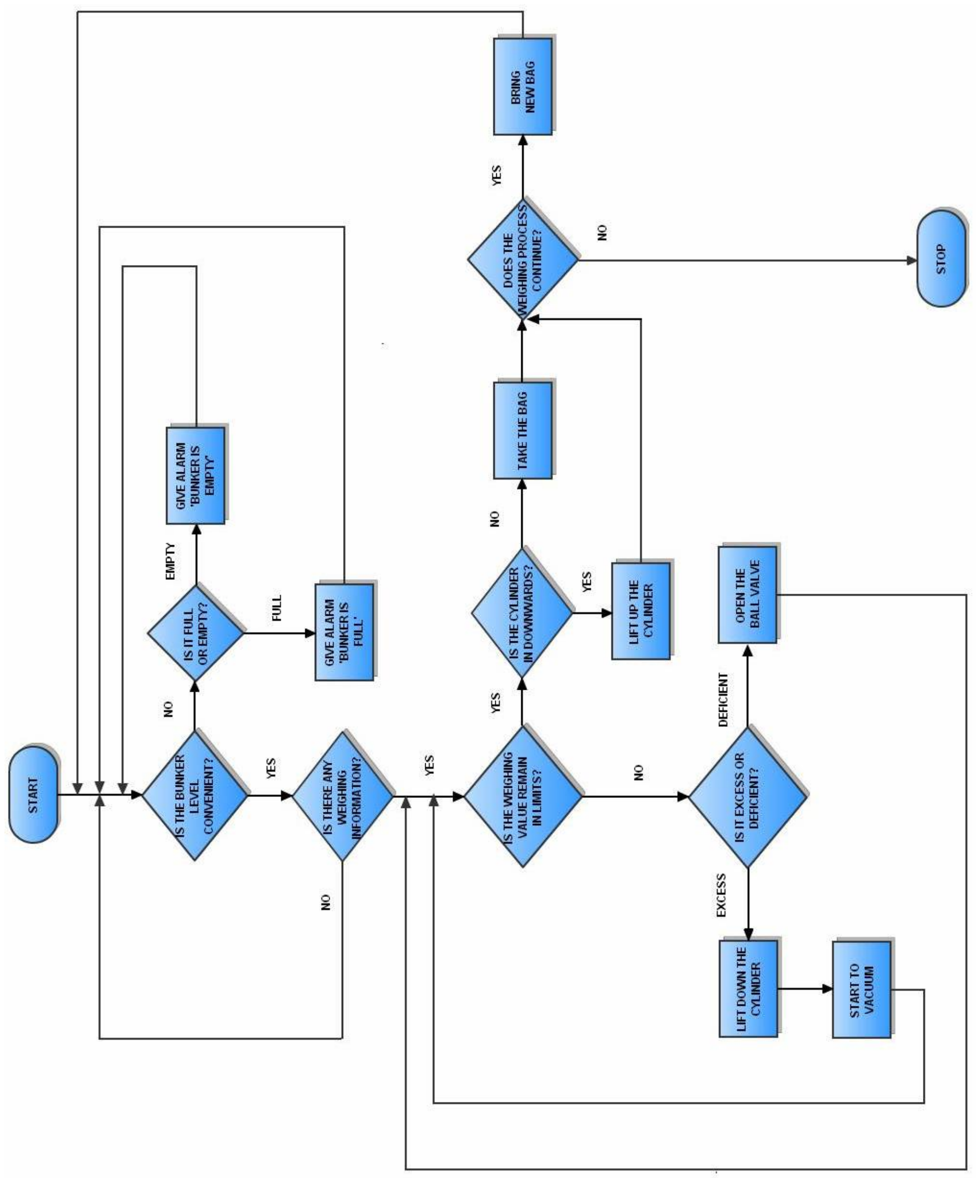

Figure 4.3: Flowchart of the process

4.1.3. PLC Programming

To operate, the CPU reads input data from connected field devices through the use of its input interfaces and then executes or performs the control program that has been stored in its memory system. Actual processing of the signals is provided by the program stored in the memory. Programs are entered into the CPU's memory prior to operation. Finally, based on the program, the PLC writes or updates output devices via the output interfaces. It will be impossible to run the PLC hardware and control the system without forming a program.

The software used in this study is provided from the PLC hardware manufacturer; Schneider Electric Telemecanique. Its name is 'TwidoSuite' and it is a 32-bit Windows-based program for a personal computer and a graphical development environment for creating, configuring, and maintaining automation applications for programmable logic controllers. Different parts of the program, its steps, variables and program itself is given in Appendix B.

4.1.4. Programming Software

The software, which is one of the important stages of this study, in other words, details of programming and application process steps are seen important to explain.

Describing

As mentioned before, "TwidoSuit" is software used for programming. In this software first, a page that is used for creating a project meets the user. On this page, as well as the presence of descriptive information such as, project name, author, department and industrial property is available also there are sections for entering pictures related to the project or extra information about the project. After completion of this part describe section should be completed. Program should recognize the used PLC hardware and the added modules to PLC and describe window is used for this recognition. The describe window provides a graphical workspace where applications can be defined and configured. The PLC hardware and extension modules are displayed together with the created networks (overall network settings, devices in use). Type of PLC hardware and models of the additional modules are selected from the 'catalog' part in describe window and are brought on to the blank page with sliding and are added to each other. In Figure 4.4, given image shows the describe page of the program and also the definitions and the parts where the procedures performed.

CommunicationThe time period that the sugar is produced is called ‘campaign’. During the campaign factory works 24 hour non-stop in three shifts. It is very important that the engineer who is responsible of the shift could see all the facilities that are automated in the factory. For this, a computer that shows all the automated facilities is placed to the automation room. In this study, a new and automated quality control unit is done that works after weighing and packing machine and if the factory conditions are taken into consideration its communication with the demanded computer should be provided. That’s why in this study, Ethernet communication is chosen instead of cabled communication.

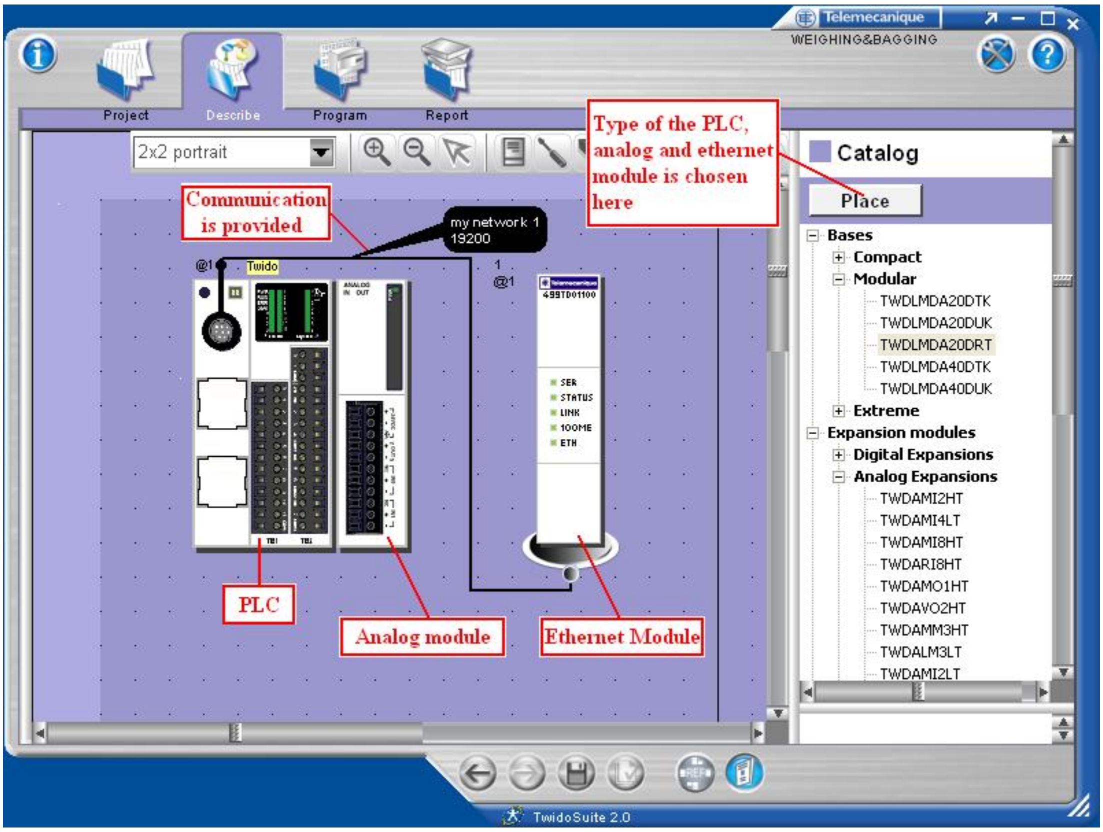

Figure 4.4: Describe window of TwidoSuit

As seen in Figure 4.4, communication of PLC hardware and Ethernet module with each other is provided. It is enabled with help of Modbus protocol. It is a master/slave protocol that allows for one, and only one, master to request responses from slaves or to act based on the request. The master can address individual slaves, or can initiate a broadcast message to all slaves. Slaves return a message (response) to queries that are addressed to them individually.

Software Configure

After the hardware has been introduced to the software, program section can be started. In this section description of inputs and outputs of PLC hardware and the attached modules are made. For that matter, input and outputs are defined for field elements. Figure 4.5 shows description of digital inputs and outputs and description of the analog inputs are represented in Figure 4.6.

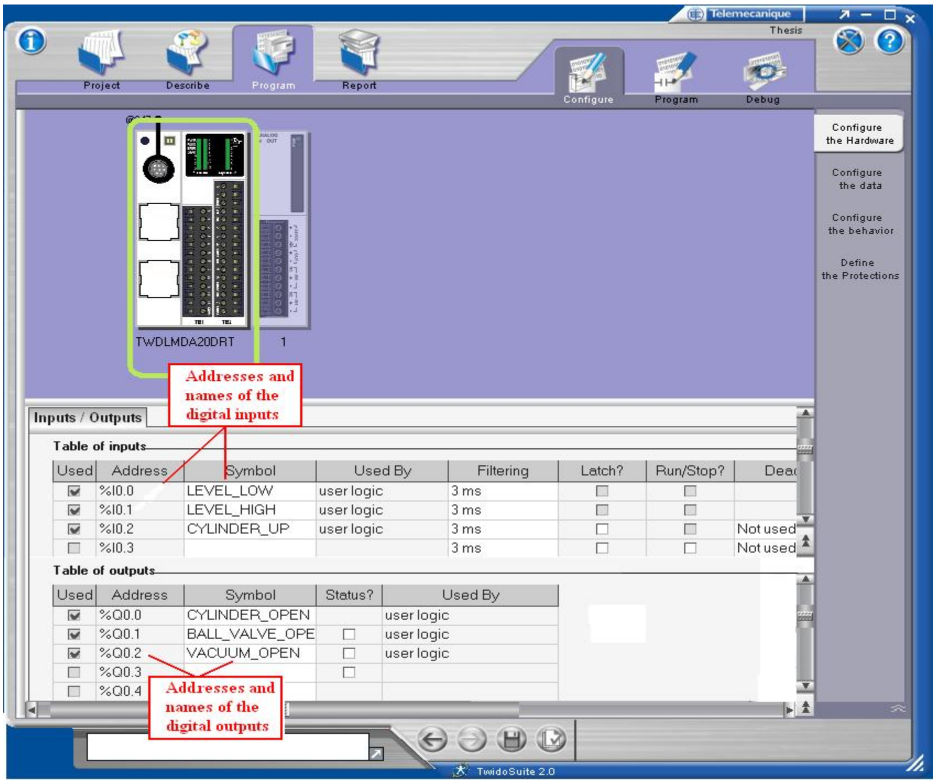

Figure 4.5: Digital inputs and outputs

To configure the analog inputs and outputs the type of data that will be transferred to the analog input and output should be introduced first. Therefore, in the program channel type part should be filled in. In this study data to be transferred from the field will be denominated in amperes, so the input channel type is chosen as 4 – 20 mA and it is shown in Figure 4.6.

In this configuration, there are two inputs and one analog output in analog module and the resolution of the entries is 12 bits. These 12 bits indicates that it has a digital resolution of 2^{12} = 4096. In other words, to give an example; if data received from the field is in the range of 4 – 20 mA, this value is divided into 4096 parts for a precision measurement. To clarify, if necessary; 4 mA is taken as zero and 20 mA is taken as 4096 and it can be seen that 16 mA range is divided into 4096 so measurements are taken in high resolution. Resolution increases as the bit value increases.

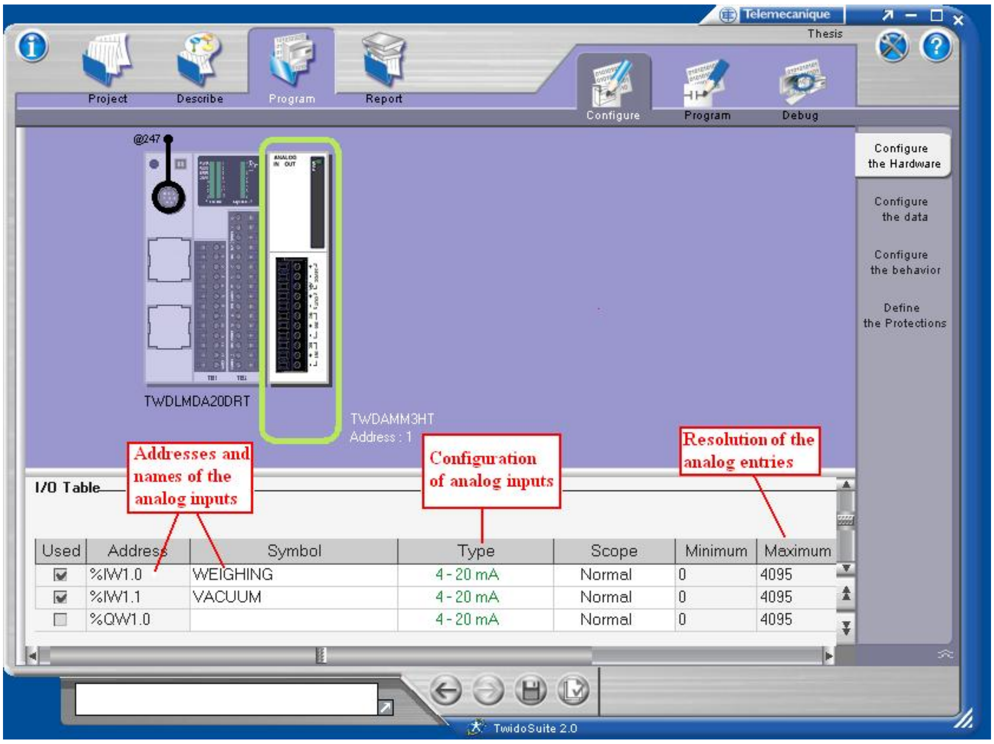

Figure 4.6: Analog inputs

Memory

If the Figure 4.5 and the Figure 4.6 given above is examined, variables such as I, Q, IW will be seen. It is required to introduce these memory elements. Therefore, it is necessary to mention about the memory to understand what was written on the PLC program. The controller memory accessible to the application is divided into two distinct sets which are bit values and word values. Bit is the smallest data storage element and eight-bits are equal to one byte. Also there are bigger memory elements such as word. Word is a set of bits constituting the smallest unit of addressable memory. It is a collection of characters which is 16 bits in size. This means that it can contain an integer value between -32768 and 32767. The number of bit in a word is an important characteristic of software [22]. The Table 4.1 and Table 4.2 show the type of the bit and word objects.

Table 4.1: Bit Objects

Words	Description	Address or value
Immediate values	0 or 1 (False or True)	0 or 1
Inputs Outputs	These bits are the "logical images" of the electrical states of the I/O. They are stored in data memory and updated during each scan of the program logic.	%Ix.y %Qx.y
Internal (Memory)	Internal bits are internal memory areas used to store intermediary values while a program is running.	%Mi

Table 4.2: Word Objects

Words	Description	Address or value
Immediate values	These are integer values that are in the same format as the 16-bit words, which enable values to be assigned to these words.	
Internal words (memory words)	Used as "working" words to store values during operation in data memory.	%MWi
Analog I/O words	Assigned to analog inputs and outputs of analog modules	%IWi, %QWi%
Extracted bits	It is possible to extract one of the 16 bits from %MW	%MWi:Xk

Figure 4.7 given below shows the examples of extracted bit memory element (%MWi:Xk) containing in the program.

The above variables given as an example forms the memory elements. To explain this, if necessary, for example, let's suppose the sugar level in the bunker (it should be reminded that bunker works for adding the deficient sugar to the sugar bags or taking the excess sugar from sugar bags) dropped enough to give alarm. This alarm information is kept in the %MW0:X12. To give another example; in the process sugar bag comes to the platform scale after it is weighed and packed with weighing and packaging machine. However, this prototype should understand whether the weighing value exceeds the allowable limits or not and also it should decide the type of difference (Is it positive or negative?). If the value that is found with comparing some data is positive difference then this information is written to the %MW0:X9 memory element, in other words positive difference data is kept in here.

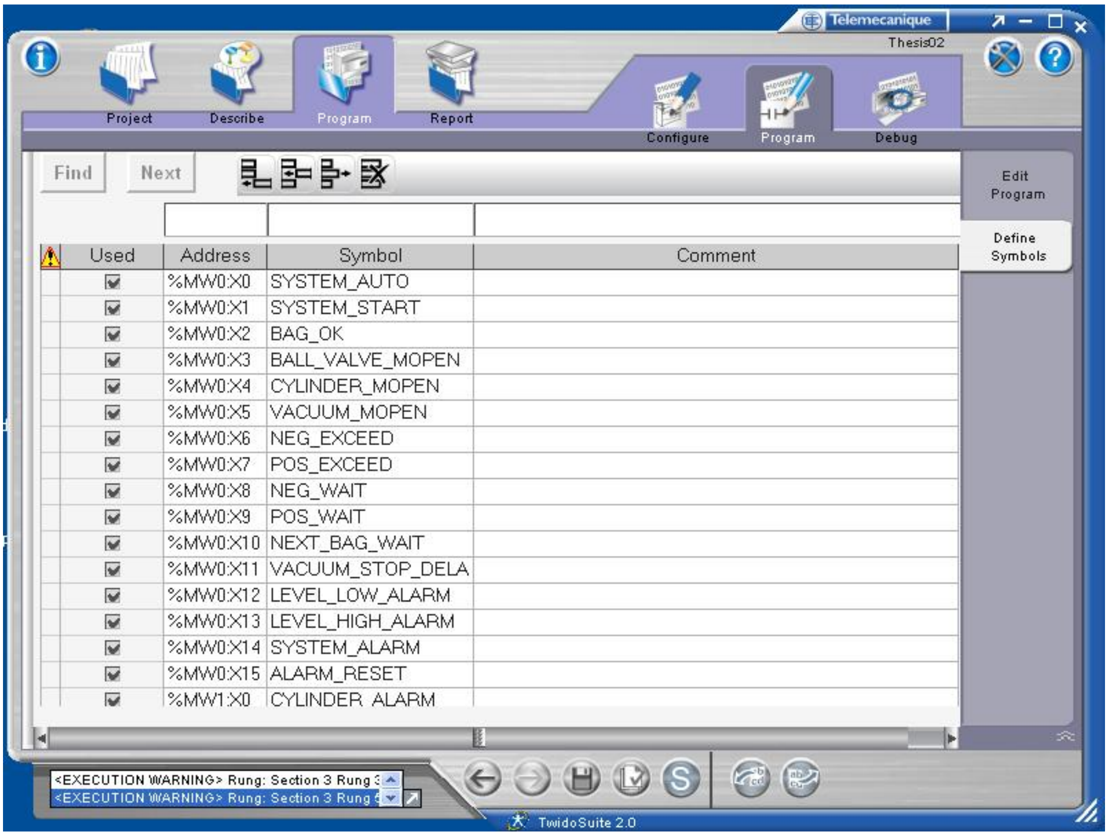

Figure 4.7 Example of a memory element

Memory elements list

All the memory objects are given with their names in the following list. Understanding this memory objects is vital to understand the written program.

Table 4.3: List of the memory objects

MEMORY OBJECT	OBJECT NAME	EXPLANATION
Internal Bits		
%MW0:X0	SYSTEM_AUTO	System works automatically
%MW0:X1	SYSTEM_START	System starts
%MW0:X2	BAG_OK	Bag is existing
%MW0:X3	BALL_VALVE_MOPEN	Open the valve manually
%MW0:X4	CYLINDER_MOPEN	Open the cylinder manually
%MW0:X5	VACUUM_MOPEN	Open the vacuum manually
%MW0:X6	NEG_DIFFERENCE	Sugar is deficient
%MW0:X7	POS_DIFFERENCE	Sugar is exceeding
%MW0:X8	NEG_WAIT	Wait the negative difference loop
%MW0:X9	POS_WAIT	Wait the positive difference loop
%MW0:X10	NEXT_BAG_WAIT	Wait until the next bag come
%MW0:X11	VACUUM_STOP_DELAY	Delaying of vacuum cut
%MW0:X12	LEVEL_LOW_ALARM	Sugar level is low in the bunker
%MW0:X13	LEVEL_HIGH_ALARM	Sugar level is high in the bunker
%MW0:X14	SYSTEM_ALARM	System alarm
%MW0:X15	ALARM_RESET	Reset the alarms
%MW1:X0	CYLINDER_ALARM	‘Cylinder cannot be started’ alarm
%MW1:X1	VACUUM_ALARM	‘Vacuum cannot be started’ alarm
%MW1:X2	VALVE_ALARM	‘Valve cannot be started’ alarm
%MW1:X3	BAG_IN_LIMITS	Bag stays in the allowable limits
%MW1:X4	MCYLINDER_OPEN	Memory for reading the ‘open cylinder manually’ data to SCADA interface

Table 4.3: List of the memory objects (continued)

%MW1:X5	MVALVE_OPEN	Memory for reading the 'open ball valve manually' data to SCADA interface
%MW1:X6	MVACUUM_OPEN	Memory for reading the 'open the vacuum manually' data to SCADA interface
%MW1:X7	FACTORY SETTINGS	Factory settings for some variables
%MW1:X8	SYSTEM_RESET	Resetting the system
Internal Words		
%MW10	WEIGHING_ASSIGN	Reads the weight value from analog input %IW 1.0
%MW11	BAG_WEIGHT	Decide the bag weight
%MW12	LIMIT	Decide the limits
%MW13	MIN_DIFFERENCE	Minimum amount of sugar that will be add or extract from bag
%MW14	ACCUMULATOR	Temporary memory for calculations
%MW15	WEIGHT_COMPR	The weight value to understand the existence of bag
%MW16	ACT_DIFFERENCE	Weighing value – Accumulator
%MW17	VACUUM_COMPR	The vacuum value to understand the existence of vacuum
%MW18	VACUUM_ASSIGN	Reads the vacuum value from analog input %IW 1.1
%MW20	LOW_LIMIT	Calculated allowable low limit
%MW21	HIGH_LIMIT	Calculated allowable high limit
Digital Inputs		
%I0.0	LEVEL_LOW	Signal come from low proximity sensor in the bunker

Table 4.3: List of the memory objects (continued)

%I0.1	LEVEL_HIGH	Signal come from high proximity sensor in the bunker
%I0.2	CYLINDER_UP	Signal come from micro switch
Digital Outputs		
%Q0.2	CYLINDER_OPEN	Signal send for opening cylinder
%Q0.3	BALL_VALVE_OPEN	Signal send for opening ball valve
%Q0.4	VACUUM_OPEN	Signal send for opening vacuum
%Q0.5	ALARM	Signal send for starting alarm in voice and flashing format
Analog Inputs		
%IW1.0	WEIGHING	Weighing data come from indicator
%IW1.1	VACUUM	Vacuum data come from pressure transmitter
Function Blocks		
%TM1	BAG_OK_DELAY	Waiting time for the stabilization of weighing value
%TM2	VACUUM_DELAY	Vacuuming waits when cylinder is closed in positive difference
%TM3	LOW_ALARM_DELAY	The time needed to give the low
%TM4	HIGH_ALARM_DELAY	The time needed to give the high level alarm
%TM5	VACUUM_ALARM_DELAY	The time needed to give ‘vacuum cannot be started’ alarm
%TM6	VALVE_ALARM_DELAY	The time needed to give ‘ball valve cannot be started’ alarm
%TM7	CYLINDER_ALARM_DELAY	The time needed to give ‘cylinder cannot be started’ alarm

Programming Language

A programmable controller reads inputs, writes to outputs, and solves logic based on a control program. Creating a control program for a controller consists of writing a series of instructions. This can be accomplished with different programming languages. Here are a few different programming languages that are used:

- Instruction List Language: Consists of a series of instructions executed sequentially by the controller
- Ladder Diagrams: Ladder diagrams are similar to relay logic diagrams that represent relay control circuits. Graphic elements such as coils, contacts, and blocks represent instructions
- Grafcet Language: The Grafcet analytical method divides any sequential control system into a series of steps, with which actions, transitions, and conditions are associated.

In this study, the simplest and widely used language; ladder diagram is used. Ladder diagrams consist of blocks representing program flow and functions such as the following:

- Coils
- Program flow instructions
- Function blocks
- Comparison blocks
- Operation blocks

These functions are described in detail in the following subject to provide the understood of this language and the program written with this language.

Ladder Rungs*:* A program written in Ladder language is composed of rungs which are sets of graphical instructions drawn between two vertical potential bars. The rungs are executed sequentially by the controller. Example of a rung can be seen from Figure 4.8.

The set of graphical instructions represent the following functions:

- Inputs/outputs of the controller (push buttons, sensors, relays, pilot lights, etc.)
- Functions of the controller (timers, counters, etc.)
- Math and logic operations (addition, division, AND, OR, etc.)
- Comparison operators and other numerical operations (A<B, A=B, shift, rotate, etc.)
- Internal variables in the controller (bits, words, etc.)

These graphical instructions are arranged with vertical and horizontal connections leading eventually to one or several outputs and/or actions. A rung cannot support more than one group of linked instructions.

Contacts and Coils: An electrical contact is a conductive device for joining electrical circuits together and coil is a device that allows the current, pass through itself when a supply is given to it. When a program is written by ladder diagram, one should pay attention to 'all inputs are represented by contact symbols and all outputs are represented by coil symbols'. Figure 4.8 shows the contacts and coil types that are used in this program, in fact there are various type of contact and coil is available in the software that are suitable for different applications. The explanations of the contact and coils that are shown in Figure 4.8 are given in Appendix B.

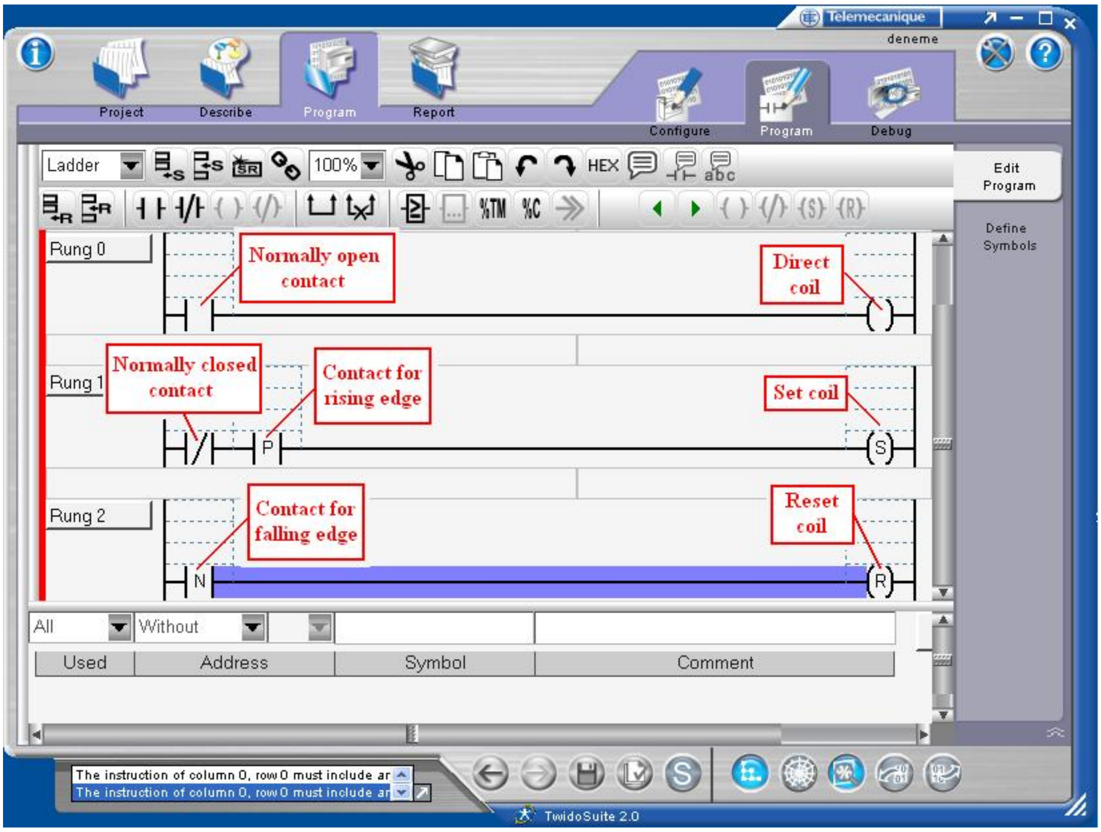

Figure 4.8: Representation of contacts and coils

Function Blocks: Function blocks are the sources for bit objects and specific words that are used by programs. Basic function blocks provide simple functions such as timers or up/down counting. Function blocks include the timers, counters, step counters and so on. In this study, timer function blocks are used for time delaying applications in the program and an example of a function block can be seen from Figure 4.9.

Comparison and Operation Blocks: Comparison blocks as the name suggests; compares two operands. The comparison is executed inside square brackets following instructions LD, AND, and OR. The result is 1 when the comparison requested is true. On the other hand operation block performs arithmetic and logic operations. Example of both these two blocks can be seen from Figure 4.9.

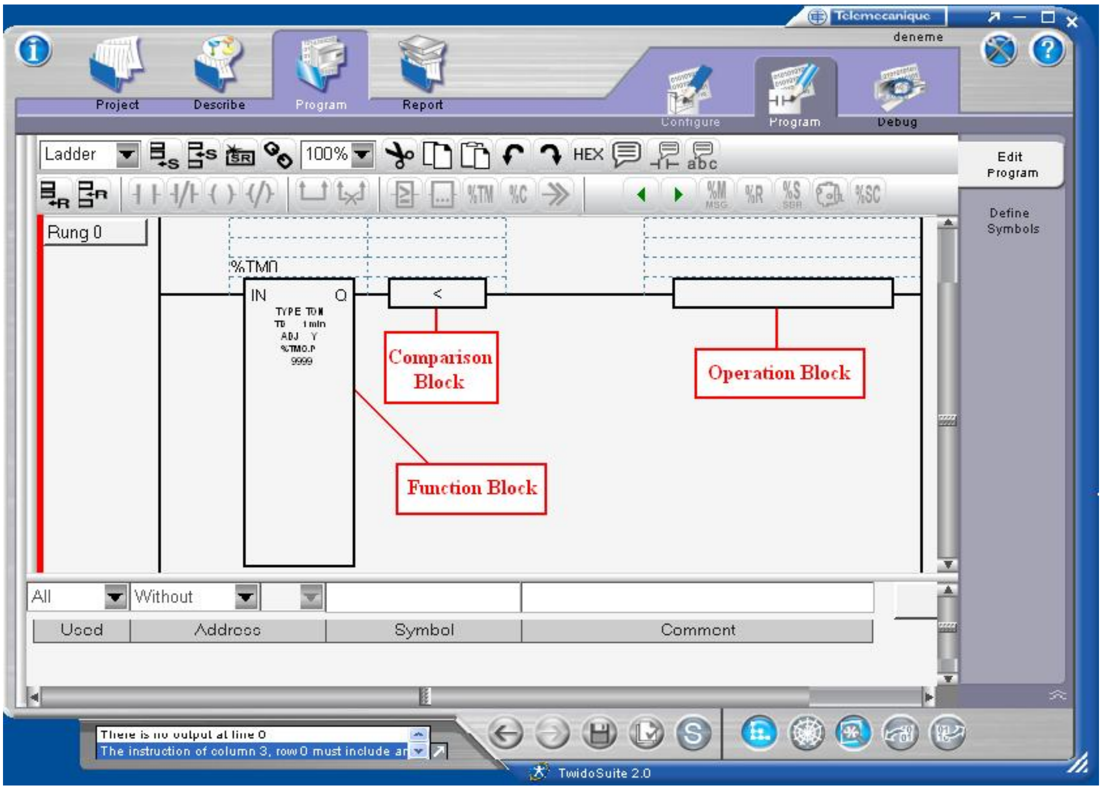

Figure 4.9: Example of function, comparison and operation blocks

Various functions and software tools that used in the program are mentioned so far. Besides these stated, there is another element that is available which is used in this study. It is a special instruction and its name is 'SHORT'. It should be used at the beginning of the rung and its duty is allowing the continuity to pass through the rung regardless of the result of the last logical operation.

To summarize all these explained briefly, if necessary, in the development of PLC programs relays and contacts are added and joined manually due to the nature of the program. The state of the relays and contacts in the program gives the information to the controller PLC hardware that which element will be initialized in which conditions. In programming applications, to achieve comparing, delaying, calculation and similar controlling functions various blocks operators must be used. That is to say; a timer is needed to delay time, a comparison block is needed to compare two values each other and operation block is necessary for making arithmetic operations such as addition, subtraction etc. The issues mentioned here, will be the source to comprehend the written program.

Technical drawing and photograph of the panel which the PLC hardware, electrical components and pneumatic components is placed is given in Appendix A with Figure A.7, Figure A.9, Figure A.10, Figure A.11 and Figure A.12.

4.2. SCADA interface

In Section 4.1, the PLC device, control mechanism of PLC hardware to check the system, and the program that is prepared for providing this control are described in detail. In this section controlling with SCADA interface which gives the name to this thesis study and is commonly used in industrial automation applications will be introduced. SCADA interface, although at first glance, just seems like a graphical display but if the controlling process is taken into account its programming should be prepared carefully.

In this program, preparation of graphics according to the project, introducing the previously defined field components and inputs and outputs of the system to the program, supplying the communication between SCADA interface and another device that works as another control unit such as PLC hardware are made. SCADA interface is briefly introduced below and the working logic is given as a summary.

4.2.1. What is SCADA interface?

The term SCADA was formed from the initials of the words "Supervisory Control and Data Acquisition". Briefly; it is the general name of a controlled and supervised system that is created from computers, communication equipments, sensors or other devices. A SCADA interface system gathers information then transfers the information back to a central site and alerts the home station about the alarm, carries out necessary analysis and control, and displays the information in a logical and organized fashion. SCADA interface systems can be relatively simple, or incredibly complex.

The development of the applications is typically done in two stages. First the process parameters and associated information (e.g. relating to alarm conditions) are defined through some sort of parameter definition template and then the graphics, including trending and alarm displays are developed, and linked where appropriate to the process parameters [23].

Recent improvements in computer and communication technologies and cost savings in equipments related to these technologies make the automation of the systems technically and economically practicable. SCADA interface that is used for the systems that makes monitoring and data collection procedures for the processes, forms a substructure with the devices used in the controlling of factory processes (raw materials, production and finished goods tracking, etc..) such as PLC hardware. Objective is to form the necessary structure for producing more at minimum cost with better quality. SCADA software packages take the role of substructure software and provides the traceability of the process from anywhere by connecting to the networks in a facility. The advantages of SCADA interface system are:

- The computer can record and store a very large amount of data
- The data can be displayed in any way the user requires
- Thousands of sensors over a wide area can be connected to the system
- The operator can incorporate real data simulations into the system
- Many types of data can be collected from the PLC hardware
- The data can be viewed from anywhere, not just on site

4.2.2. Planning a Project

Projects must be planned before starting to work on. It is important to consider the following when planning a system:

The physical layout of a plant: physical layout of the system should be considered. It will help to determine the architecture of the SCADA project and its operational requirements also this process allows the designer to determine the needed additions or requirements.

Operational requirements: operational requirements are needed to define a comprehensive list of needs and objectives that the system should effectively monitor and control. These operational requirements include such as security, reliability, monitoring, data collection etc.

Project design: Once operational requirements are developed how to design the project should be planned.

Building the project: Once requirements and design are determined implementing the design in SCADA program can be started.

4.2.3. SCADA Software

In this study Vijeo Citect software is used to ensure the controlling procedure. This software is a production of Schneider Electric. Because Vijeo Citect is produced compatible with the PLC model and the software it was easy to adapt program variables, inputs and outputs defined in PLC program to the SCADA program. The most important performance criterion that is expected from a SCADA interface is to capture data from the field without any problem. Citect is able to communicate seamlessly with field elements via different communication protocols.

Vijeo Citect’s architecture can be divided into three parts as configuration, runtime and drivers. Runtime is the implementation of a project in a live production environment. The runtime tools enable to run, monitor, and control projects during runtime.

Drivers enable communication with devices via a number of communication protocols. Vijeo Citect can communicate with I/O devices such as PLC hardware. The I/O device may be directly connected or remotely connected to the I/O server. Drivers can communicate with devices with some communication protocols including Ethernet, TCP/IP, and Serial. In this study Ethernet protocol is used to communicate PLC hardware and SCADA interface with each other.

Configuration involves all the tasks required to prepare and build a project. Configuration consists of three main sections. Sections are preferred according to the process. The names of these sections are defined as follows:

- Citect Explorer
- Citect Project Editor
- Citect Graphic Builder

Citect Explorer is the application used to create and manage projects. Citect Explorer displays a list of all projects, and provides direct access to the components of each.

Citect Project Editor is the application used to create and manage the configuration information for the project, including tags, alarms, system components, and communications components.

Citect Graphics Builder is the application used to design, create, and edit the graphics components of a project, including templates, graphics objects, symbols and etc.

All stages of the project takes place in these three windows that open in different types, and these three pages serves as a configuration tool. Detailed information will be given in the next sections about the parts used when creating this study.

4.2.4. SCADA programming

Creating a project file

First it is needed to create a project file to start the program. This file contains the components of the project. These components are named as graphics components, tags, alarms, system components, communications components, I/O Server components and Cico / CitectVBA. Project components are kept inside the related created file. Project components part and creating a file is shown in Figure 4.10 below.

The graphical components part that is seen in Figure 4.10 represents the content used to create the screens presented on display clients such as pages, templates, symbols etc. All pages that compose the project are stored inside this file.

Tags are used to identify the end points that are used for monitoring and controlling by Citect.

Alarms are used to identify conditions that require attention.

The system allows the user to customize, manage, and track the runtime system. It includes components such as keyboard commands, reporting information, configuring devices, fonts, users etc.

The communications components are the configured representation of the communications hardware in the system.

The server components are the configured representation of the server computers in the system.

Lastly two programming languages with which you can control and manipulate the program are also given as a component that has the names CiCode and Citect VBA. In this study both two languages are used for programming.

Making the communication settings

SCADA interface will serve as a control element of a project, but communication should be provided with the other control unit PLC hardware that takes the data from field. Thus, from Citect Project Editor page communication settings should be realized and the information such as the addresses from where SCADA interface takes the data and send commands to exactly where, the communication type, IP address, Ethernet module should be introduced to SCADA interface. For this, some data should be available in the PLC program and must be transferred to this communication part.

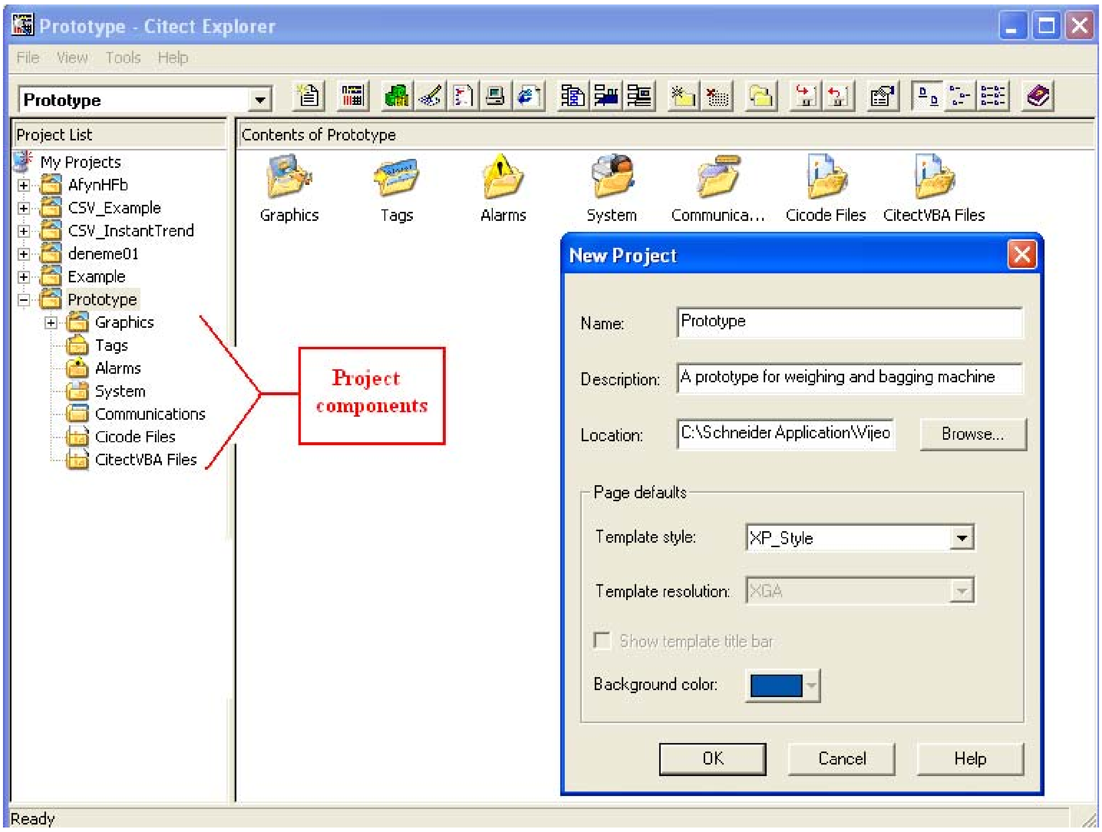

Figure 4.10: Project components and creating a new file

Creating the shape of the pages

After the project file is defined and formed, the creation of pages that the user see can be called as the second step. New pages are created through the graphics component shown in Figure 4.11 to provide the user to fully control the system or to see all the objects such as system variables, graphs, trends and alarms. Arrangement of these pages depends on the design of the programmer. Generally, process to be controlled should be taken into account to determine the appropriate page. In this study, a simple design is made considering the plant that the prototype will be placed on and the workers who will operate this prototype. Figure 4.11 shows an example of a newly formed page.

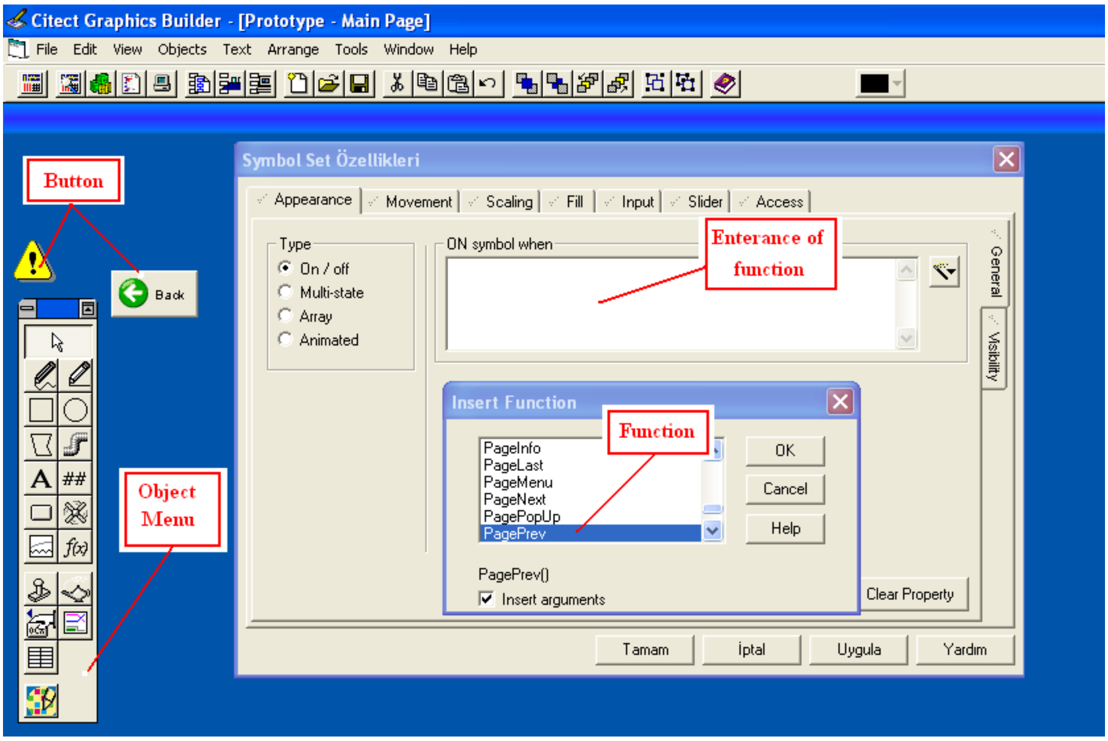

Figure 4.11: Forming a page

Necessary objects must be selected from the object menu when creating a page. Objects are basic drawing entities that are added to the graphics pages. Objects are drawn using the tools in the drawing toolbox, and can be moved, reshaped, or copied after they are drawn. A button, a text, a function or any geometric shape can be an object. The ‘back button’ appears in the Figure 4.11 is created by combining several objects such as a rectangle, a button and an arrow image. A variety of buttons which can be chosen from the library is also available, just as the alarm button as shown in the Figure 4.11. Whether it is chosen from the library or prepared by the programmer all objects certainly should know its duty. In other words object should realize what to do when it is activated. For that, assignments should be made for the used objects in the ‘Object Properties Window’. Assignment is performed by inserting the function that is related to the duty of the object. This function can be taken from the predefined functions or the programmer can write a function. The task of the ‘back button’ shown in Figure 4.11 is to translate the page to the previous page. For this, ‘PagePrev’ phrase is entered into the ‘entrance of function part’. All the buttons should be created by making appropriate assignments like this way and then designing the page could be completed.

Adding the variable tags

After all these instructions are made, a little confusing but one of the crucial points of the program, tags must be added to the program. Tag means that the data comes from the field or the data send to the field by the PLC hardware is addressed and labeled. Each I/O device variable (PLC hardware input and outputs) that is used by Citect should be assigned a variable tag. To define variable tags, they should be declared in the variable tag database. The variable tag becomes a label, used to reference the address of the I/O device register. Using labels has several benefits such as programmer does not have to remember the address every time he/she want to use the variable (tag name should be logical and descriptive and less confusing) and because of the address in the I/O device is defined only once if the address is changed, the only need is to update the variable tag definition, not every instance in the configuration.

For example; PLC hardware controlled 'low limit' or 'system auto' data should be assigned to a particular address to be processed also by SCADA interface and it should be labeled to understand of what action it is performing. However, this labeling is different for digital and analog data. Here shown in the Figure 4.12 sample entrance has been made for both digital and analog data. These entries are made by using the Project Editor page. As it is seen from the Figure 4.12 names are given to the variable tags, I/O devices are introduced and addresses are assigned depending on whether it is digital or analog by taking into account the memory places of the data on PLC program.

The name of the I/O device (PLC hardware) is where the variable is stored. In the communication part the type of the PLC hardware is introduced to SCADA interface. So identified name can be written. The register address in the I/O device (PLC hardware) is where the variable is stored. Every SCADA interface determines its own form of addressing. Data to be digital or analog or being an input or an output changes the presentation of the address. This value is written by researching the library of the SCADA interface. Another space to be filled is the type of the data.

As described previously in PLC hardware module inputs and outputs, resolution should be inserted for the analog data. 'Raw zero scale and raw full scale' sections contain this data. For this study it is zero and 4096 (resolution of the module inputs and outputs are 2^{12}). 'Eng zero scale and eng full scale' sections include the information of maximum range of the measurement data. For example for 'weighing value' eng zero scale should be entered zero and full zero scale should be inserted 5000, because the load cell performs the weighing operation in this range. Lastly, unit of the measured value is inserted. Figure 4.12 shows all these described.

After variable tags are defined they can be used for; displaying objects on a graphics page, storing data for trending and analysis, monitoring alarms, controlling equipment and processes and lastly store data in memory. SCADA software Vijeo Citect stores the variable tags in an MS Excel file shown in Figure 4.13

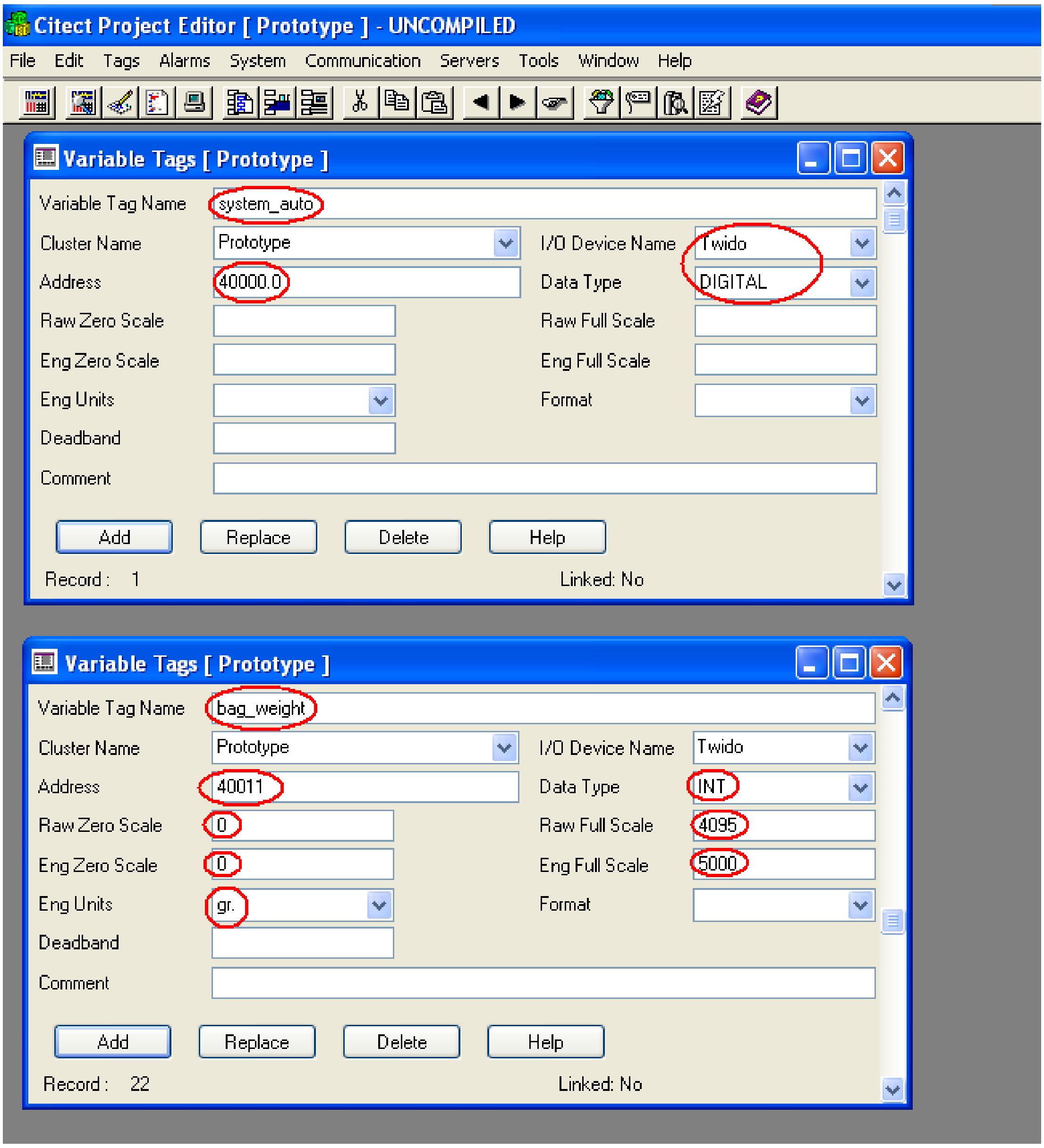

Figure 4.12: Entrance of variable tags

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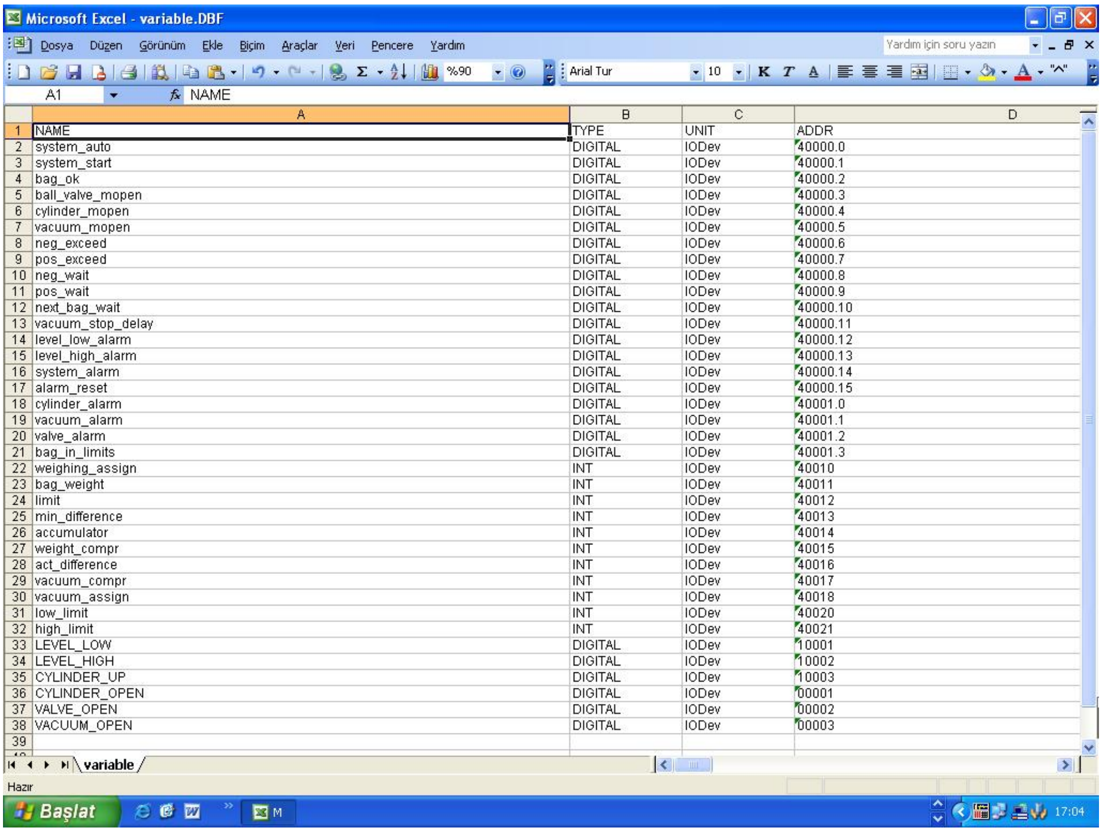

NAME	TYPE	UNIT	ADDR
system_auto	DIGITAL	IODev	40000.0
system_start	DIGITAL	IODev	40000.1
bag_ok	DIGITAL	IODev	40000.2
ball_valve_mopen	DIGITAL	IODev	40000.3
cylinder_mopen	DIGITAL	IODev	40000.4
vacuum_mopen	DIGITAL	IODev	40000.5
neg_exceed	DIGITAL	IODev	40000.6
pos_exceed	DIGITAL	IODev	40000.7
neg_wait	DIGITAL	IODev	40000.8
pos_wait	DIGITAL	IODev	40000.9
next_bag_wait	DIGITAL	IODev	40000.10
vacuum_stop_delay	DIGITAL	IODev	40000.11
level_low_alarm	DIGITAL	IODev	40000.12
level_high_alarm	DIGITAL	IODev	40000.13
system_alarm	DIGITAL	IODev	40000.14
alarm_reset	DIGITAL	IODev	40000.15
cylinder_alarm	DIGITAL	IODev	40001.0
vacuum_alarm	DIGITAL	IODev	40001.1
valve_alarm	DIGITAL	IODev	40001.2
bag_in_limits	DIGITAL	IODev	40001.3
weighing_assign	INT	IODev	40010
bag_weight	INT	IODev	40011
limit	INT	IODev	40012
min_difference	INT	IODev	40013
accumulator	INT	IODev	40014
weight_compr	INT	IODev	40015
act_difference	INT	IODev	40016
vacuum_compr	INT	IODev	40017
vacuum_assign	INT	IODev	40018
low_limit	INT	IODev	40020
high_limit	INT	IODev	40021
LEVEL_LOW	DIGITAL	IODev	10001
LEVEL_HIGH	DIGITAL	IODev	10002
CYLINDER_UP	DIGITAL	IODev	10003
CYLINDER_OPEN	DIGITAL	IODev	00001
VALVE_OPEN	DIGITAL	IODev	00002
VACUUM_OPEN	DIGITAL	IODev	00003

Figure 4.13: MS Excel file of the variable tags

User Interface of the SCADA Program

After completing the procedure described above, preparing and assignment of graphics, control buttons or other objects which we want to see on the pages remains to be done. The Figure 4.14, Figure 4.15, Figure 4.16 and Figure 4.17 below show the pages that are prepared for this study.

This project is mainly made up of four pages. The first page is the ‘Start up Page’ that meets the operator. On this page the assembly drawing of the prototype is located and also the manufacturing company's logo is available. Page automatically switches to the main page after 20 seconds of appearance. The Start-up page is shown in Figure 4.14.

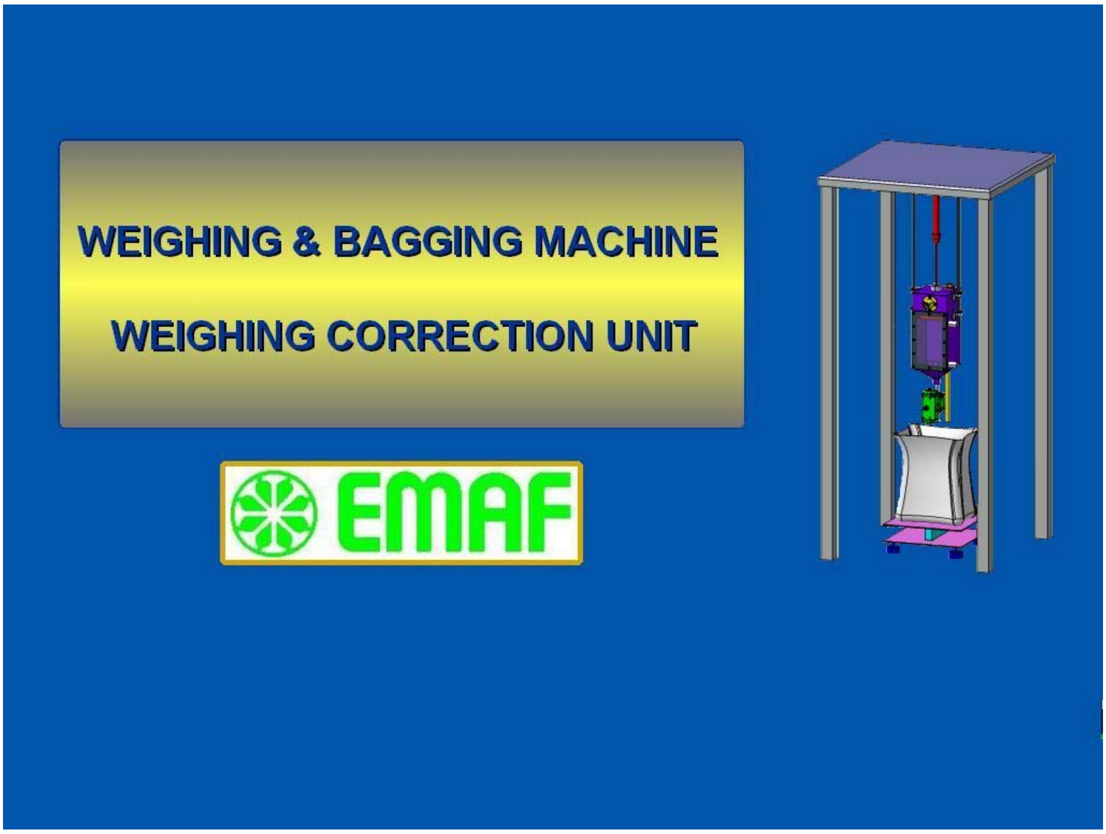

Figure 4.14: Start up Page

The second prepared page has the name of 'Main Page' and it is the main control page that the operator uses frequently. However, before that, 'Adjustments and Component Properties Page' is necessary to explain. As shown in Figure 4.15 Adjustments and Component Properties Page is a page that includes entrances for the numeric values required for the calculation of some variables in the system, at the same time trademarks and the models of the components that used in the system is given on this page. The values shown on this page can be defined as follows:

- There is a 'BAG WEIGHT' tab for entering the weight of the bag that will be measured. In this study, the prototype is tested for 1-kilogram bags so the value 1000 grams should be entered to the tab. This value is necessary for determining the weight of the bag is whether in limits or not.

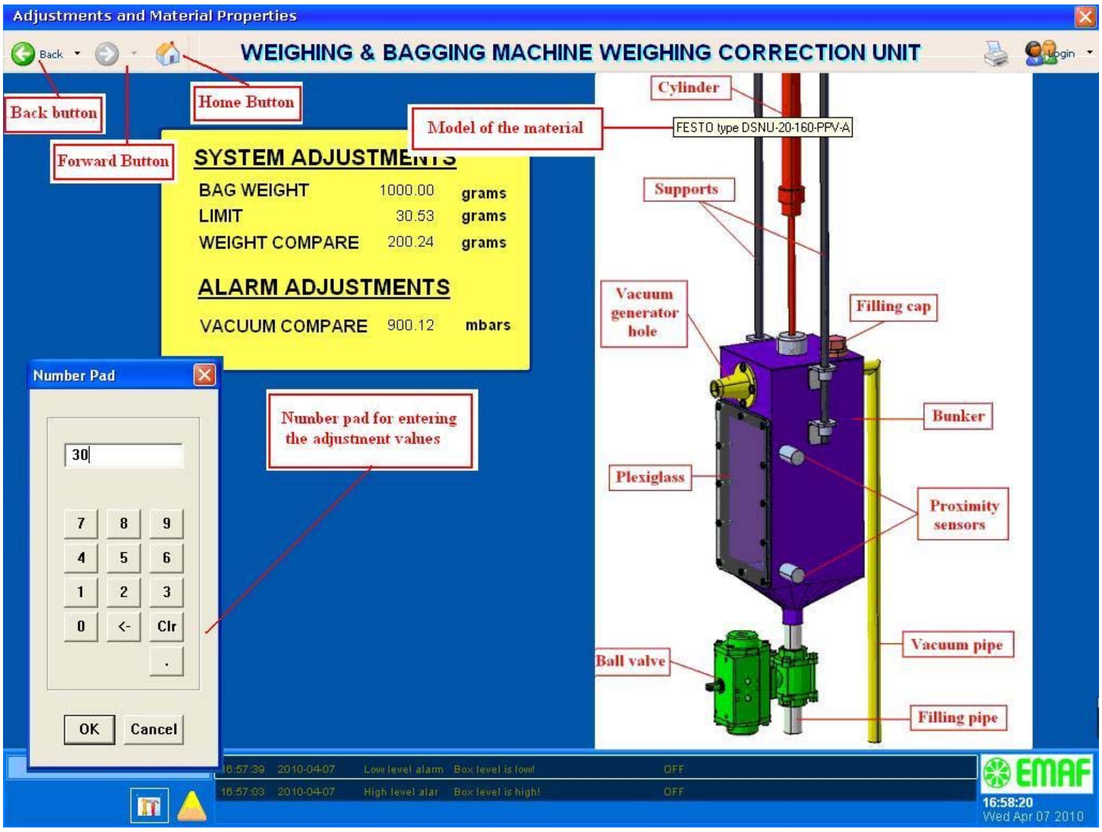

Figure 4.15: Adjustments and Component Properties Page

- Entering the limit value is necessary to calculate the allowable limits. There is a tab that seems as ‘LIMIT’. For this study as mentioned before the allowable limits for the sugar bags are ±30 grams. So the value 30 should be entered to this tab. The program now knows the permitted bag weight is changes between 1000+30=1030 grams and 1000−30=970 grams.

- There is another tab to be filled. ‘WEIGHT COMPARE’ tab is placed there for understanding if there is any bag or not on the scale. It is a comparison value. Program compares the weight value on the scale with this written value. The value that will be written here should be very smaller than 1000 grams for system to detect the presence of bag that’s to say 200 grams. In other words, if there is a weight data larger than 200 grams system understands that there is a bag on the scale.

- With the same logic, there is a tab named as ‘VACUUM COMPARE’. It is a comparison value and program compares the vacuum value read from the pressure transmitter with this written value. Absolute pressure value is measured in Ankara as 914 mbar. Any value that is below this value can be written as a comparison value.

- After a long time working, absolutely wear and defect problem will arise in certain parts of the system. So, replacement of some parts will be needed in the future or somehow operator can require help or need catalogue information about the devices mounted on to the system. That's why the trademark and the model of each device mounted on to the system are included on this page. By this means, ordering even maintenance will be easier for the operator.

The most used page for the operator will be the ‘Main Page’. As seen in Figure 4.16 it is possible to see all the operations related about the prototype. Belonging to the prototype; bunker, cylinder, proximity sensors that measure the level, ball valve, vacuum process, scale, bag are all ready with their graphics and animations on this page. Controls that will be carried out according to the process and everything that is to be displayed on the screen are realized in the following way:

- When this page comes along, the control buttons, two graphs and graphic of the prototype will appear on the page.

- Control buttons are named as ‘MANUAL’, ‘AUTO’, ‘START’, ‘STOP' and ‘SYSTEM RESTART’. The system starts by pressing the ‘START’ button. If automatic operation of system is desired, ‘AUTO’ button is used, if manual operation is desired operator should push the ‘MANUAL’ button. As its name suggests, the ‘STOP’ button stops the system. Restarting of the system is provided by the ‘SYSTEM RESTART’ button.

- When the prototype starts working, only the bunker and weighing mechanism appears on the page.

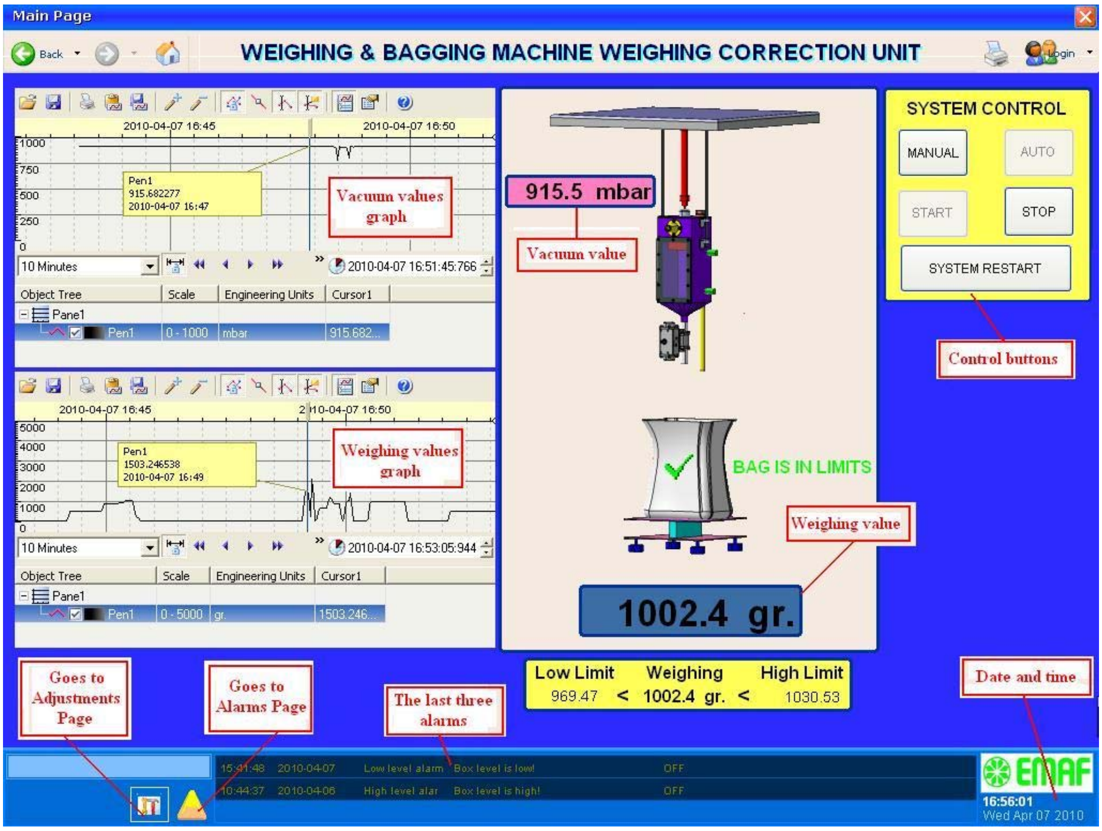

Figure 4.16: Main page

- When a bag comes on to the scale, first, system checks whether there is a bag or not according to the ‘BAG COMPARE’ value entered in the Adjustments and Component Properties Page. If the system convinces that there is a bag, a bag graphic appears.
- If the system fails to convince that there is a bag, there will not be a bag graphic on the page.

- Weighing value can be read from screen all the time. Also it is possible to see the calculated low limit and high limit constantly on the window.

- Now, system knows there is a bag on the scale and starts to calculate the bag is whether in the desired range or not. After system decides that the bag stays in the allowable limits, a check mark appears on the bag graphic and at the same time 'BAG IS IN LIMITS' text comes to the screen to inform the operator that bag stays in the allowable range and no intervention will be done by the system.

- After the calculation, if the bag doesn't stay in the desired limits, vacuuming or filling process starts. In vacuuming, cylinder moves down as an animation. If the process is vacuuming then the vacuum value will be visible on the screen together with its unit mbar. When the process turns to filling, the operator sees the ball valve is working. If the valve is green this means that valve is opened, if its color is grey then this represents that the ball valve is closed.

- After filling or vacuuming process are completed cylinder moves upwards with an animation. In the meantime, system again checks the bag after the weighing correction finishes.

- System continuously checks for alarms. If a component doesn't work in a desired way an alarm appears on the screen. When the cylinder doesn't make the asked behavior, 'cylinder cannot be started' text come into view. If there is any problem with the working of the vacuum, the alarm 'vacuum cannot be started' appears at the bottom of the screen. When ball valve doesn't open or closed although it is asked to do it, system gives alarm by flashing animation. Valve flashes with changing colors. On the other hand 'valve cannot be started' text can be read at the bottom of the page. For each alarm, the alarm icon can be observed with flashing on the screen and each alarm is written to the Alarms Page.

- Sugar level of the bunker is also continuously checked by the system. If there is no problem occurred related to the level of the bunker, then the proximity sensors are green. If a level alarm exists, sensor begins to flash in different colors in where the problem occurs.

- Meanwhile, last three alarms are shown at the bottom of the page.

- The weighing data and vacuum data are displayed graphically on the left side of the page. Owing to this graphs vacuum and weighing trends can be observed.

- On the upper left corner of the page operator sees ‘forward’, ‘back’ and ‘home’ buttons. The ‘forward’ button is available to switch the current page to the next page and with the ‘back’ button previous page can be displayed. The ‘home’ button switches the page to the main page no matter where the operator is. Page's upper right corner has the ‘log’ button for entering a password and ‘print’ button for printing the current page.

- In the lower left corner of the page there are two buttons for direct switching to Alarms Page and Adjustments and Component Properties Page. The company’s name also included on the bottom right, with the data of date and time. All of these controlling buttons is available in all other pages except the Start up Page

The last page that is prepared is the ‘Alarm Page’. This page shows all the alarms that the system gives with their occurring date and time. At the same it is possible to see the time of starting and resetting of the alarms. Differently from other pages, there is small menu that is used for choosing the appearance of alarm showing on the left side of the page. This page can be seen from Figure 4.17.

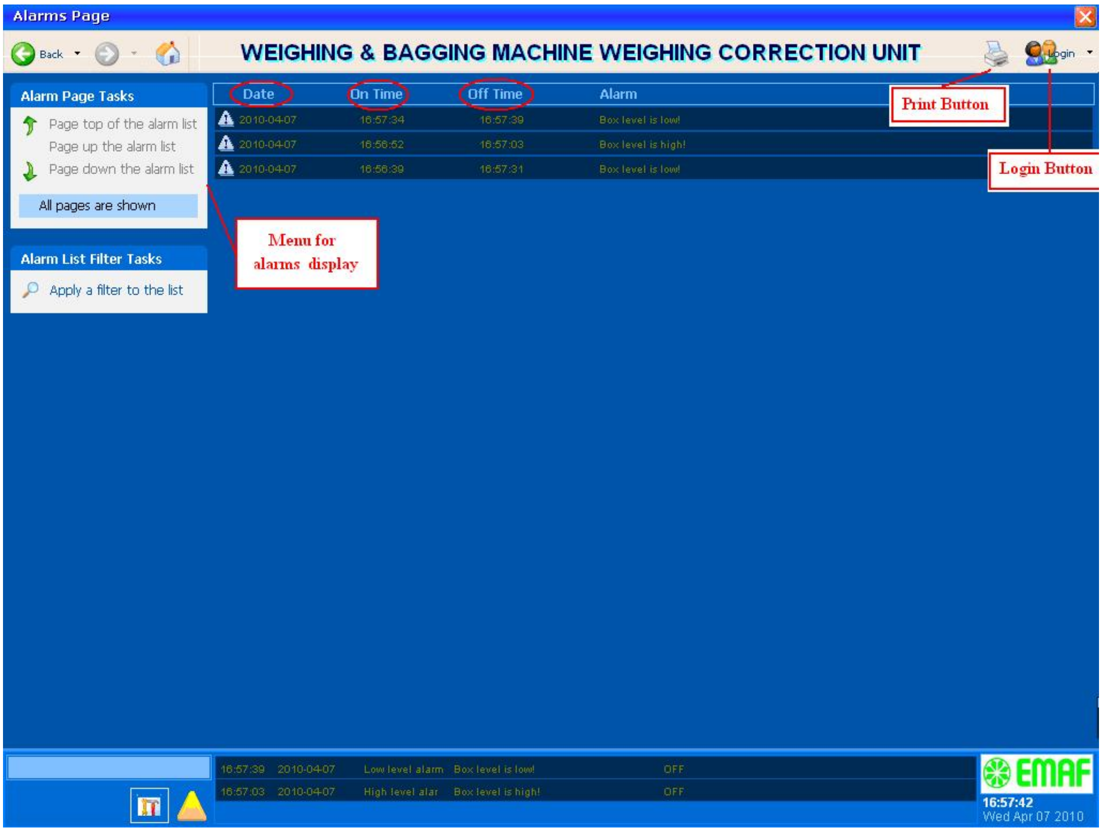

Figure 4.17: Alarms Page

CHAPTER 5

TEST RESULTS and DISCUSSION

5.1. Test results and discussion

Organizing the mechanical parts and hardware parts of the prototype and development of software are explained up till now. After the prototype is constructed and PLC and SCADA software are completed, performance of the system is tested with experimental study.

For the test weight 2-kilogram bags are chosen, then they are filled with sugar and prototype is tested. First, performance of the extraction process, then working accuracy of the filling process is tested. The test amount of the sugar that exceeds the allowable limit or the test amount of sugar that is deficient is designated by the data obtained from statistical analysis. That is to say; excess weights and deficient amounts are same with the result of the statistical analysis that shown in Table 3.2.

Lower and upper allowable limit is calculated according to deviation value that appears in the regulations of Ministry of Industry. To remind if necessary; the regulations explains that allowed deviation for X class weighing machines is ± 30 grams. So, by taking the deviation value as ± 30 grams the limits are calculated. Tests are realized according to the values given below:

Test weight : 2000 grams

Deviation : ± 30 grams

Upper allowable limit: 2000 + 30 = 2030 grams

Lower allowable limit: 2000 – 30 = 1970 grams

These values states that after prototype vacuums the excess sugar or fills the deficient bags, all the weighing values should remain in the 1970 – 2030 grams range. If weighing stays in these limits this means that prototype works as requested.

Testing weights of the bag and the weight of the bag after the intervention of the prototype is given in Table 5.1 and Table 5.2. Table 5.1 shows the test results of the excess sugar bags and Table 5.2 represents the test results of the deficient sugar bags.

To comprehend the given tables two examples will be given for the excess sugar bags and deficient ones. For instance, if Table 3.2 is examined; it can be seen that one of the excess sugar amount is 48 grams. If this value is added to the upper limit 2030 grams; 2078 grams is obtained. This value forms the testing weight and it can be seen in Table 5.1. This means that to achieve the allowable range prototype should suck at least 48 grams. Similarly, if one of the deficient values in Table 3.2 is chosen, for example 82 grams, this value should be subtracted from lower limit 1970 grams, result should be 1888 grams. This is the value of the test weight and it is shown in Table 5.2. According to 1888 grams, prototype should add at least 82 grams of sugar to make the weighing stay in desired limits.

Results of the tests seem very affirmative if Table 5.1 and Table 5.2 are examined. Prototype appears to work accurately for the vacuuming and filling processes. Totally 220 measurements are realized and one measurement stays out of the desired limits as shown in Table 5.1 with asterisk. However, the deviation is only 1 gram. With a rough estimation, for these tests error rate appears as 0.45%. There should be more measurement results to understand the working of the prototype is errorless. Nevertheless, this result is very convincing for deciding that the prototype works properly.

One item that should be mentioned is the time of the process. As stated in requirements of the prototype – Section 3.1– process should be completed in 8 seconds. This target value is achieved while the tests are performed. Filling process is completed in 4 – 5 seconds. Besides, time of vacuuming changes between 4 – 8 seconds due to the amount of sugar that should be sucked. These values are very appropriate for the process.

Table 5.1: Test results for excess bags

	TESTING WEIGHTS					
	2038 grams	**2048 grams**	**2058 grams**	**2068 grams**	**2078 grams**	**2088 grams**
WEIGHT OF THE BAG AFTER THE INTERVENTION OF THE PROTOTYPE	1980 grams	2010 grams	1975 grams	1980 grams	1975 grams	1978 grams
	1978 grams	2024 grams	2004 grams	1980 grams	1972 grams	2008 grams
	1984 grams	2011 grams	2000 grams	2004 grams	2000 grams	1998 grams
	1976 grams	1998 grams	1980 grams	1990 grams	2010 grams	2007 grams
	1978 grams	2006 grams	1986 grams	2016 grams	1985 grams	1996 grams
	1980 grams	2001 grams	2010 grams	1985 grams	1990 grams	2015 grams
	1982 grams	2002 grams	2006 grams	2006 grams	1992 grams	2019 grams
	1986 grams	2007 grams	2010 grams	1990 grams	2004 grams	2020 grams
	1972 grams	2000 grams	2014 grams	2004 grams	2010 grams	2024 grams
	1980 grams	2002 grams	2002 grams	2004 grams	2020 grams	2001 grams

Table 5.1: Test results for excess bags (continued)

	TESTING WEIGHTS				
	2098 grams	**2108 grams**	**2118 grams**	**2128 grams**	**2138 grams**
WEIGHT OF THE BAG AFTER THE INTERVENTION OF THE PROTOTYPE	1973 grams	2019 grams	2026 grams	2011 grams	2004 grams
	1997 grams	2014 grams	2018 grams	2019 grams	2009 grams
	2013 grams	2007 grams	2018 grams	2013 grams	2012 grams
	2017 grams	2000 grams	2023 grams	2000 grams	2012 grams
	2031** grams	2013 grams	2029 grams	2013 grams	2015 grams
	2011 grams	2008 grams	2004 grams	2012 grams	2000 grams
	2015 grams	2020 grams	2026 grams	2007 grams	2023 grams
	2020 grams	2020 grams	2006 grams	2030 grams	2026 grams
	2028 grams	2000 grams	2030 grams	2004 grams	2026 grams
	2017 grams	2026 grams	2024 grams	2029 grams	2026 grams

Table 5.2: Test results for deficient bags

	TESTING WEIGHTS					
	1968 grams	**1958 grams**	**1948 grams**	**1938 grams**	**1928 grams**	**1918 grams**
WEIGHT OF THE BAG AFTER THE INTERVENTION OF THE PROTOTYPE	2002 grams	1990 grams	1993 grams	1996 grams	2006 grams	2000 grams
	2000 grams	1994 grams	1986 grams	2000 grams	2006 grams	2007 grams
	1996 grams	1980 grams	1995 grams	2002 grams	2004 grams	2010 grams
	2004 grams	1984 grams	1998 grams	2004 grams	2006 grams	2005 grams
	1994 grams	1986 grams	2000 grams	1998 grams	1998 grams	1998 grams
	2002 grams	1992 grams	2002 grams	2000 grams	1995 grams	2004 grams
	1998 grams	1996 grams	1996 grams	1996 grams	2000 grams	2000 grams
	1995 grams	1990 grams	2000 grams	1995 grams	1996 grams	1996 grams
	2002 grams	2000 grams	2004 grams	2001 grams	1998 grams	2002 grams
	2000 grams	1998 grams	2006 grams	2000 grams	1996 grams	2004 grams

Table 5.2: Test results for deficient bags (continued)

	TESTING WEIGHTS				
	1908 grams	**1898 grams**	**1888 grams**	**1878 grams**	**1868 grams**
WEIGHT OF THE BAG AFTER THE INTERVENTION OF THE PROTOTYPE	1987 grams	1996 grams	1986 grams	1980 grams	1975 grams
	1990 grams	1990 grams	1985 grams	1984 grams	1980 grams
	1992 grams	1998 grams	1990 grams	1981 grams	1976 grams
	1985 grams	1995 grams	1993 grams	1990 grams	1982 grams
	1994 grams	1997 grams	1998 grams	1985 grams	1986 grams
	2000 grams	2000 grams	1994 grams	1993 grams	1980 grams
	1996 grams	2010 grams	2000 grams	1995 grams	1976 grams
	1996 grams	2012 grams	2000 grams	1980 grams	1990 grams
	2002 grams	2002 grams	2004 grams	1984 grams	1992 grams
	2000 grams	1997 grams	2004 grams	1992 grams	1998 grams

In Section 3.2 the aim of this study is defined and design process for the prototype is explained. Also a list is given for indicating the design goals. These goals were accuracy, resolution, computer interface, ease of use and easy maintenance. How the requirements were met is given below.

The accuracy of the system is tested using the known weights (etalons) and no error occurs in the weighing mechanism.

For the resolution; an indicator and a PLC analog input module that has a high resolution are used. The resolution of the indicator is 2^{16} and the resolution of the analog input module is 2^{12}.

The data coming from the field is translated into signals and with the help of SCADA interface it can be displayed on the screen so computer interface could be realized.

The user interface is designed with simple appearance that allow the user obtain the necessary data and control them easily.

Easy maintenance is provided by using simple attachments and devices that could be renewed readily. Replacement parts could be easily found and implemented. This also reduces the maintenance and repair costs.

As it is seen from the test results every requirement that is mentioned is realized in this thesis study. System works accurately in a desired period of time with a low error rate. This situation matches up with the aim that is explained in design process. However, some changes can make this prototype more accurate and more demandable for the users.

For future works, some studies could be made about the shape of the sugar mass that occurs after it is filled with weighing and bagging machine. Sugar in the bag takes a curve form that resembles a hill and the height of this hill is not constant for all sugar bags. Sometimes it has a small curve but sometimes the hill's height is very high. This situation affects the accuracy of the weighing in extraction process. Because, when the sugar is excess in the bag, cylinder moves downwards and vacuum pipe sucks the sugar to the bunker. During this operation vacuum pipe dives into the bag, it makes a pressure on it and changes the weight data. PLC program is designed such a way that it can overcome this problem. However, when the sugar in the bag has a higher hill the pressure of the vacuum pipe on the sugar is higher. Beside this, completing time of the process could be shortened for faster operation time.

CHAPTER 6

COST ANALYSIS

6.1. Cost analysis

In this study, a solution has been generated to a problem that affects the sugar weighing and packing facility in sugar factories. However, it is not proven whether this solution is worth implementing or not. In this solution suggestion, various components and labor are disbursed so a lot of time and money is invested to this study, even; after the system started working other costs are brought to the agenda. Thus, it seems essential to compare the new system with the former application to see the effectiveness and necessity of the new facility. To make the cost analysis simply all the expenses are added up for the new and former application and then compared with each other.

All working systems have their own various expenses that can be divided into two parts; direct costs and indirect costs. Direct costs are the component and labor costs. Indirect costs are the expenses that are not in the sight such as maintenance, personnel insurance, depreciation, electricity, compressed air, water etc. The calculations below shows the all expenses spent for this project and it includes all the costs without separating it is direct or indirect.

6.1.2. Costs in the existing system

For the current system only cost is the labor cost, since one employee corrects the faulty weighed sugar bags.

- Labor: 3 shifts a day for 124 days of campaign. This means that three worker work for 124 days. According to the data taken from counting department of the Ankara Sugar Factory a worker costs to the factory 152 TL/day with his/her wage, unemployment insurance, health insurance, clothing allowance, sugar allowance, family allowance, gratification, meal, service bus etc. This means that for a campaign one worker costs to the factory 18848 TL. For three shifts this value results as 56544 TL.

6.1.3. Costs in the new system:

- Investment costs : It is defined as labor and equipments.
- Energy costs : Energy costs are the money that is spent for making compressed air and supplying electric.
- Maintenance

Cost analysis for the new system:

Equipment

Panel

Panel's Electrical Part

Automats	100 TL
Power Supply	55 TL
CPU	375 TL
Analog in – out module	300 TL
Ethernet communication module	225 TL
Power supply	150 TL

Additional equipments (terminals, cable etc.)	100 TL
License of SCADA Software	1050 TL

Panel's Mechanical Part

Panel itself	50 TL
Vacuum generator	150 TL
Pressure transmitter	1000 TL
5/2 Directional control valve (cylinder)	115 TL
5/2 Directional control valve (actuator)	115 TL
Solenoid valve	47.75 TL
Additional equipments (regulator, silencer, hose, fittings etc.)	385 TL

Prototype's working system

Cylinder	84 TL
Bunker	10 TL
Ball valve and actuator	190 TL
Proximity switches	80 TL

Indicator and load cell (wasn't taken into account because weighing system is available in each factory)

Labor

When parts are produced, labor has been spent only for the mechanical and electrical installation of the electric panel and for manufacturing the bunker. The total cost for this labor is 1400 TL.

Electric costs

After end of the each campaign, sugar factories compute the expenditures that are made to work the factory. One of the most important of these is the cost of electricity. All electricity used in factory facilities is produced by the turbine units during the campaign. As long as any failure does not occur in turbines, city main electricity does not used. So it is relatively easy to calculate the cost of electricity. Calculated electricity costs in the 2009 – 2010 campaign period is 0.17 TL/kW.

The determination of the cost of electricity for this project has become very easy because electric consumption of the each working elements listed above is calculated. The sum of the listed components becomes as 50.736 W/h for the full performance. During the campaign this system spends 150.990 kW and this means electricity cost is 26 TL for all 124 days of campaign.

Cost of the compressed air

To compute the cost of compressed air required fee per cubic meter should be found. Because the cost of electricity is known cost of compressed air is calculated in terms of electricity consumption. For this, the flow rate and the power of the compressor have been used. Compressors used in the factory has 1290 m^3/h flow and has the energy value of 160 kW/h. Dividing the value of the power to the flow rate gives the result of consumed energy for producing a cubic meter of compressed air in kW/m^3. For this compressors value appears to be 0.124 kW/m^3.

As noted previously, the cost of electricity during the recent campaign is 0.17 TL/kW, respectively. In this case, the cost of compressed air to the factory is calculated as 0.021 TL per cubic meter.

Air consumption of the parts that works with compressed air:

Vacuum generator: 7488 l/h (Assumption: 60% usage per every hour)

Actuator: 15 l/h

Cylinder: 438 l/h

Total cost for an hour: 7941 l/h=7.94 m^3/h x 0.021 TL/m^3= 0.167 TL/h

Total cost for a campaign: 497 TL/campaign (this year campaign lasts 124 days)

Maintenance Costs

It seems that there will be no replaced or newly bought component in the revision time after the campaign but 250 TL maintenance and repair costs per campaign is considered affair.

Prototype Body	: 5981.75 TL
Annual Costs	: 773 TL
Total	: 6754.75 TL

As seen from calculations designed system is advantageous in terms of cost. Only the labor cost of the current system is 56544 TL and it is approximately nine times of total new system costs. However, it seems necessary to focus on a point. All the calculations for the new system have been done for the prototype. This means that cost analysis was performed for a small model. Whereas; if the calculations were realized by considering the real conditions size of some components (such as bunker) would increase with the rising cost. Then it would be observed that power consumption and air consumption also increases together with the increasing size. In other words a rising in total expenditures would be in question. However it should be kept in mind that cost effect of the electrical components would not be so high, because same electrical parts would be although the system grows. Despite the cost increase realizes for the real conditions it is clear from the analysis that the designed system is quite efficient and is advantageous compared to the old practice.

CHAPTER 7

CONCLUSION

7.1. Conclusion

In this thesis study, a prototype is designed for weighing and bagging machine that is used in 25 sugar factories all around Turkey. Also a PLC hardware and SCADA interface control is developed to supply full automation to these devices. Objectives of the study were obeying to the national standards, reducing the financial losses because of the faulty weighing, increasing the labor productivity by the redistribution of laborers who are working for correcting the weighing, and also drawing away a worker from production line for more hygienic and healthy fabrication.

To perform this work, first, mechanical parts of the prototype were designed and manufactured. Necessary statistical analysis has been carried out and appropriate bunker size has been computed. After that, pneumatic circuit diagram has been prepared and calculations were done to select the pneumatic components as well as the pneumatic accessories. Mechanical, pneumatic and electrical components have been gathered together and the assembly completed for creating the control panel. As the latest, to control the system PLC code and SCADA programs are written and put into operation.

Before starting this study, facilities in the sugar factories in which improvements can be made have been analyzed. Weighing and bagging facility which has problems because of inaccurate weighing is found quite suitable. Correction of faulty weighing could have been done in the weighing and bagging machine itself. However, according to Ministry of Industry, in order to have a commercial good, a product that is weighed and packed with dynamic weighing machine should also be checked by static weighing. That's why the platform scale is used after the weighing and bagging machine. An employee has been assigned to check and correct the weight of the bag statically. As long as there is a checking unit after weighing and bagging machine, correction can be done easily without interfering the structure of the machine.

As told before in this facility an employee has been assigned to correct inaccurate weighing of sacks manually. If production requirements are taken into account, it is clear that a person could not reach to a speed high enough to correct the faulty weighing. It does not seem possible for an employee to take the excess sugar or fill the deficient bag exactly in 8 seconds time period. However, the designed system has achieved the desired performance criteria and has been able to complete all operations in 8 seconds. This brings a product that is suitable to the standards and more acceptable as a commercial good.

If the cost analysis is considered as well as the production requirements, the system developed in this study is proven to be advantageous in comparison with the current application. Considering all these advantageous, this study will be a basic source for developing automation solutions and applications. This study introduces faster solutions to correct the inaccurate weighing so that sugar factories could use their resources more effectively. As a result, it will be a positive contribution to the public economy.

Today, development of automation technologies has gained momentum in the world. SCADA interface being a part of this technology serves its benefits for users. SCADA interfaces are easy to use and has very low margin as well and also they can work stable without consuming the PC resources. By monitoring the process in real time we can minimize the operational costs by means of providing direct information of system performance so it improves the system efficiency and performance. This increasing performance results in extended life of equipments and reducing the labor costs required for troubleshooting or servicing the equipment. Also, archiving the system data and statistical reports provides effective and economical process management.

As a result, the system is produced and activated satisfying the design criteria, and the desired affirmative results are obtained. This study is an initial step in the progress of full automation of the facilities in sugar factories all around Turkey that belongs to TŞFAŞ as well as a contribution to minimizing the costs.

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APPENDIX A

DETAILS OF MECHANICAL COMPONENTS

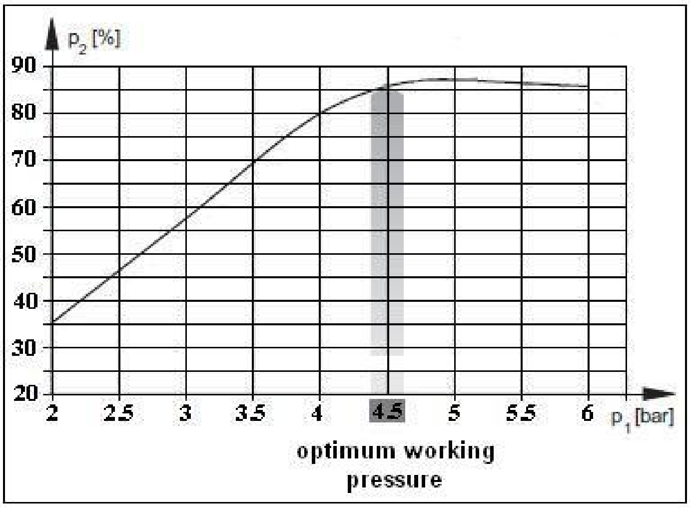


Figure A.1: Vacuum P_2 depending on working pressure P_1 for vacuum generator

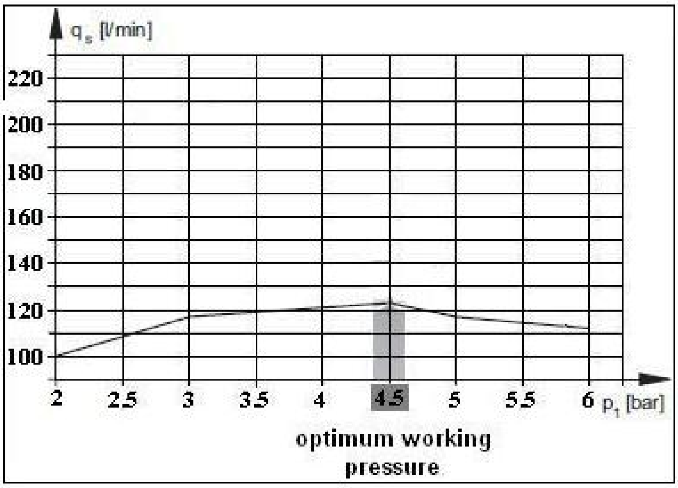


Figure A.2: Suction capacity q_s depending on working pressure P_1 for vacuum generator

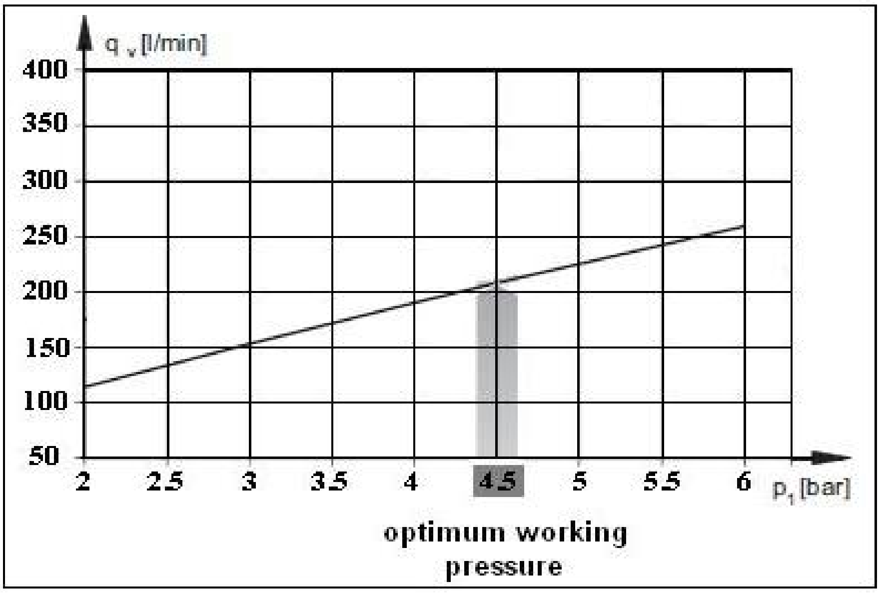


Figure A.3: Air consumption q_v depending on working pressure P_1

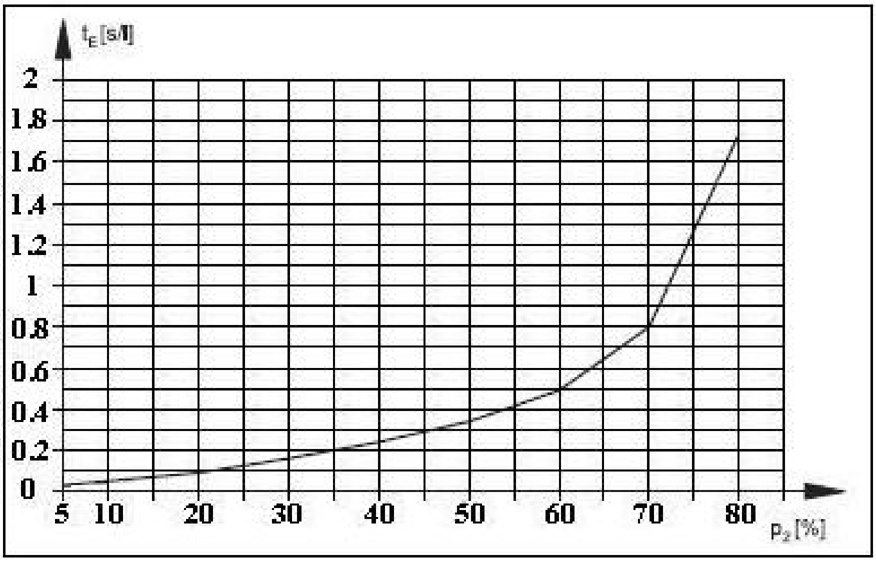


Figure A.4: Evacuation time t_E depending on vacuum P_2 for 1 liter volume (with optimal operating pressure)

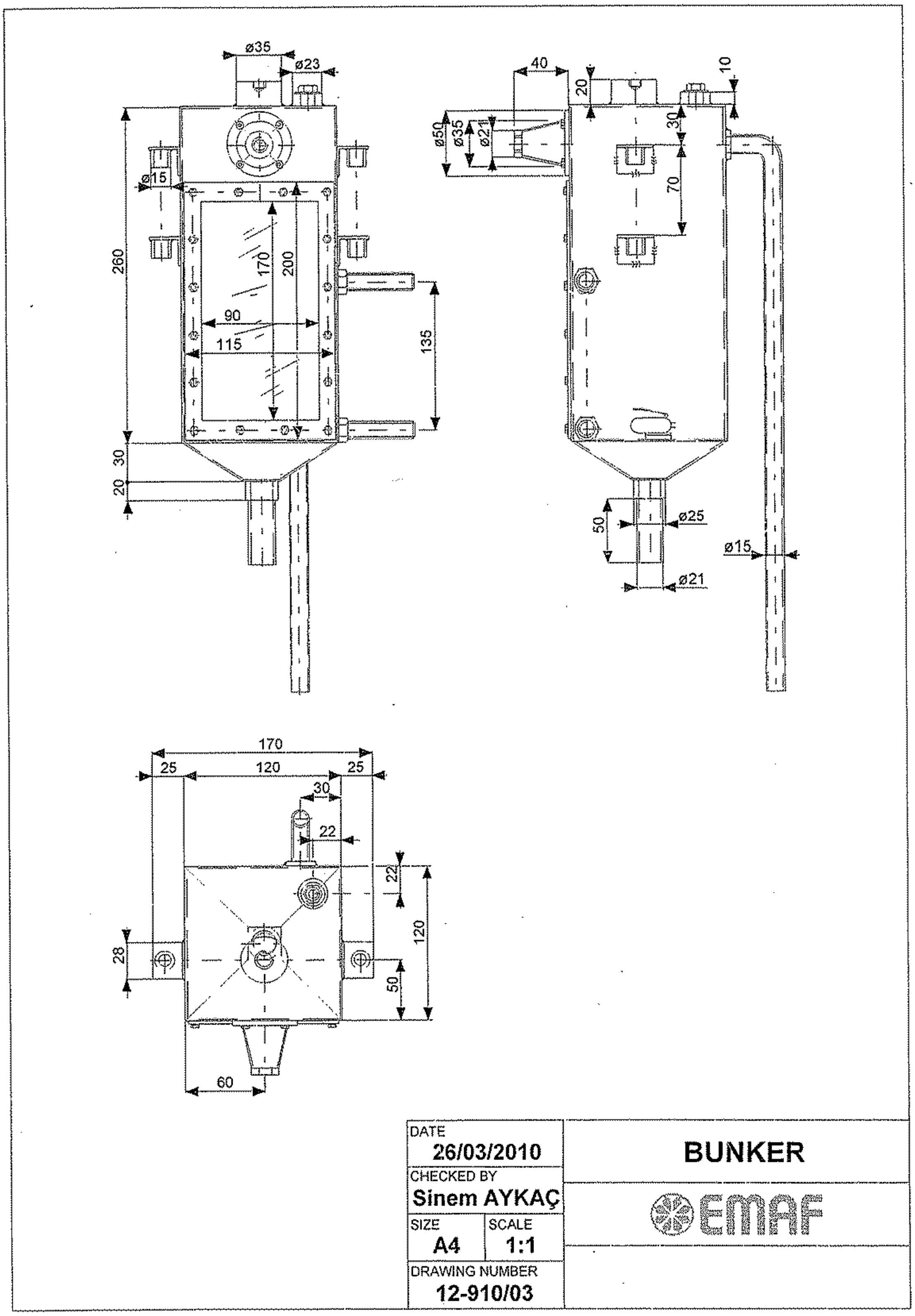


Figure A.5: Dimensions of the bunker

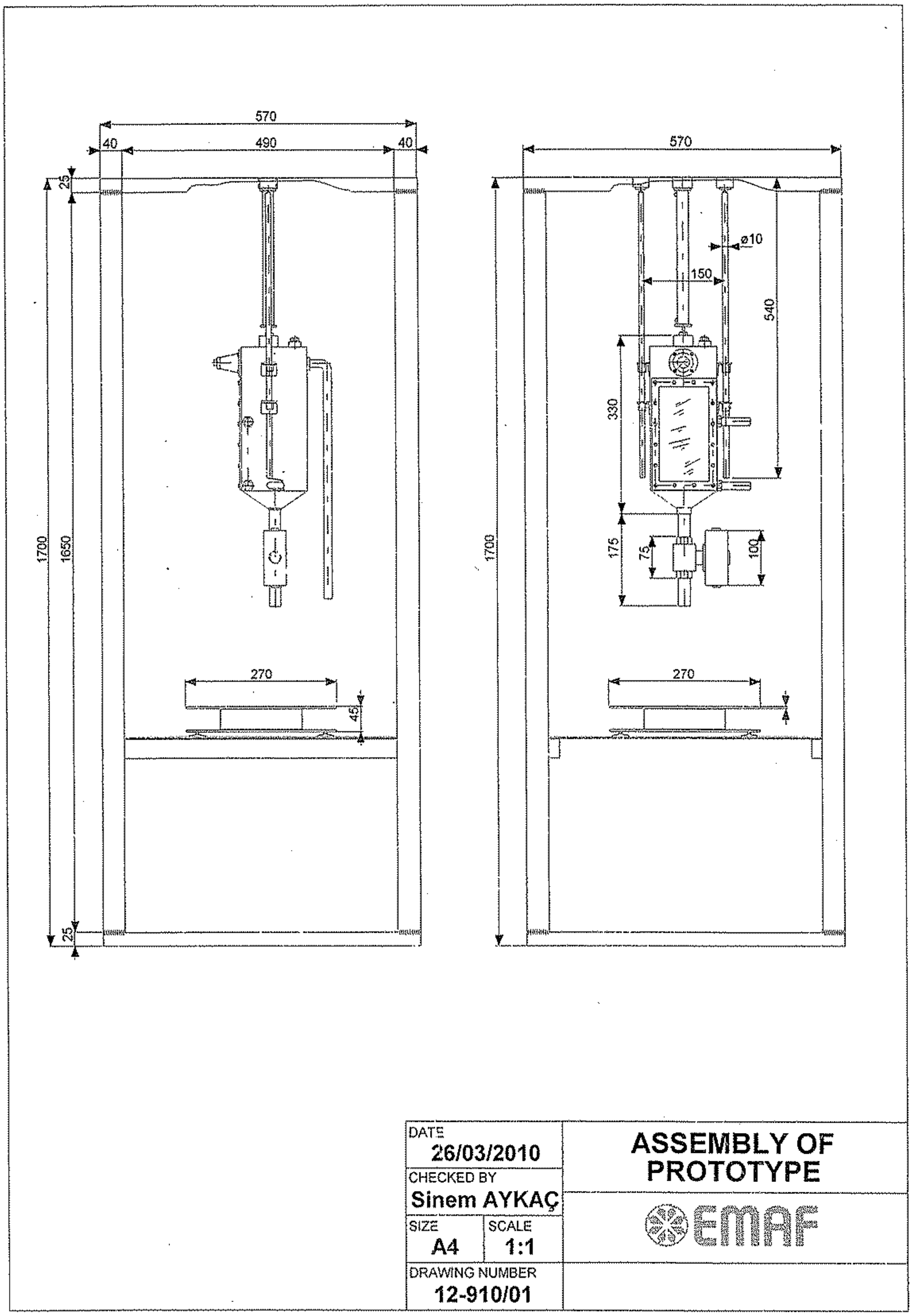


Figure A.6: Assembly of the prototype

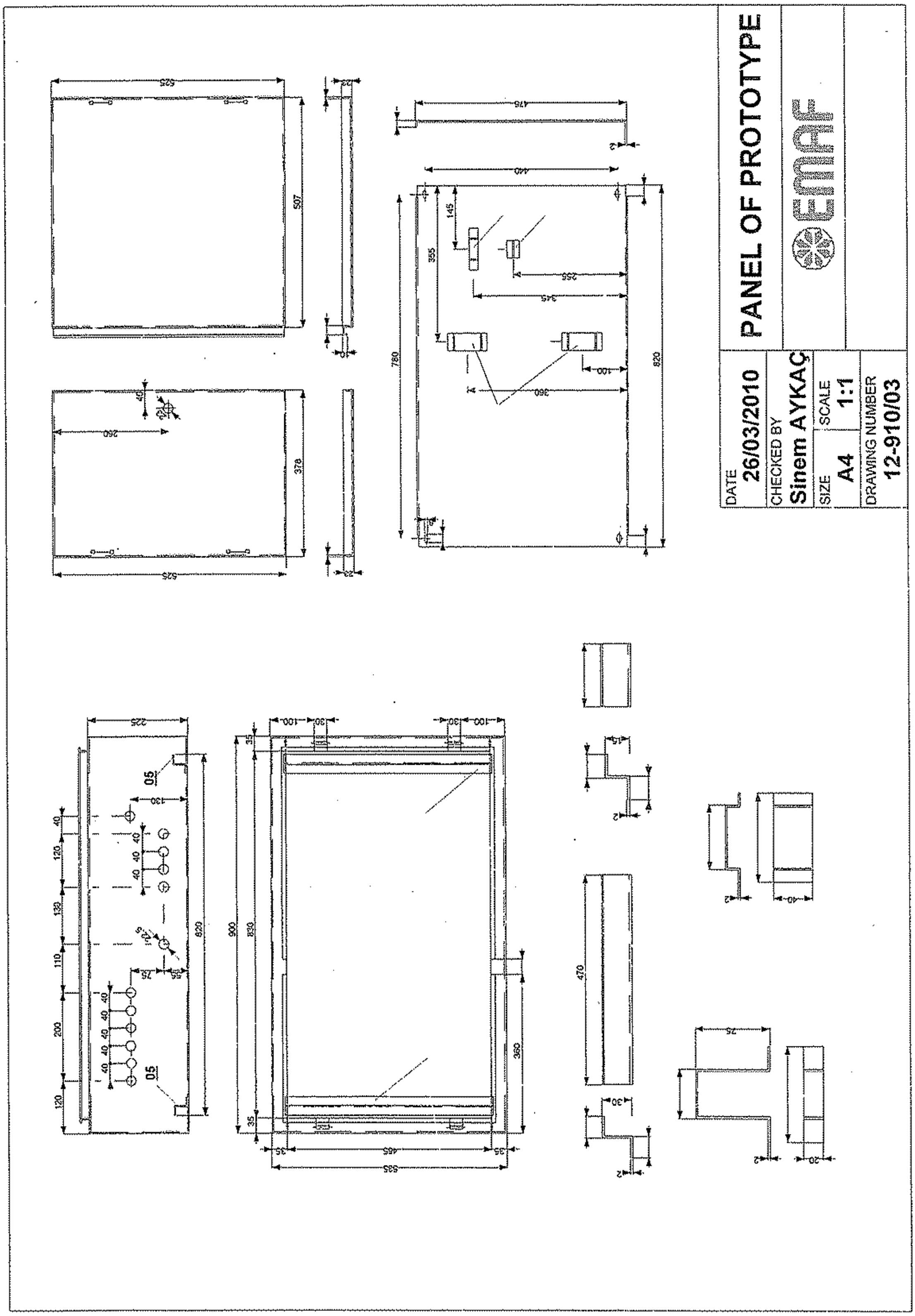


Figure A.7: Electric Panel

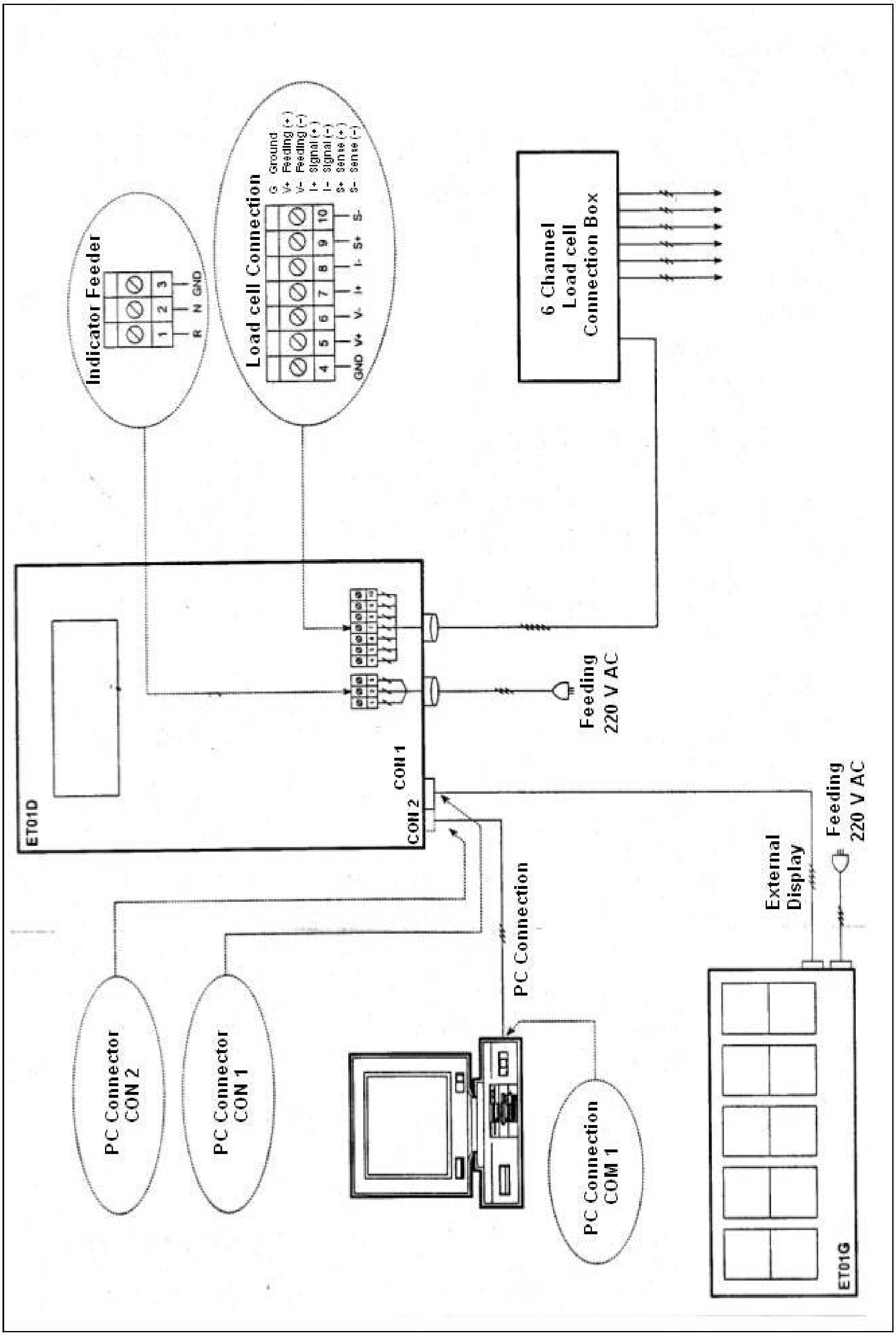


Figure A.8: Indicator connection scheme

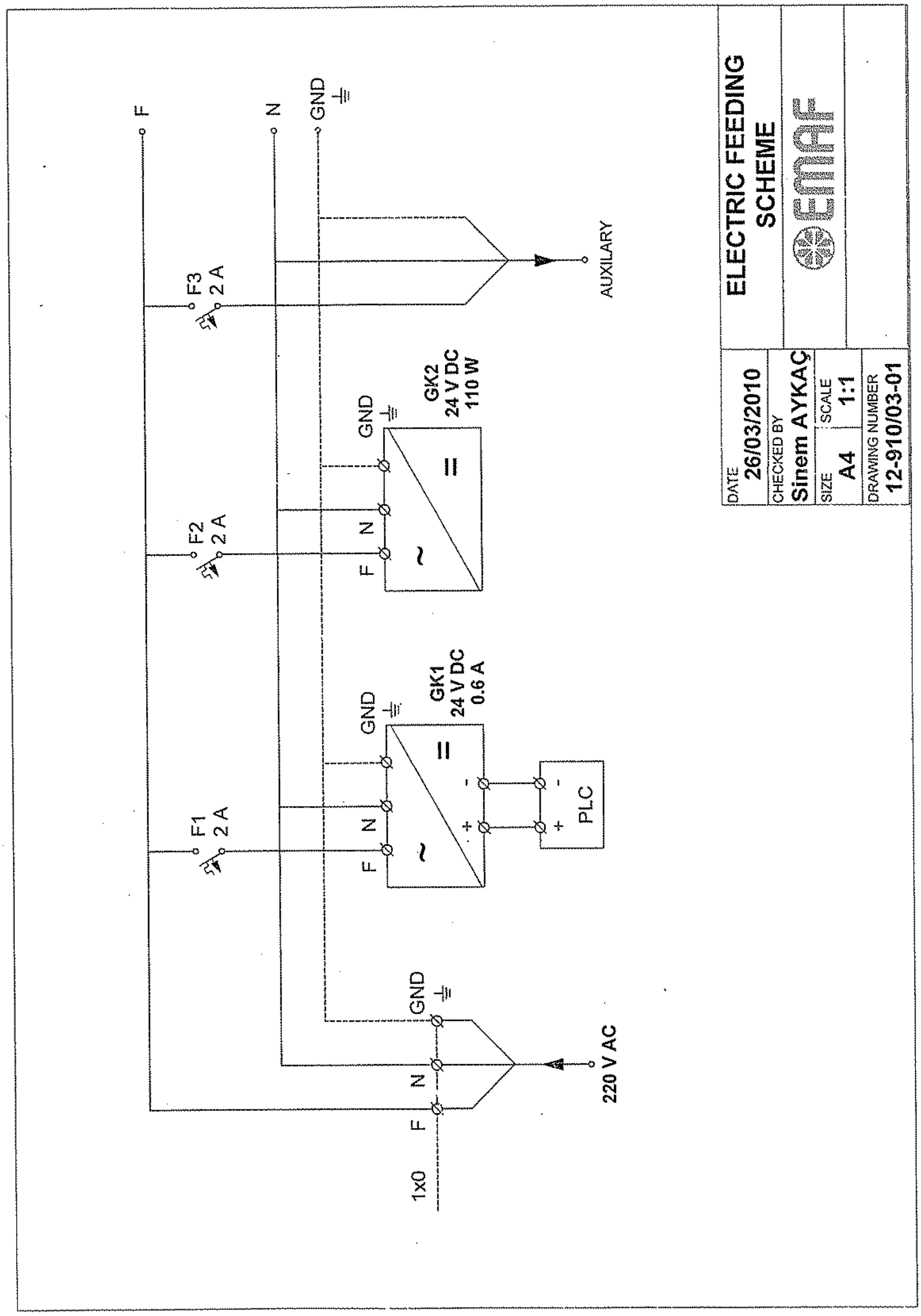


Figure A.9: Electric feeding scheme

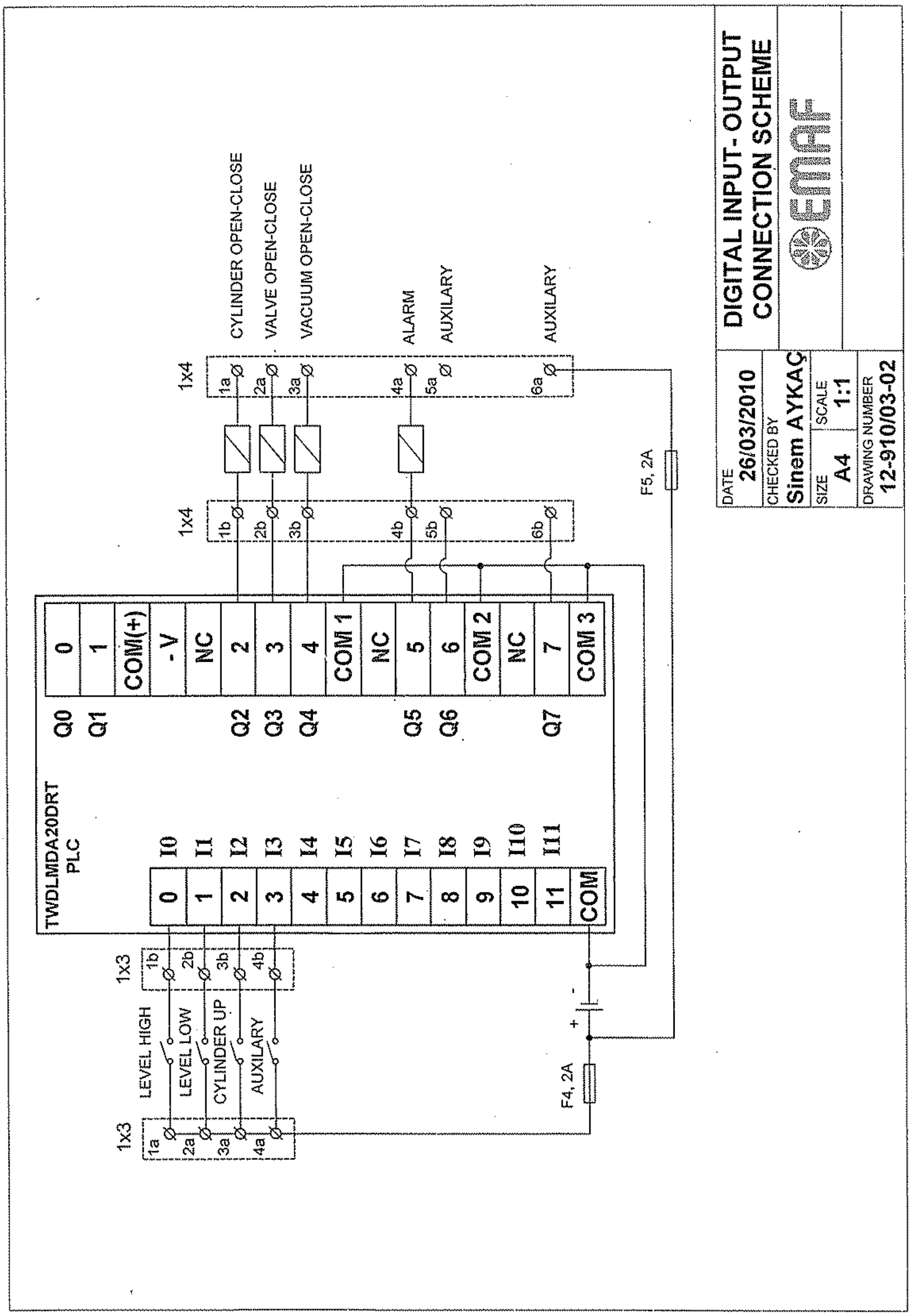


Figure A.10: PLC Digital input-output connection scheme

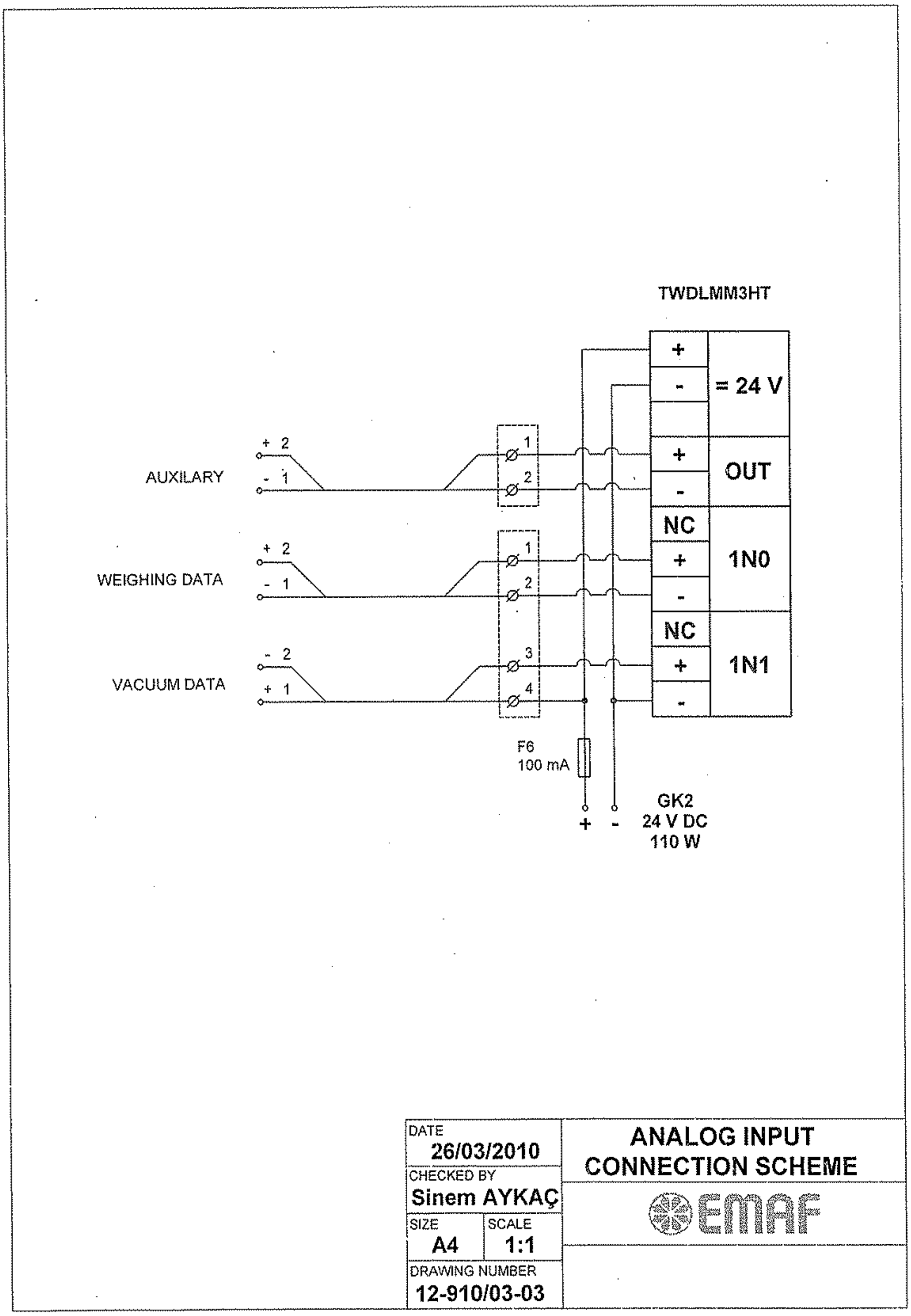


Figure A.11: PLC Analog input-output module connection scheme

Figure A.12: Photograph of the electric panel

Figure A.13: Photograph of the prototype

APPENDIX B

PLC PROGRAM AND DETAILS

Memory objects configuration

Timer configuration (%TM)

Used	%TM	Symbol	Type	Adjustable	Time Base	Preset
Yes	%TM1	BAG_OK_DELAY	TON	Yes	100 ms	30
Yes	%TM2	VACUUM_DELAY	TON	Yes	100 ms	30
Yes	%TM3	LOW_ALARM_DELAY	TON	Yes	100 ms	50
Yes	%TM4	HIGH_ALARM_DELAY	TON	Yes	100 ms	50
Yes	%TM5	VACUUM_ALARM_DELAY	TON	Yes	100 ms	100
Yes	%TM6	VALVE_ALARM_DELAY	TON	Yes	100 ms	100
Yes	%TM7	CYLINDER_ALARM_DELAY	TON	Yes	100 ms	100

Counter configuration (%C)

Register configuration (%R)

Drum configuration (%DR)

Scheduler block configuration (%SCH)

Fast counters configuration (%FC)

Very fast counters configuration (%VFC)

Memory words (%MD)

Memory words (%MW)

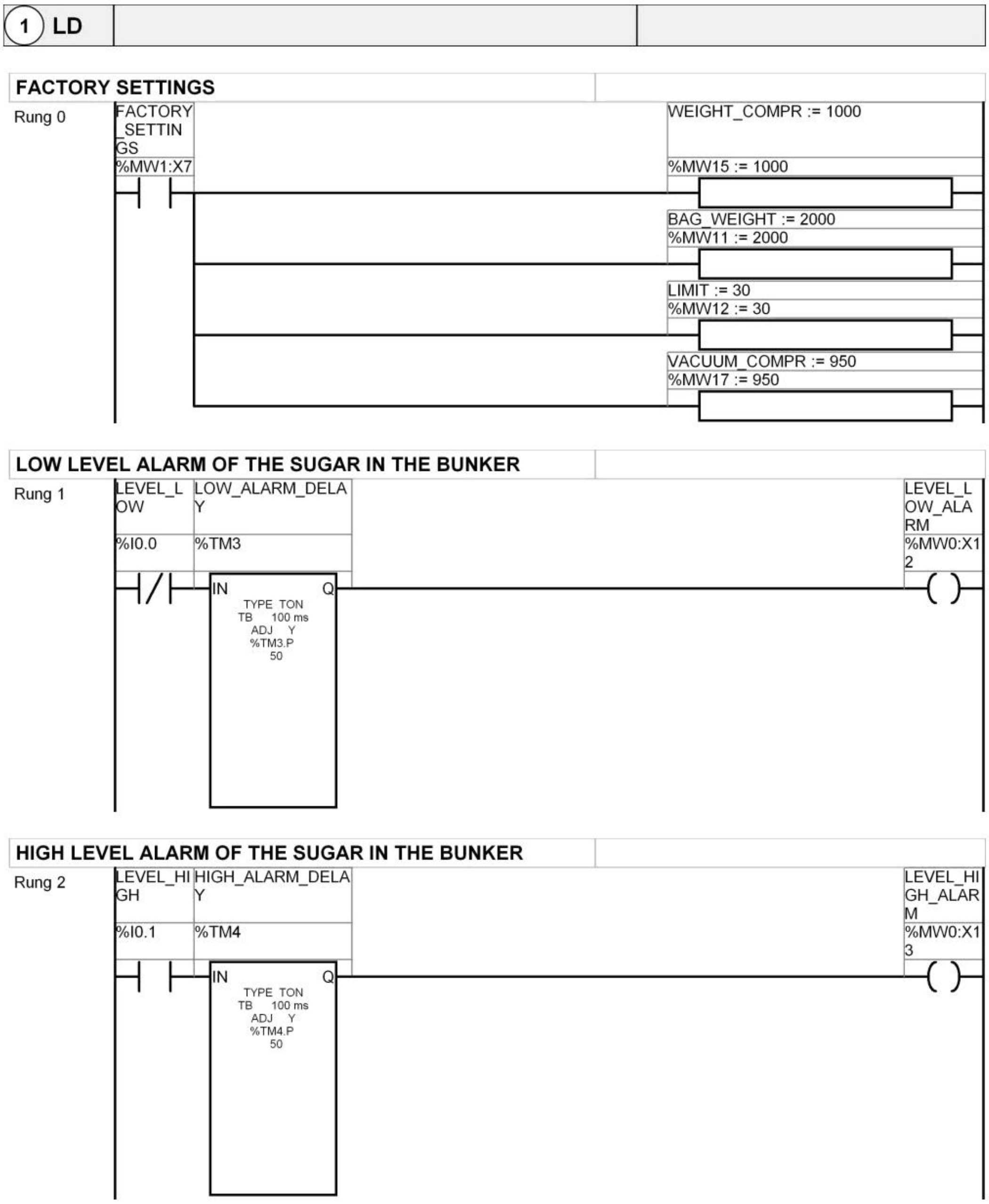
Used	%MW	Symbol	Allocated
Yes	%MW0		Yes
Yes	%MW1		Yes
Yes	%MW10	WEIGHING_ASSIGN	Yes
Yes	%MW11	BAG_WEIGHT	Yes
Yes	%MW12	LIMIT	Yes
Yes	%MW13	MIN_DIFFERENCE	Yes
Yes	%MW14	ACCUMULATOR	Yes
Yes	%MW15	WEIGHT_COMPR	Yes
Yes	%MW16	ACT_DIFFERENCE	Yes
Yes	%MW17	VACUUM_COMPR	Yes
Yes	%MW18	VACUUM_ASSIGN	Yes
Yes	%MW20	LOW_LIMIT	Yes
Yes	%MW21	HIGH_LIMIT	Yes

Memory words (%MF)

Memory bits (%M)

Used	%M	Symbol	Allocated
Yes	%M0	NEXT_BAG_WAIT_P	Yes
Yes	%M1	POS_EXCEED_P	Yes

Program lists and diagrams



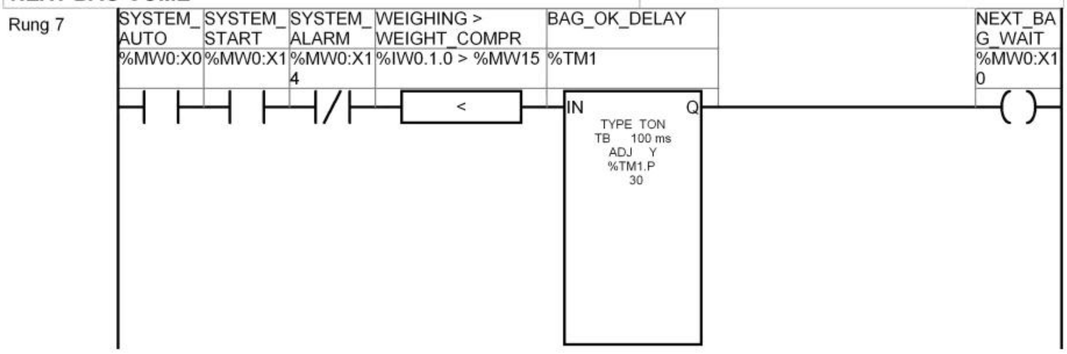
SETTING OF THE SYSTEM ALARM

RESETTING OF THE SYSTEM ALARM

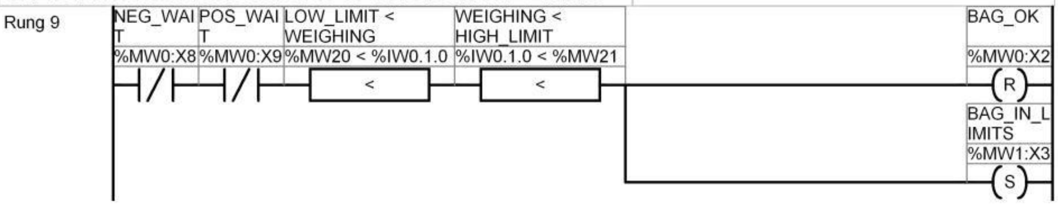
BAG OK (THERE IS A BAG IN THE SCALE)

RESETTING THE 'BAG IS IN LIMITS'

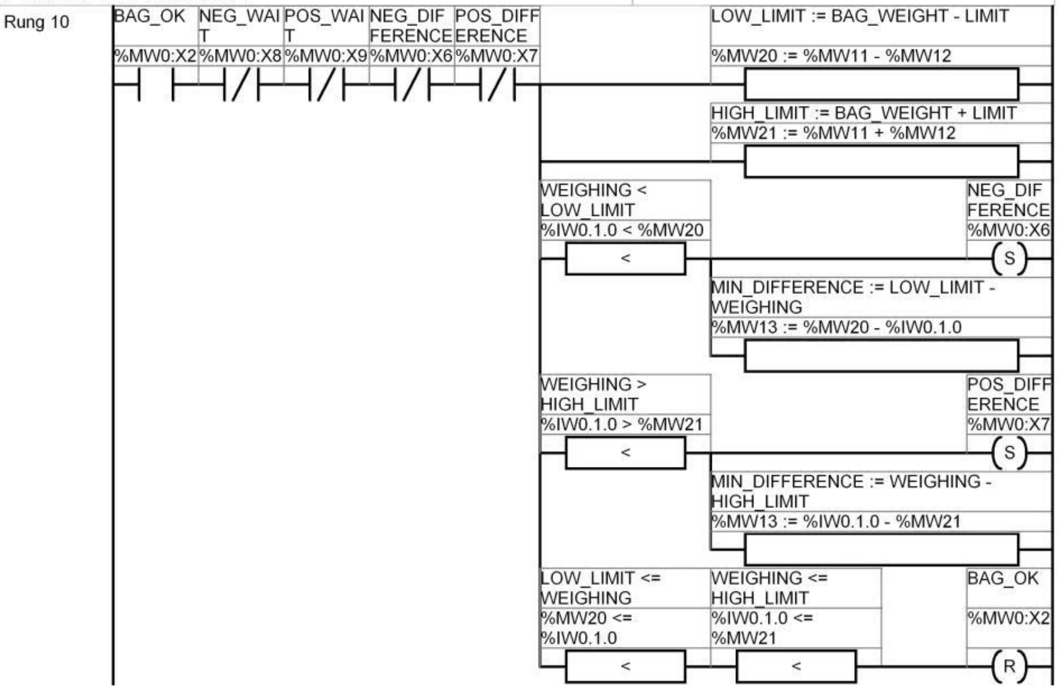
WAIT FOR THE COMPLETING OF THE LOOP UNTIL THE NEXT BAG COME



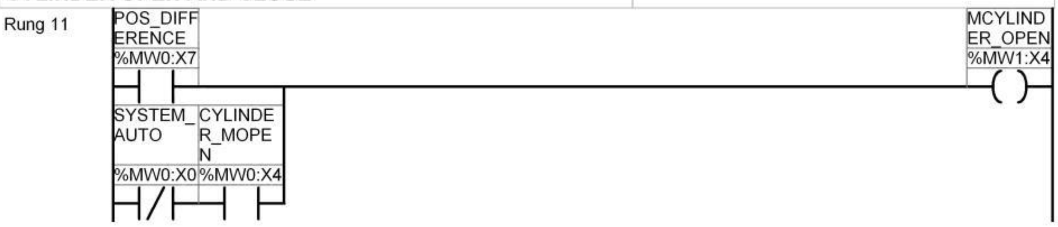
CALCULATIONS AND DECISION OF BAG IS IN THE LIMITS



CALCULATIONS AND DECISION OF NEGATIVE OR POSITIVE DIFFERENCE



CYLINDER OPEN AND CLOSE

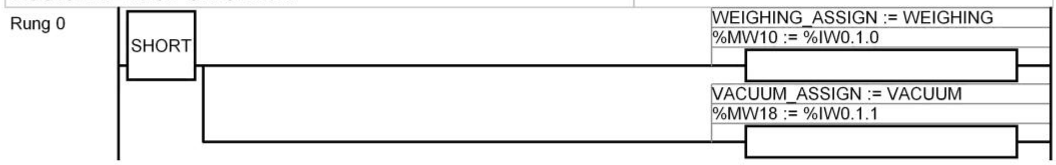


DETECTING THE POSITION OF THE CYLINDER

DETECTING THE INFLUANCE OF CYLINDER

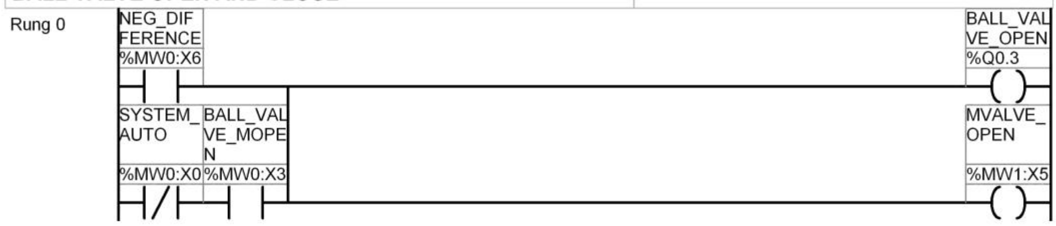
2 LD

ASSIGNMENTS FOR SCADA

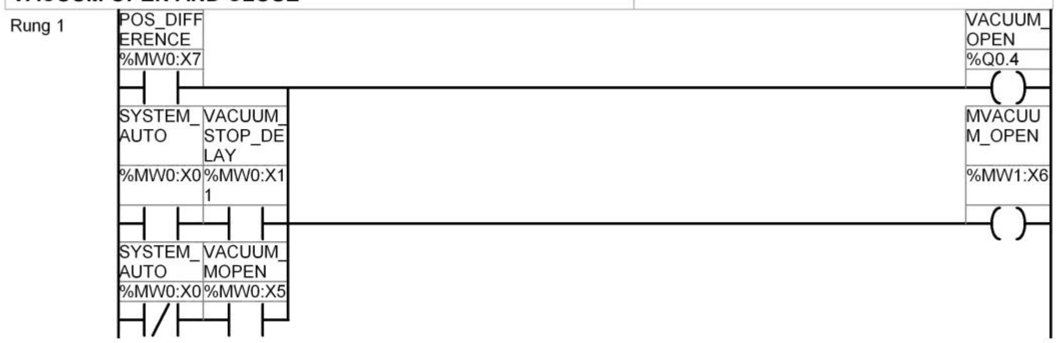


3 LD

BALL VALVE OPEN AND CLOSE

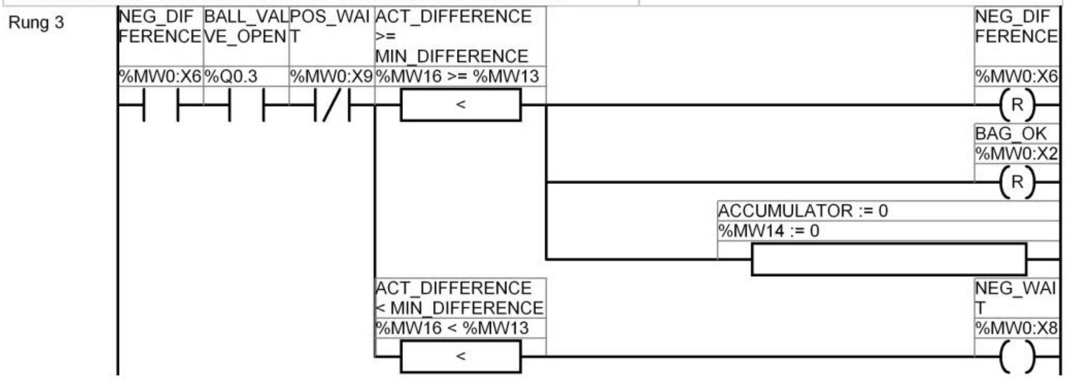


VACUUM OPEN AND CLOSE

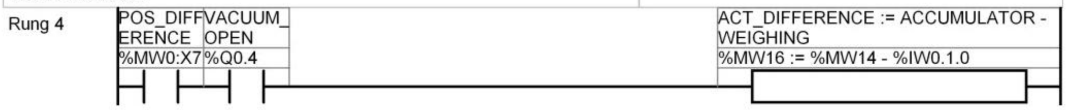


CALCULATION OF ACTUAL DIFFERENCE AT NEGATIVE DIFFERENCE

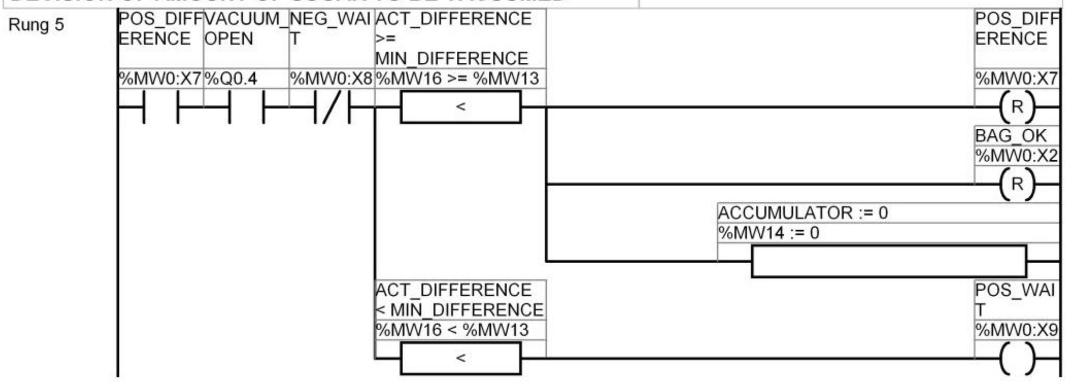
DECISION OF THE AMOUNT OF SUGAR TO BE FILLED

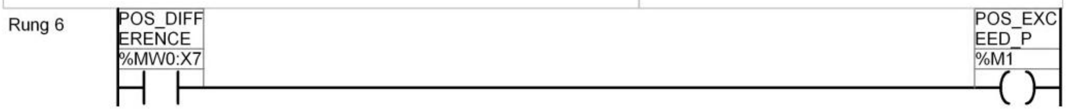


CALCULATION OF ACTUAL DIFFERENCE AT POSITIVE DIFFERENCE

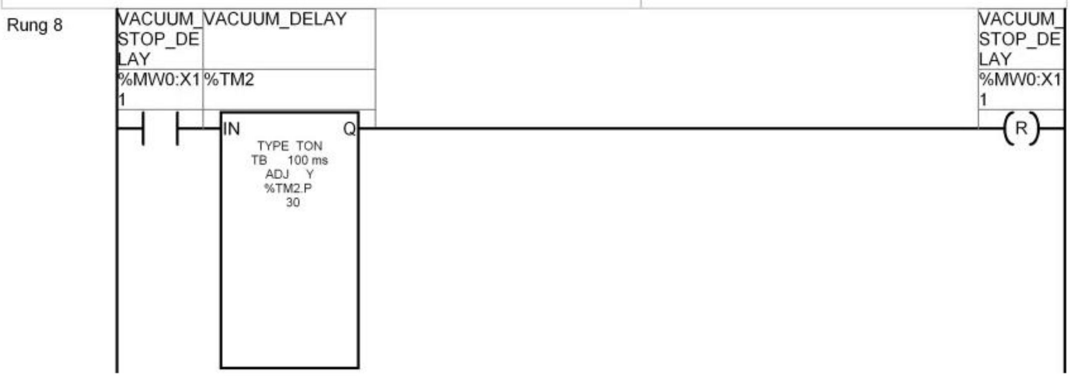


DECISION OF AMOUNT OF SUGAR TO BE VACUUMED

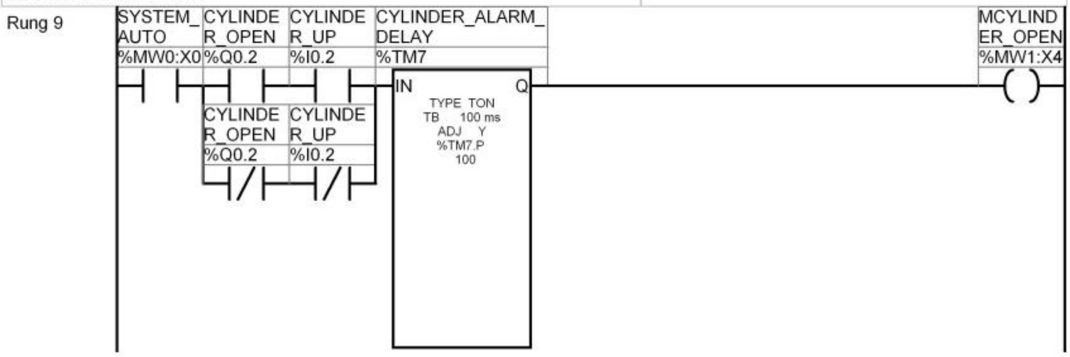




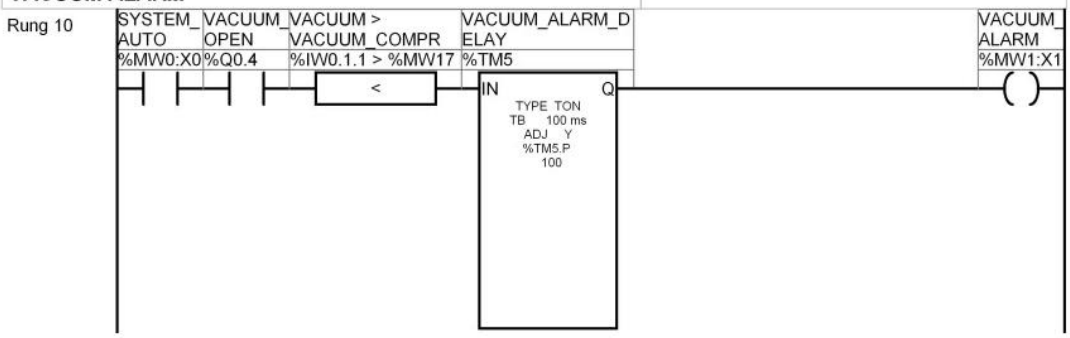
VACUUM STOP DELAY



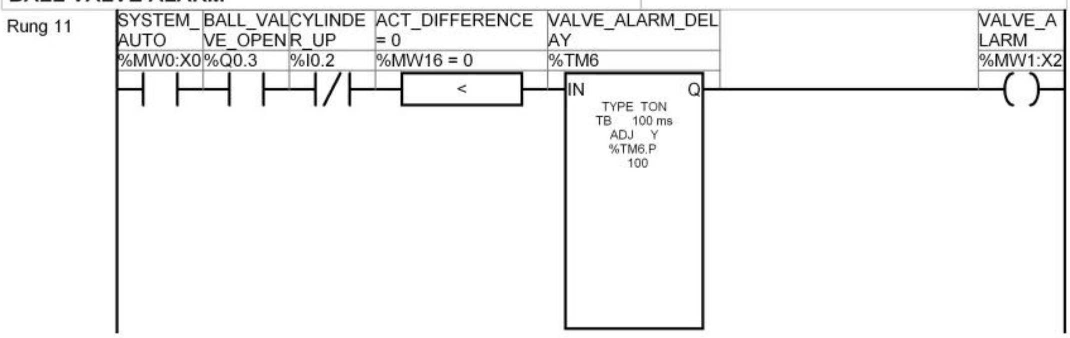
CYLINDER ALARM



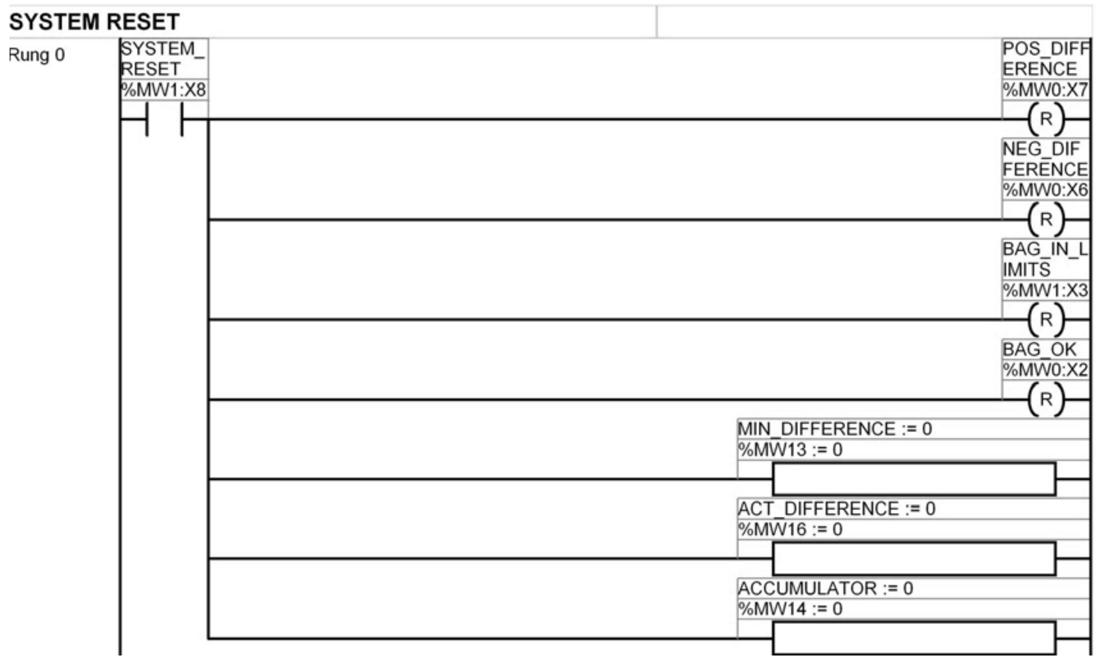
VACUUM ALARM



BALL VALVE ALARM



4 LD


SYSTEM RESET
Rung 0
SYSTEM_
RESET
%MW1:X8
POS_DIFF
ERENCE
%MW0:X7
R
NEG_DIF
FERENCE
%MW0:X6
R
BAG_IN_L
IMITS
%MW1:X3
R
BAG_OK
%MW0:X2
R
MIN_DIFFERENCE := 0
%MW13 := 0
ACT_DIFFERENCE := 0
%MW16 := 0
ACCUMULATOR := 0
%MW14 := 0

The explanations of the contact and coils that are shown in Figure 4.8 are:

- **Normally open contact**: Passing contact when the controlling bit object is at state 1.
- **Normally closed contact**: Passing contact when the controlling bit object is at state 0
- **Contact for rising edge**: detecting the change from 0 to 1 of the controlling bit object.
- **Contact for falling edge**: detecting the change from 1 to 0 of the controlling bit object.
- **Direct coil**: The associated bit object takes the value of the test zone result
- **Set coil**: The associated bit object is set to 1 when result of the test zone is 1.
- **Reset coil**: The **associated** bit object is set to 0 when the result of the test zone is 1.

APPENDIX C

STATISTICAL ANALYSIS

Table C.1: Statistical calculations (for mean value) for the bags remain above +30 grams

Values (m_i)	**Frequency (f_i)**	**Value x Frequency ($m_i.f_i$)**
8	1600	12800
18	486	8748
28	335	9380
38	227	8626
48	249	11952
58	762	44196
68	156	10608
78	57	4446
88	98	8624
98	194	19012
108	516	55728
Total Measurement (Σf_i): 4680		**Sum ($\Sigma m_i.f_i$):** 194120
Mean Value (μ): 41.478		

Table C.2: Statistical calculations (for standard deviation) for the bags remain above +30 grams

Values (m_i)	**Difference from mean value ($m_i - \mu$)**	**Square of difference $(m_i - \mu)^2$**	**Frequency x Square of difference $[f_i . (m_i - \mu)^2]$**
8	-33.478	1120.818	1793310.132
18	-23.478	551.246	267905.645
28	-13.478	181.673	60860.633
38	-3.478	12.100	2746.900
48	6.521	42.528	10589.530
58	16.521	272.955	207992.155
68	26.521	703.382	109727.737
78	36.521	1333.810	76027.186
88	46.521	2164.237	212095.288
98	56.521	3194.664	619765.007
108	66.521	4425.092	2283347.646
		Sum ($\Sigma[f_i . (m_i - \mu)^2]$): 5644367.863	
Standard Deviation (σ): 34.732			
Variance: 1206.319			

Table C.3: Statistical calculations (for mean value) for the bags remain below -30 grams

Values (m_i)	**Frequency (f_i)**	**Value x Frequency ($m_i.f_i$)**
2	69	138
12	61	732
22	51	1122
32	421	13472
42	56	2352
52	32	1664
62	23	1426
72	12	864
82	85	6970
92	15	1380
102	9	918
Total Measurement (Σf_i): 834		**Sum ($\Sigma m_i.f_i$):** 31038
Mean Value (μ): 37.215		

Table C.4: Statistical calculations (for standard deviation) for the bags remain below -30 grams

Values (m_i)	**Difference from mean value ($m_i - \mu$)**	**Square of difference $(m_i - \mu)^2$**	**Frequency x Square of difference $[f_i\ (m_i - \mu)^2]$**
2	-35.215	1240.154	85570.660
12	-25.215	635.837	38786.114
22	-15.215	231.521	11807.591
32	-5.215	27.204	11453.243
42	4.784	22.88	1281.745
52	14.784	218.571	6994.296
62	24.784	614.255	14127.869
72	34.784	1209.938	14519.264
82	44.784	2005.622	170477.880
92	54.784	3001.305	45019.583
102	64.784	4196.989	37772.901
		Sum ($\Sigma[f_i\ (m_i - \mu)^2]$): 437811.151	
Standard Deviation (σ): 22.925			
Variance: 525.583			