Saimaa University of Applied Sciences
Faculty of Technology, Lappeenranta
Degree Program of Mechanical Engineering and Production Technology

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# Automated production line of detergents

Thesis 2017

## Abstract

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The main aim of this study was to identify and analyze the constraints which occur while designing a production line and to develop a production line for detergents which would fulfill both the constraints and the requests of the customers. Getting more knowledge in the fields of fluid dynamics and control science was the minor purpose.

This paper consists of several parts in which theory of control, diverse physical phenomena are presented as well as analysis of advantages and disadvantages of elements of various production lines. All the information about the subject was collected from literature and internet sources.

As the result of this project the effective and sustainable automated production line was designed.

Keywords: Detergents, Automation, PLC, Production line

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## Terminology

IL – Instruction List

ST – Structured Text

FBD – Function Block Diagram

LAD – Ladder

SFC – Sequential Function Chart

PLC – Programmable Logic Controller

2D – two dimensional

rpm – rounds per minute

HP – Horse power

m – meter

s – second

Pa – Pascal

kg - kilogram

kW – kilowatt

N – Newton

P&G – Procter & Gamble

# 1 Introduction

This project was made because of the request of “GrinTec” company which specializes in selling chemicals, especially detergents. Previously, the company did distributing of chemicals and had an experience of manual production of detergents. But due to relatively low profit and increasing demand it was decided to introduce a semi-automatic production/packaging line.

This work provides a knowledge about fluid science and theory of control which is then used for investigating the advantages and disadvantages of existing production lines of different companies such as P&G. Based on the analogs a new production line is designed.

## 1.1 Objectives

Production line is a very broad definition. Production lines are used almost in all industries, starting with automotive and finishing with pharmacy. In this work only production of detergents is described that is why some of the objectives and constraints can be applied specifically to this system.

Several objectives were provided by the customer which should have been fulfilled. Firstly, the cost of the production line should be relatively low. Secondly, system should be reliable. Lastly, the system should be capable of producing different detergents of different volumes.

## 1.2 Structure of thesis

The thesis consists of five main chapters:

- First chapter describes and distinguishes all the constraints of the project which were set by the customer company.
- Second part includes a knowledge about all the components which are used in the production line and physics standing behind. Components

such as: mixing machine, pipelines, pump, filling machine, conveyor belt, sensors, manipulator, PLC.

- Third part is about analyzing the examples which can be found in the industries, highlighting their advantages and disadvantages.
- Fourth part introduces the designed production line of detergents and all the components used in the system.
- Fifth part combines the knowledge included in other parts and then used for analyzing the results. Approximation of the future look of the system is also a topic of this part.

# 2 Constraints of the project

In thesis real-life scenario of constructing production line is described, because of that constraints were crucial.

## 2.1 Costs

Cost of the project is always the main constraint. The budget of the project was not unlimited. It was necessary to find a compromise between price of the machines and quality which they could provide.

## 2.2 Productivity

The productivity of the production line was set by customer to be 60 tones per month, which approximately equals to 83,3 liters per hour. To fulfill the needs, equipment capable to keep such high production rates was chosen.

## 2.3 Complexity of maintenance

The company does not have a maintenance team, because it was its first experience in producing something. Considering that the maintenance should have been as simple as possible, so that the operator of the production line could do something. However, complex problems, such as dysfunction of PLC can be solved only by PLC expert.

## 2.4 Safety

Safety is always one the most important factors in production. To ensure safety of people working on or next to the production line special fences had been installed. All the moving parts of the mechanisms were covered. Besides that, several buttons for emergency stop of the line were added.

## 2.5 Area used

Production rates were decided to keep low that is why the area for such a manufacturing unit is also limited. Height of the place where the system was decided to be built is the determining factor for the whole production line. The height equals to 3 meters.

## 2.6 Handling forces

Handling forces were not the most critical constraint due to the low operating masses. The mass of the bottled detergent varies from 0,5 liters up to 1,5 liters. Such masses in manufacturing are not considered as big.

The only problem that occurred was handling the pallets with filled bottles. One pallet can have 6*6*5 bottles of detergent of volume 1,5 liters. So, the overall weight of one pallet is approximately 270 kg. For such mass it was needed to find special conveyor.

## 2.7 Other constraints

Viscosity of the detergents produced is varying from 80mPa*s up to 3000mPa*s, that is why equipment capable of dealing with such high-viscous liquid should have been selected.

# 3 Theory

Design of any production line is impossible without relevant knowledge. Only by combining theory from various fields of studies sustainable production line can be built.

In case of the project described in this paper knowledge from electrical engineering, mechanical engineering, control engineering were required.

## 3.1 Fluids

The whole automation process in case of the project is mainly about handling viscous liquids, that is why knowledge about flow and viscosity is very important. Depending on these physical phenomena different equipment may be used in the manufacturing process.

### 3.1.1 Viscosity

Viscosity is one of the most important fluid properties. Viscosity of a fluid is a measure of its resistance to deformation by stress. The shear resistance occurs because of inter molecular friction exerted when layers of fluid attempt to slide by each other. Viscosity is represented in two different ways:

**Dynamic**

Absolute viscosity - is a measure of internal, shear resistance. Dynamic (absolute) viscosity is the force per unit area required to move one plane with respect to another one at a certain velocity when being apart in the fluid.

$$\tau = \mu \times \frac{dc}{dy} = \mu \times \Upsilon \qquad \text{(Formula 1)}$$

$\tau$ - shearing stress in fluid($N/m^2$), $\mu$ - absolute viscosity($Ns/m^2$), $dc$ - unit velocity(m/s), $dy$ - unit distance between layers(m), $\Upsilon$ = dc / dy - shear rate ($s^{-1}$)

**Kinematic**

Kinematic viscosity describes a substance's flow behavior under the influence of Earth's gravity. Kinematic viscosity is the ratio of - absolute (or dynamic) viscosity to density - a quantity in which no force is involved. Kinematic viscosity can be obtained by dividing the absolute viscosity of a fluid with the fluid mass density.

$$V = \frac{\mu}{\rho} \qquad \text{(Formula 2)}$$

V – kinematic viscosity($m^2/s$), $\mu$ - absolute viscosity($Ns/m^2$), $\rho$ – density($kg/m^3$)

### 3.1.2 Fluid flow

There are two types of flow in liquids:

- **Laminar** – laminar movement happens when a fluid moves within equivalent layers one above another, without interruption between the levels. At reduced velocities, the fluid has a tendency to stream without having lateral blending, as well as adjacent layers. There aren't any cross-currents vertical with respect towards the path associated with movement.
- **Turbulent** – interrupted flow of the fluid. Turbulent flow, the kind associated with fluid movement in which the liquid passes through unpredictable variances as opposed to laminar flow, during which the fluid proceeds in sleek ways or even levels. (differencebtw)

The type of flow can be considered using so called Reynold's number.

$$R_e = u\frac{L}{V} \quad \text{or} \quad R_e = u\frac{d_h}{V} \quad \text{for the pipe} \quad \text{(Formula 3)}$$

$R_e$ – Reynold's number, $u$ – flow velocity(m/s), $L$ - characteristic length(m), $V$ - kinematic viscosity($m^2/s$), $d_h$ – hydraulic diameter(m)

If $R_e<2300$, then the flow is laminar.
If $R_e>2300$, then the flow is turbulent.

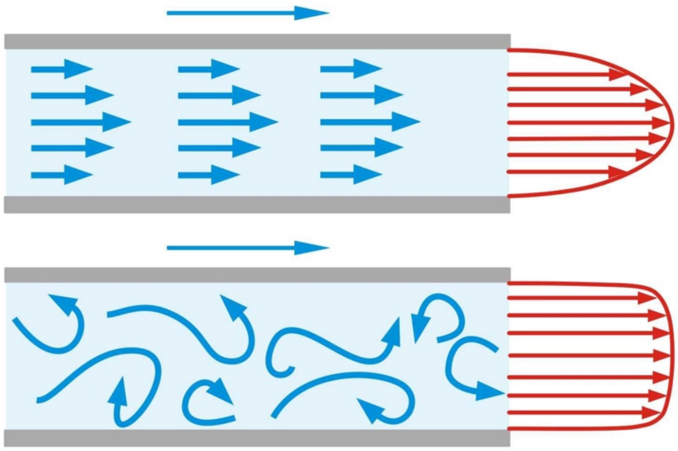

Figure 1 Representation of the laminar and turbulent flow in the pipe

Top: laminar flow; bottom: turbulent flow; blue – flow; red - velocity profile

### 3.2 Fluid mechanics

Just knowing how the liquid behave it is impossible to build a manufacturing system. Manufacturing can be split into several parts, where each stage is performed by the special machine. That is why knowledge about the machinery is required.

#### 3.2.1 Mixing machine

Mixing machine is the first and one of the most important stages of the whole system. Blending machine which is used to combine reagents to get detergents. Depending on how well the chemicals are mixed the viscosity of the product will change. The main parameters of this machine as follows:

- Production Capacity ≅ 300kg/20min
- Machine Weight ≅ 380kg
- Machine Motor ≅ 5HP
- Possibility to blend dry powders

#### 3.2.2 Pipelines

Pipe is a connecting device transferring the liquid or gas from one place to another. Choosing the right pipe and the length of it is always very critical, because the whole system which manages actions with liquids/gases is built with use of pipelines.

Pipelines can differ between each other in several parameters. **Cross section area, length, material** are the main parameters:

- **Material** of the pipe defines what type of the liquid can be transported by it as well as in what environment it can be used. Different pipes should be used in dessert and swamp, because temperatures are not the same (some materials are not fire-resistant) and moisture is distinct as well (it causes faster corrosion). Some of the materials can be welded, some are not.

- **Cross section area** is used to estimate the amount of fluid that can transferred using a pipe.

$$\dot{m} = \rho \times v \times A \qquad \text{(Formula 4)}$$

$\dot{m}$ - mass flow rate (kg/s); $\rho$ – mass density of the fluid (kg/m$^3$); $v$ - flow velocity of the mass elements (m/s); $A$ - cross-sectional vector area/surface (m$^2$).

- Greater **Length** of the pipe causes more leakages in the pipeline. That is why most manufacturing systems which handle liquids or gases have small pipelines with a lot of interconnections. But nowadays there are several industries where long pipelines are indispensable. Extraction of the oil is one of them. That is why a lot of effort is put into research of new better pipes.

$$\Delta \mathrm{P} = \frac{f \rho L V^2}{2d} \qquad \text{(Formula 5)}$$

$\Delta \mathrm{P}$ - pressure drop (Pa); $f$ - Darcy friction factor; $\rho$ – density (kg/m$^3$); $L$ - length of the pipe (m); $V$ - flow velocity(m/s); $d$ - inner diameter of the pipe (m).

Other crucial parameters of the system which help to find the right pipe is operating temperature and the wall thickness which is defined by the operating pressure.

### 3.2.3 Pump

Pump is a device which is used to increase the pressure inside the pipelines and though make the movement of fluid or gas possible. Using the difference in pressure the movement is performed. Another use of the pimp is compressing gases to make the transportation of them easier. For manipulating high viscous liquids pump may be used as well.

Pump is used for changing the flow rate of liquid or gas inside the pipelines. The Formula 6 calculates the flow in geared pump (Ajdesigner).

$$Q\left(\frac{gallons}{minute}\right) = \frac{3960 \times WHP(HP)}{H(foot)} \qquad \text{(Formula 6.1)}$$

$$Q\left(\frac{liters}{minute}\right) = \frac{6.13 \times WHP(Watt)}{H(meter)} \qquad \text{(Formula 6.2)}$$

Q – pump outlet flow; WHP – water horse power; H – total head;

To calculate the torque of the motor of the pump the following formula can be used.

$$T = 9.5488 \times P \times n \qquad \text{(Formula 7)}$$

T- torque of the motor (N*m); P – power of the motor (kW); n - rpm

There are various types of hydraulic pumps. Depending on viscosity of the fluid, diameter of the pipe, possible consumption of electricity, working principal different types of pumps may be used.

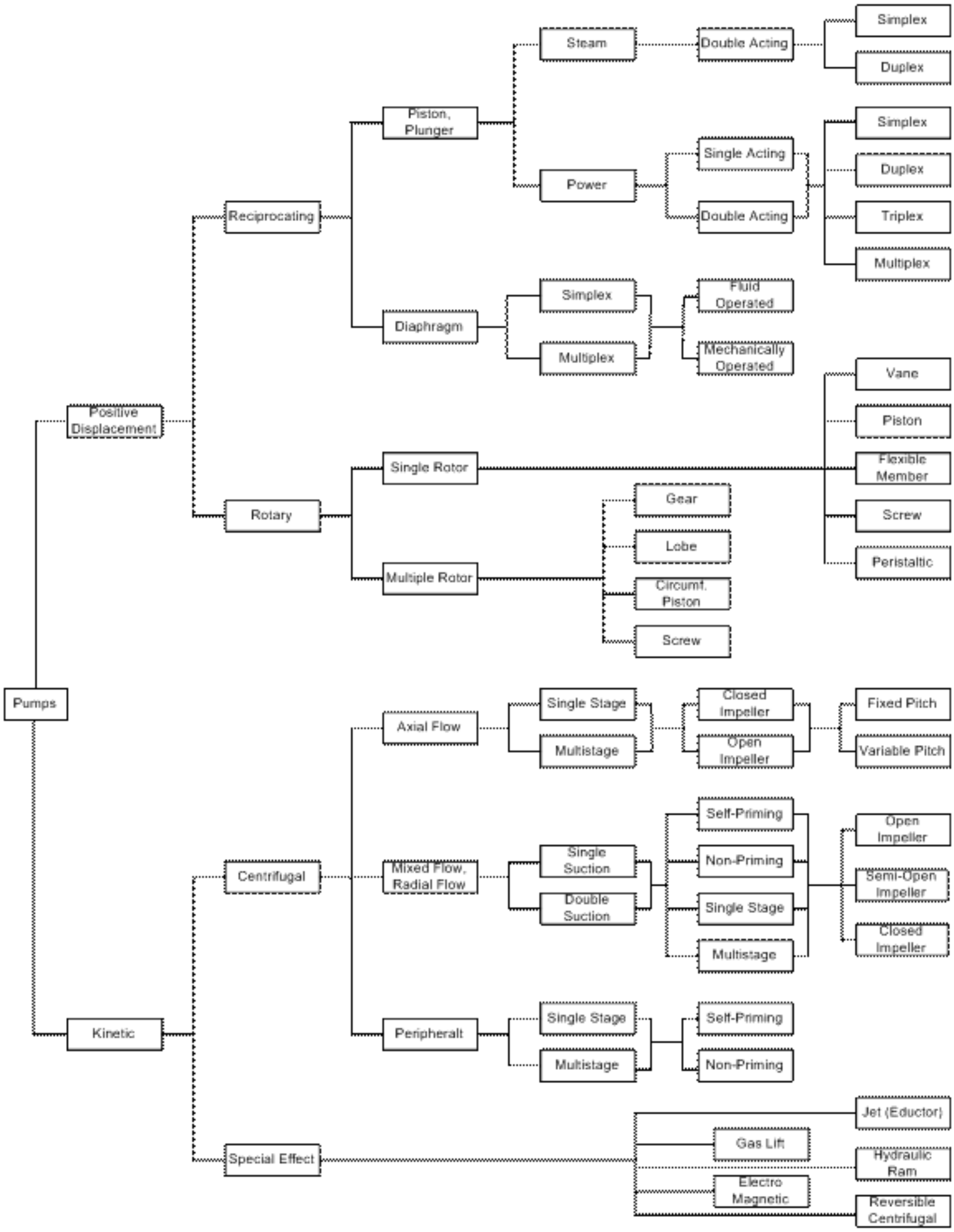


Figure 2 Block scheme representing various types of pumps (Engineering 360)

### 3.2.4 Filling/bottling machine

Filling machine is a type of machine which is used to fill bottles with different types of materials, such as liquids and gases. The main parameters of such machine as follows:

- Container type - bottle, multi-container, can, container, pail, for jars, can, tin can, drum
- Capacity ≅ 50 milliliters – 117 liters (1 barrel)
- Product applications – hazardous liquids, viscous liquids, dairy products
- Type - volumetric, linear, weight, multi-head, in-line, online, monobloc, gravimetric
- Operational mode – automatic, semi-automatic, manual

### 3.2.5 Flow meter

Flow meter is a device which is used to measure the amount of substance going through the unit area in the unit time. There is a big variety of flowmeters:

- Rotameter (Glass tube with float, moved by the flow)
- Spring and Piston Flow Meters for Gases and Liquids (A piston rotating within a chamber of known volume)
- Thermal Mass Gas flowmeters (Use combinations of heated elements and temperature sensors to measure the difference between static and flowing heat transfer to a fluid)
- Ultrasonic flowmeters (Utilize ultrasound to make measurements)
- Turbine flowmeters (Rotation of the turbine around the axis in the flow)
- Paddlewheel Sensors (Wheel rotated by the flow affecting the wheel's paddles)
- Magnetic flowmeters

The first step in flow sensor selection is to determine if the flow rate information should be continuous or totalized, and whether this information is needed locally or remotely. Viscosity of the liquid is needed to choose the most suitable flowmeter.

Magnetic Flowmeters is the most common type of the flowmeters, because they do not have real contact with the material inside the tube. Magnetic flowmeters use Faraday's Law of Electromagnetic Induction to determine the flow of liquid in a pipe. In a magnetic flowmeter, a magnetic field is generated and channeled into the liquid flowing through the pipe. Following Faraday's Law, flow of a conductive liquid through the magnetic field will cause a voltage signal to be sensed by electrodes located on the flow tube walls. When the fluid moves faster, more voltage is generated. Faraday's Law states that the voltage generated is proportional to the movement of the flowing liquid. The electronic transmitter processes the voltage signal to determine liquid flow. (Flowmeters)

### 3.3 Conveyor belt system

A belt conveyor is used to move the material around. A belt conveyor system consists of two or more pulleys (sometimes referred to as drums), with an endless loop of the belt which rotates about them. Pulleys can be powered, moving the belt and the material on the belt. The powered pulley is called the drive pulley while the pulley unpowered is called the idler pulley. Belt conveyors can be two types. Those handling general material (solid materials e.g. boxes) and bulk material handling (large volumes of resources and agricultural materials, such as grain, salt, coal, ore).

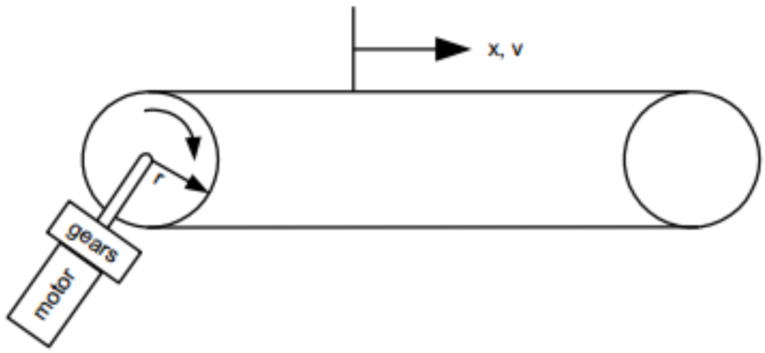


Figure 3 A driven conveyor belt

Conveyor belts have lots of parameters, such as elasticity, tensile strength, mass, etc. All of these parameters combined cause changes in the system.

The most important parameters of the conveyor belt system are: the effective pull (Formula (8)), required motor power (Formula (10)), maximum elongation of the belt at the fitting on the head drive (Formula (12)).

$$F_U = \mu_R \times g \times (m + m_B + m_R) \qquad \text{(Formula 8)}$$

$$F_1 = F_U \times C_1 \qquad \text{(Formula 9)}$$

$$P_M = \frac{P_A}{\eta} = \frac{F_U \times v}{1000 \times \eta} \qquad \text{(Formula 10)}$$

$$F_2 = F_1 - F_U \qquad \text{(Formula 11)}$$

$$\varepsilon \approx \frac{F_U/2 + 2 \times F_2 + F_U}{2 \times SD \times b_0} \qquad \text{(Formula 12)}$$

$F_U$ - effective belt pull (N); $\mu_R$ – coefficient of friction with support rollers; $g$ - acceleration due to gravity (m/s$^2$); $m$ – mass of the material conveyed (kg); $m_B$ – mass of the belt (kg/m); $m_R$ – mass of the rotating rollers(kg); $F_1$ – maximum belt pull (N); $C_1$ - calculation constant; $P_M$ – motor power (kW); $P_A$ - power at drive drum (kW); $\eta$ – drive efficiency; $v$ - velocity of the belt (m/s); $\varepsilon$ - elongation at fitting for a drive drum (%); $F_2$ - minimum belt pull (N); $SD$ - belt pull at 1% elongation per unit of width (N/mm); $b_0$ - belt width (mm).

| **Transilon with underside of** | **V3, V5, U2, A5, E3** | | | **V1, U1, UH, U2H V2H, V5H** | | | **0, U0, NOVO, T, P** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Arc of contact β** | **180°** | **210°** | **240°** | **180°** | **210°** | **240°** | **180°** | **210°** | **240°** |
| **smooth steel drum** | | | | | | | | | |
| dry | 1.5 | 1.4 | 1.3 | 1.8 | 1.6 | 1.5 | 2.1 | 1.9 | 1.7 |
| wet | 3.7 | 3.2 | 2.9 | 5.0 | 4.0 | 3.0 | not recommendable | | |
| **lagged drum** | | | | | | | | | |
| dry | 1.4 | 1.3 | 1.2 | 1.6 | 1.5 | 1.4 | 1.5 | 1.4 | 1.3 |
| wet | 1.8 | 1.6 | 1.5 | 3.7 | 3.2 | 2.9 | 2.1 | 1.9 | 1.7 |

Figure 4 Table for calculation constant - C1 (Transilon)

Using Formulas (8-12) the mass of the product conveyed can be easily found.

## 3.4 Sensors

For the automation of the process such components as sensors should be included in the system. A sensor acquires a physical quantity and converts it into a signal suitable for processing, the most common is electrical signal. Sensors are usually used as a part of different measuring devices, but could be used alone as well. Wide range of sensors is generated by diverse working principals of them.

| | |
|---|---|
| Acoustic | Wave (amplitude, phase, polarization), Spectrum, Wave Velocity |
| Biological & Chemical | Fluid Concentrations (Gas or Liquid) |
| Electric | Charge, Voltage, Current, Electric Field (amplitude, phase, polarization), Conductivity, Permittivity |
| Magnetic | Magnetic Field (amplitude, phase, polarization), Flux, Permeability |
| Optical | Refractive Index, Reflectivity, Absorption |
| Thermal | Temperature, Flux, Specific Heat, Thermal Conductivity |
| Mechanical | Position, Velocity, Acceleration, Force, Strain, Stress, Pressure, Torque |

Figure 5 Type of the sensor on the right, detected (measured) parameter/phenomena on the left

### 3.5 PLC

PLC (Programmable Logic Controller) as well as sensors is essential if automation of the process is needed. PLC is a device through which the programmer can control and manipulate the production process. If PLC and code for it are chosen in the best way possible, the manufacturing line most probably will perform the way it was supposed to.

#### 3.5.1 PLC hardware

PLC hardware consists of the modules which help the computer to recognize and understand the information transferred to it from other devices. Modules are represented by the boxes with multiple ports and lights.

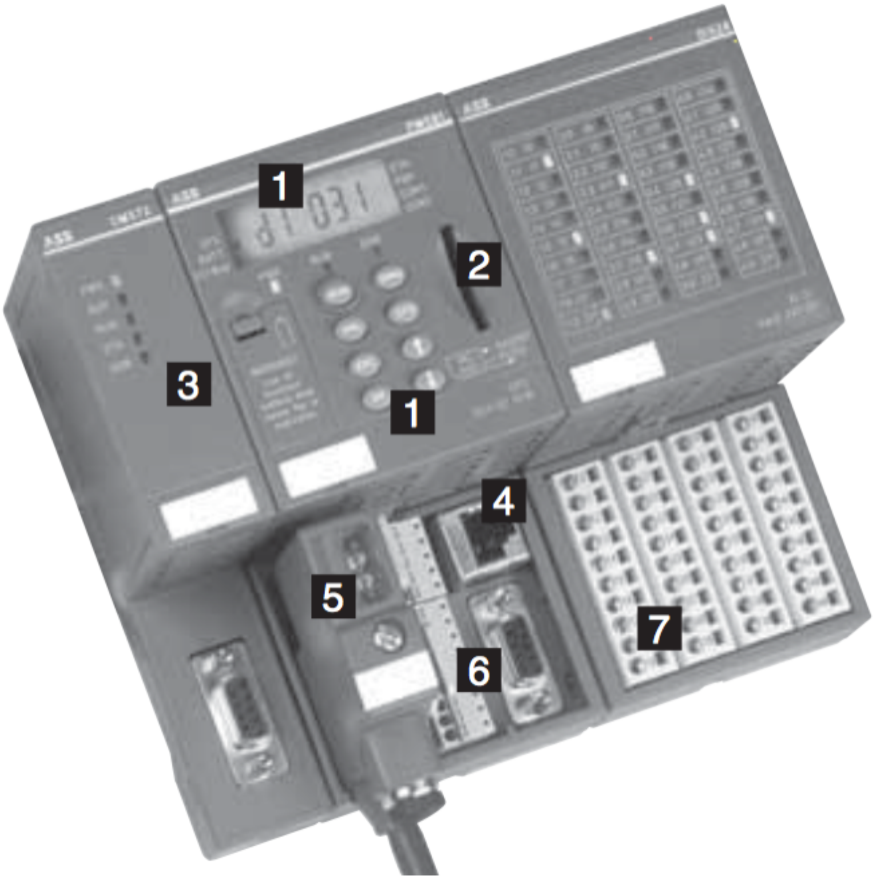


Figure 6 ABB AC500 PLC (ABB)

PLC box has several parts which have various intents (ABB Company):

1. Back-lighted LCD display and keypad – used for showing the code of the error and setting additional parameters
2. SD card slot – for stand-alone running of the program code without PLC being connected to the computer.
3. Plug-in communication modules (1 to max. 4)
4. Optionally with integrated Ethernet or ARCNET – for communication with the computer
5. FBP interface (for slave) – for communication with other PLCs and additional equipment
6. Two serial interfaces for programming, ASCII, Modbus or CS31 field bus (master)
7. Expandable by up to seven local I/O modules – for communication with other devices

Elements may vary from the type of PLC and the company producing it.

### 3.5.2 PLC software

There is a big number of the companies who sell PLCs and almost all of them are designed to work with one or two program which are defined by the producer. To write a program for Siemens PLC "SIMATIC Manager" software is needed. On the other hand, ABB PLCs work only with the program so called "Automation Builder". Even though programs differ a lot, the programming languages on which they are based are always the same. There are five programming languages which are mentioned in IEC 61131-3. They are: IL, Ladder, FBD, SFC, ST. IL - Similar to mnemonic programming languages. Ladder - Graphical programming language evolved from the electrical relay circuit. FBD - Graphical dataflow programming method. SFC - Graphical technique to write concurrent control programs. ST - Similar to High level programming language such as C. (PLC Programming Languages, 6-14)

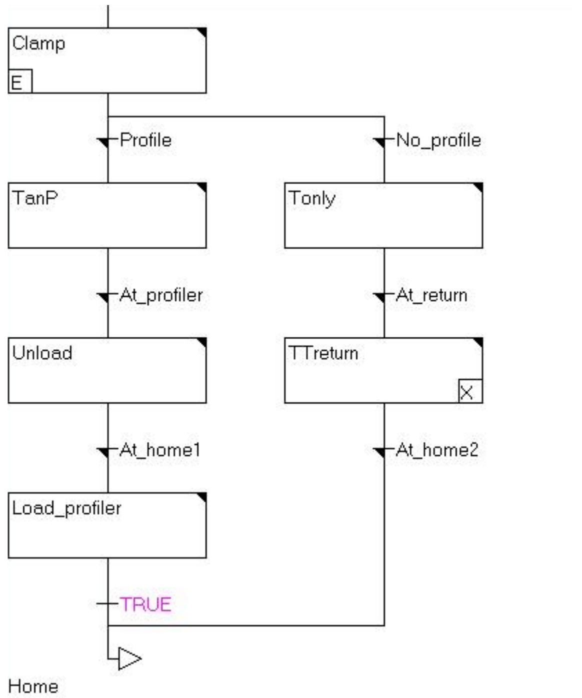


Figure 7 example of SFC

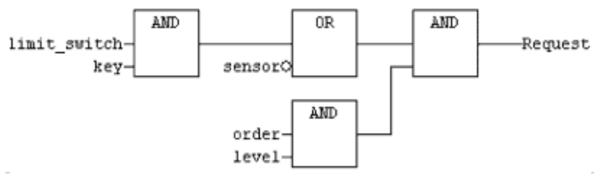


Figure 8 example of FBD

### 3.5.3 Human Machine Interface (HMI)

HMI is used on the production lines which are not fully automated and need communication with operator. HMI helps to make the process of manipulation of the production more interactive and simple. In cases where frequent changes of the parameters of the system are needed HMI is a very useful tool, because it gives such a possibility.

Figure 9 Festo HMI

### 3.6 Other machinery

Other machinery was used such as wrapping, capping, labelling machines and dispensers for ease of manipulating the containers and preparing them for selling on the market. Even though all the processes described below are the ending process of the production, they require a lot of automation and choosing the machine should be performed with additional precise.

#### 3.6.1 Dispensers

Dispenser is an automatic machine or container which is designed to release a specific amount of something. Firstly, items are inserted in the machine by any means and then are fed into the system at the specific time or when meeting certain conditions.

Dispensers are mainly chosen depending on the shape of the product. Also the special parameters of the product may lead to the changing the type of dispenser (e.g. fragility).

#### 3.6.2 Labelling

Labelling is good for the product recognition done both by the customer and by the producer. Label is one of the ways to protect the product from being illegally copied and sold. Label may carry pricing, barcodes, UPC identification, usage guidance, addresses, advertising, recipes, and so on (Wikipedia)

Labelling machines can be divided into two groups: labelling machines for round-shaped products and machines for random-shaped items. Other important parameters of the labelling machines are: labelling speed, maximum label size.

### 3.6.3 Wrapping machine

Wrapping machine is the last stage of the production line. It is used for decreasing the difficulty of transportation and increasing the safety of the product before the consumer's use of it.

Both automated and semi-automated wrapping processes are used in industry. Depending on the area availability and number of produced items the way of wrapping is chosen.

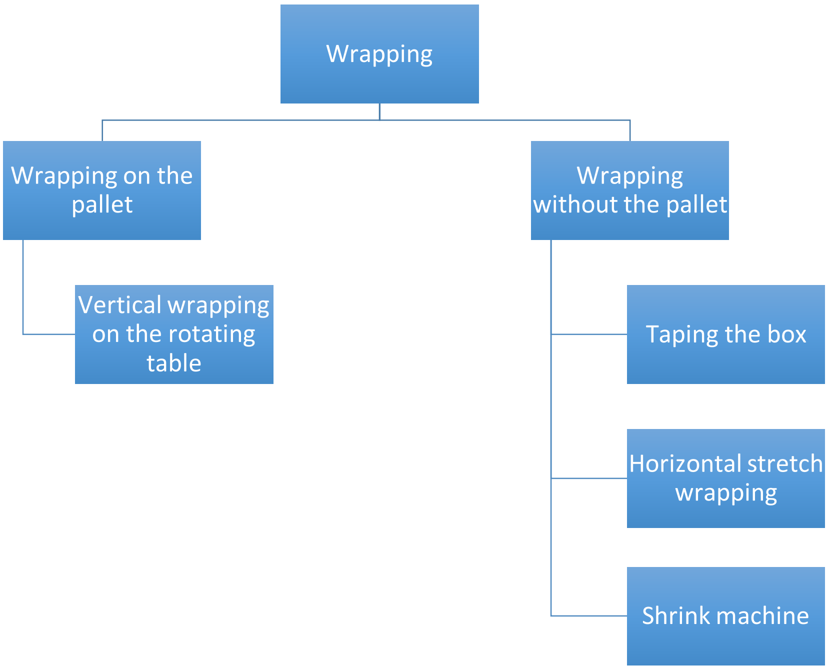


Figure 10 Different types of wrapping methods

Sometimes, wrapping goes before labelling. It is done like this to put the label on the wrapping paper or the box not to damage the container.

### 3.6.4 Capping machine

Capping machines are used for the application of plastic and metal threaded caps as well as plastic snap caps, some fitments. Capping is one of the most difficult aspects of a liquid packaging line. Sometimes the range of geometries and sizes of caps and bottles is so wide that the capping machine components become expensive or the platform of that particular type of capping machine is not suitable for all sizes and geometries in the range. Sometimes the bottle and cap combination are not ideal with the threads of the bottle being in conflict with the threads of the cap and great force is needed to apply the cap. Sometimes caps can only be placed vertically on the container which increases the capital cost of the machinery. (Inline Filling Systems)

## 3.7 Manipulator

Manipulator is the most knowledge requiring device in the system, because it is usually a hard process to create a program for one of those. Often manipulators are represented by linear motion modules which has one degree of freedom, combining of several of those can increase a degree of freedom. Another common type of manipulators is a robotic arm, which is more complex compared to the linear motion system, but has more axis of freedom.

Figure 11 4-axis robotic arm Figure 12 Bosch Rexroth Linear module

Depending on the situation different types of grip can be used. Jaws and vacuum sucking disk are the most common grabbing devices.

### 3.8 Connections

To make communication between the machines and PLC possible various types of connections/wires are required. There are different cables for connecting motors, sensors, controls, valves. The main distinction between them is the type of plug used on the cable. Working principal of the connecting wires is often the same, transfer of the digital data. In the process of production of detergents main connections are wires going from the devices to the PLC and pipelines, transferring liquefied detergents.

# 4 Difference between fully-automated and semi-automated production lines

There is a huge amount of companies producing the detergents nowadays. Such companies as “Procter & Gamble” produce “Fairy” detergents in the big amounts with help of the fully automated production process. By analyzing existing manufacturing lines, finding their weak and strong sides, it was decided to use semi-automated production process.

Production line of “Procter & Gamble” and manufacturing line described in the paper both were designed for production of detergents. However, in closer look the systems have more differences than similarities.

Big production lines of the companies represented on the market have lots of advantages compared to the paper’s system for several reasons. Firstly, production scales differ a lot. Also, money and human resources involved are considerably bigger.

On the other hand, production lines of big companies are all about saving time and money. That is why lots of other aspects of the production are missing or get less attention than possibly could.

## 4.1 Advantages of fully-automated systems

- The main advantage of fully-automated detergents manufacturing is high production rate.
- In long run big production units which are run by existing companies save lots of time, which means saving money.
- Less human resources required compared to the manual production.
- Smaller possibility for the workers to get injuries.
- Fully-automated production system can run 24/7 without breaks.

## 4.2 Disadvantages of fully-automated systems

- When high level of automation is involved in the manufacturing process, maintenance complexity is necessarily increased as well.
- High production rate requires a lot of the storage space.
- Fully automated manufacturing process usually is not flexible. Only one type of detergent is produced.
- More professional knowledge is required.
- Less attention to the needs of the final customer.
- Fully-automated system cost a lot and it does not make sense to introduce it when production rate is rather low.

## 5 Description of the semi-automated detergent production

Using the knowledge gained from theory part and taking into account advantages and disadvantages of existing systems new system was designed. It was supposed to fulfill all the needs of the customer and work properly in the given conditions.

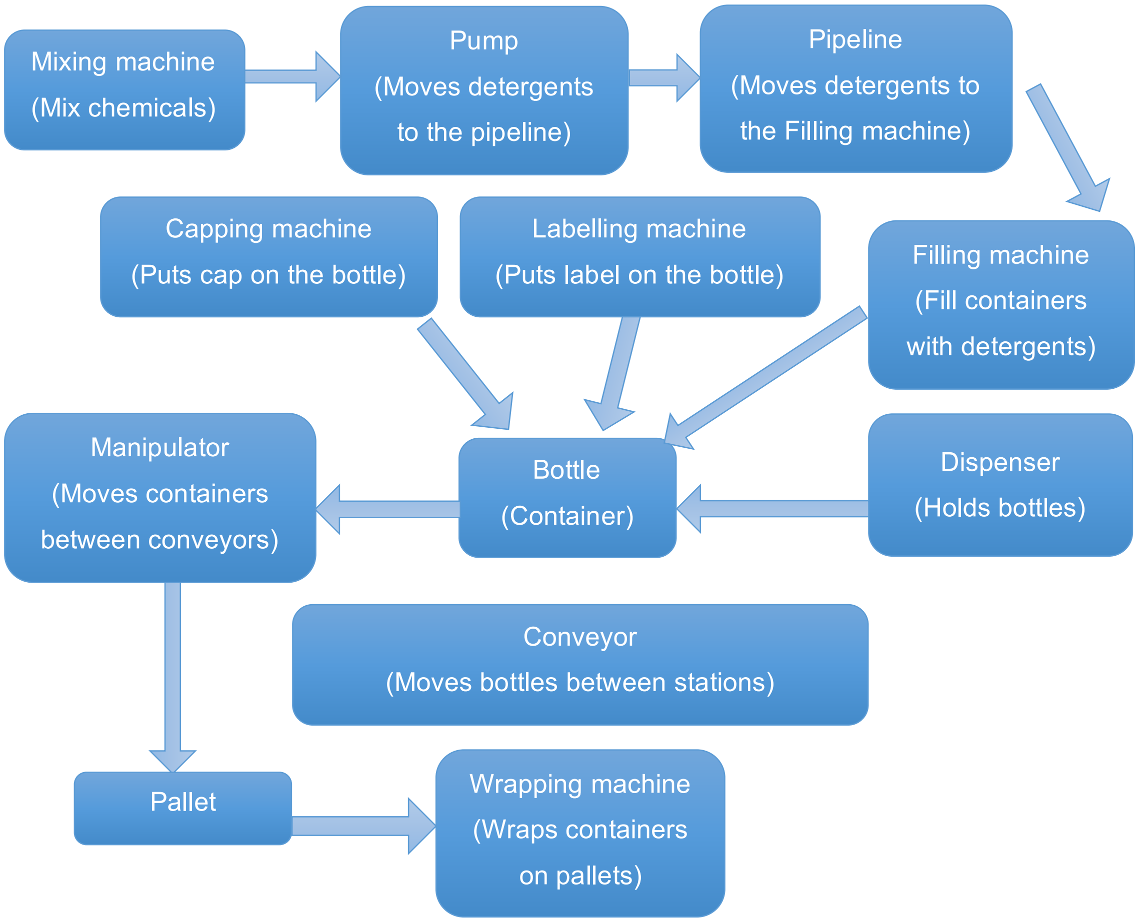


Figure 13 Manufacturing process

### 5.1 Components used

**Mixing machine:**

Several possibilities for mixing machine were found. First is ISIMSAN Ribbon mixer (directindustry) which is a commonly used equipment in food industry, but can be used in the production of chemicals due to its outstanding parameters. Another choice was mixer mounted on kettle of Shanghai SIEHE Mechanical and Electrical Equipment Co., Ltd (Siehe Industry). Third option was dynamic mixer of ZHEJIANG XINGSHENG MACHINERY CO.,LTD (Xingsheng machinery). To fully understand which machine fits the production better, comparison process was used. From the Table 1 it can be seen that all the machines are approximately identical, but ISIMSAN has several advantages which make it better. Firstly, ease of access to the vessel through the special port. Then, heating of the liquid inside the tank. Also, possibility of increasing the pressure inside the tank makes this option even better. Even though, the capacity of ISIMSAN mixer is smaller than of other mixers, the difference is 10000l, it does not play an important role in the selection process, because 40000l is still more than enough for the current situation.

| Parameters | ISIMSAN | SIEHE | XINGSHENG |
|---|---|---|---|
| **Application** | Solid/liquid, powder | Liquid, solid proportion <= 60% | Liquid, solid |
| **Material** | Stainless steel | Stainless steel | Stainless steel |
| **Heating/cooling** | + | + | - |
| **Capacity** | 40000l | 50000l | 50000l |
| **Pressure** | Withstand high-pressure | Normal pressure | Integrated pressure vessel |
| **Ease to clean** | Special maintenance door for easy access | Inlet port is used for maintenance | Inlet port is used for maintenance |
| **Viscosity** | High-viscous materials | High-viscous materials | High-viscous materials |
| **Continuous/batch** | Batch | Continuous | Batch |

Table 1 Comparison table of mixing machines.

**Pump:**

Pump is implemented into one the first stages of the production process, that is why it should be very reliable and withstand high temperatures.

First choice was a Circulation pump for paint, adhesives and oil (Sames Kremlin) commonly used equipment in painting vehicles. Another option was Desmi electrically-driven internal gear pump for high-viscosity fluids made from cast iron, typical pump in marine (Desmi).

| Parameters | Factor | Desmi | Value | Sames Kremlin | Value |
|---|---|---|---|---|---|
| **Working principal** | **1** | Internal gear | **3** | Piston | **3** |
| **Material** | **2** | Cast iron | **3** | Stainless steel, top coat epoxy | **4** |
| **Flow rate** | **3** | 170 $m^3$/h | **4** | 360 $m^3$/h | **5** |
| **Operation** | **5** | Electricity | **5** | Electricity + Pressurized air | **3** |
| **Pressure** | **4** | 16 bar | **4** | 18 bar | **4** |
| **Media** | **4** | High-viscous liquids | **5** | High-viscous liquids | **5** |
| **Max. Temperature** | **5** | 250°C | **5** | 80°C | **2** |
| **Ease to maintain** | **5** | Reliability, easy construction | **4** | Modularity | **4** |
| **Total** | | **127** | | **107** | |

Table 2 Pumps' parameters

In Table 2 each parameter has factor from 1 to 5 showing how important this parameter is for the task. Pumps have values (1-5) which represent how this equipment fulfills the needs in the parameter. Total row shows sum of values multiplied by factor of the parameter.

From Table 2 it can be seen that both pumps are suitable for the current situation. Sames Kremlin has better flow rate, can produce more pressure in liquid, has better corrosion resistance (because of the stainless steel use) and easier to clean and maintain because of modularity. But Desmi pump is better in the end, it scored 20 points more compared to Sames Kremlin. Also, to work with Sames Kremlin external pneumatic system should be introduced and working temperature is rather low. Some of the detergents after mixing can reach temperature of 100°C. That is why Desmi pump was chosen.

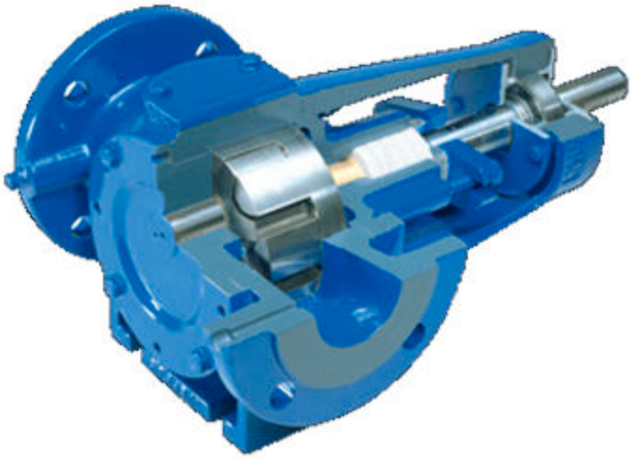

Figure 14 Desmi electrically-driven pump *(Desmi - YouTube)*

**Bottling machine:**

Viscosity of the detergents produced is varying from 80mPa*s up to 3000mPa*s, which makes it impossible to use the most common types of the bottling machines. Synchromat Filling Machine (Filamatic) and Bottle filler / multi-container / can / container (Chabot Delrieu Associes) are two great solutions, because they make filling the bottle with high viscosity liquids possible. Both of them are inline fillers.


Figure 15 Synchromat Filling Machine and Chabot Filling Machine

| Parameters | Factor | Filamatic | Value | Chabot | Value |
|---|---|---|---|---|---|
| **Working principal** | **1** | Volumetric pump | **4** | Centrifugal or volumetric pump | **4** |
| **Capacity** | **5** | 1 ml – 1100 ml | **3** | 50 ml – 5000 ml | **5** |
| **Container** | **5** | Cans, bottles, vials | **4** | Cans, bottles, vials, drum | **5** |
| **Operation** | **4** | Electricity | **5** | Electricity | **5** |
| **Expendability** | **3** | Possibility to increase number of nozzles and stroke length for higher capacity | **5** | - | **1** |
| **Total** | | **74** | | **77** | |

Table 3 Filling machines

From Table 3 it turned out that Chabot filling system is a bit better, it is so because the machine can fill all the volumes of the containers which are needed from the very beginning, without any additional equipment. This is it's main and the only advantage compared to Filamatic. However, Filamatic bottling machine gives an opportunity to increase the productivity to a very high level using additional strokes and nozzles (max. 24) provided by the manufacturer.

Taking into account all the advantages and disadvantages it was decided to choose Chabot Filling Machine, because it shows very good results without any additional investments.

**Capping machine:**

Due to the shape of the bottle, especially the thread on its bottleneck, spindle/rotary capping is needed. There is a big variety of capping machines on the market nowadays. The most relevant machines for the production line described in the paper are : E-PAK machinery Spindle capper (E-PAK machinery), NK Industries Rotary capper (NK Industries) which is normally used in the pharmacy industry, Rotary capper of Zalkin (Zalkin). The main parameters of such machines are capping speed and complexity.

| | E-PAK | NK Industries | Zalkin |
|---|---|---|---|
| **Speed** | Up to 60 caps/minute | Up to 60 caps/minute | Up to 40 caps/minute |

Table 4 Table of comparison of capping machines

Even though all of the machines fit the system perfectly it was decided not to use Zalkin and NK due to several reasons. In the future the customer may decide to expand the production line and speed of the Zalkin machine will not be suitable any longer. NK option was eliminated because of the relatively high complexity, compared to the E-PAK.

**Dispenser:**

Hoppers are used to insert the bottles into the system. Three hoppers were designed in the shape of the tube and so that all the types of bottles could fit into them. Conveyor belt was put below the hoppers, so that when certain type of the bottle is needed the lowest bottle in the specific hopper is moved.

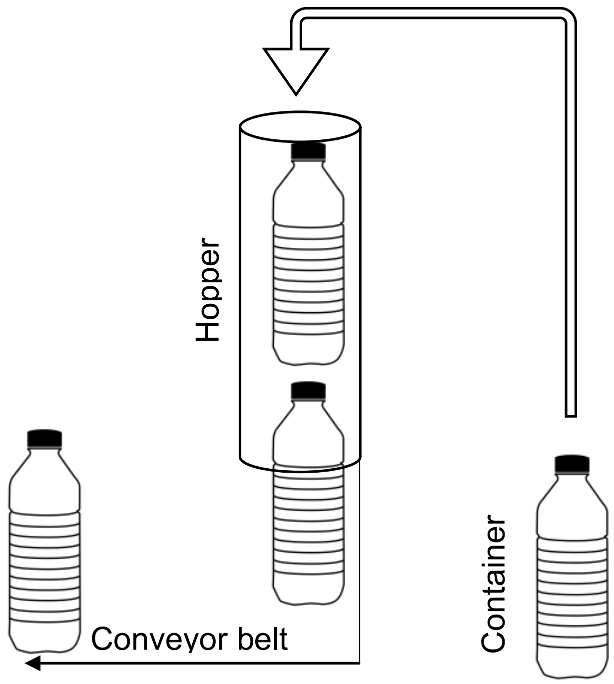


Figure 16 Scheme of the dispenser

Such an idea was used because the hoppers which are represented nowadays on the market are either not suitable for the system or unnecessary complicated (electric drives, etc.). The hopper represented above is very simple, because the deposition of the containers is performed only by gravitational force. Also, the number of such hoppers can be increased easily.

**Labelling machine:**

The main criteria while choosing the labelling machine were its high level of automation, big amount of time between maintenance, relatively easy construction (ease of maintenance), labelling speed fulfilling the needs of the system.

Side labeling HERMA 362C was considered as one of the options for the described system. Other options were Automatic labeler of IMA Industries (IMA) and R1000 Mixte of CDA (Chabot Delrieu Associes), machine used for labelling wine bottles.

| Parameters | HERMA | IMA | CDA |
|---|---|---|---|
| **Level of automation** | Fully - automated | Fully - automated | Fully - automated |
| **Labelling speed** | 80 bpm (bottles per minute) | 75 bpm | 17 bpm |

Table 5 Labelling machines' parameters

From the very first look at the Table 4 it is easy to understand that CDA R1000 Mixe barely fits the system with such low labelling speed. On the other hand, HERMA and IMA machines are pretty similar. They have the same labelling speed and reliability of them is quite identical. But HERMA provides several features which make this option the best. Firstly, a printer can be installed if required to allow for optional label overprinting, such as the date of manufacture or a sell-by date. Secondly, flexible retooling for precise side labeling. Thirdly, additional top belt for stabilizing the packages.

**Wrapping machine:**

Technoplat 2000 of Robopac company (Robopac) and ULINE Automatic Stretch Wrap Machine (ULINE) are two typical wrapping machines used in the industry.

| Parameters | Factor | Robopac | Value | ULINE | Value |
|---|---|---|---|---|---|
| **Load capacity (kg)** | **5** | 1500 | **5** | 1800 | **5** |
| **Table rotation speed (rpm)** | **4** | 15 | **5** | 12 | **4** |
| **Height of the machine (m)** | **5** | 3,33 | **3** | 2 | **4** |
| **L x W pallet (m)** | **1** | 2x1,2 | **5** | 1,3x1,3 | **3** |
| **Carriage up-down speed (m/min)** | **4** | 0,27 | **4** | 0,17 | **2** |
| **Total** | | **81** | | **72** | |

Table 6 Wrapping machines' parameters

Both machines are pretty similar and have almost the same parameters. But Technoplat 2000 of Robopac company was installed into the production line. Firstly, it showed itself better in the comparison Table 5. Moreover, Technoplat 2000 has a list of additional advantages, such as: rotating table of the machine is (HERMA) incrusted with rollers which significantly increase the level of automation and decrease the involvement of the operator (inline process), Technoplat 2000 is equipped with automatic clamp, cutting and spreading or welding unit (this feature allows a perfect automatic sealing of the film tail at the end of each cycle). Film clamping unit with automatic tilt to optimize stretch wrapping at the base of the load is also added to the station (Robopac).

Figure 16 Technoplat 2000

**Pipelines:**

The chemicals produced on the manufacturing line are transferred at the high temperature. Also, the pH-level of the detergents vary from their composition. Acids and alkalis are the main components of the detergents. Because of that, it was essential to choose the pipe which could withstand the effect of the harmful factors of the chemicals.

Most common types of pipes used in chemical industry are: HDPE, PVC , Kynar, CPVC, Polypropylene (Westlund). They all perform very well in terms of chemical resistance and durability.

| | **HDPE** | **PVC** | **Kynar** | **CPVC** | **Polypropylene** |
|---|---|---|---|---|---|
| **Temperature** | 90°C | 92°C | 121°C | 93°C | 82°C |

Table 7 Temperature resistance of pipes

In Table 4 it is shown that the only pipe which can withstand the operating temperatures of the production process is Kynar (PVDF) piping. General / chemical grade polyvinylidene fluoride (PVDF) is a high molecular weight fluorocarbon with superior abrasion resistance, dielectric properties and mechanical strength (AETNA Plastics). These pipes show high resistance to most types of the chemicals. High temperatures do no damage to this pipes.

**PLC:**

Even though most of the machines provide their own interfaces it was not enough to use only those, because the automation level of such system would be too low, a lot of work would be done by the operator. To combine all the machinery and make machines communicate with each other it was decided to use additional PLC.

The SIMATIC S7- 300 controller of Siemens was installed. It saves on installation space and features a modular design. A wide range of modules can be used to expand the system centrally or to create decentralized structures according to the task at hand, and facilitates a cost-effective stock of spare parts (SIEMENS).

There was an alternative of S7 - 1500, but because of the cost and absence of need in such fast processing unit, S7 - 300 was used.

KTP400 Basic HMI was installed as well. 4-inch widescreen touch panel with color display and 4 function keys was enough for the processes involved in the manufacturing process.

**Conveyor belt:**

Two different conveyors were used in the system. First conveyor, belt conveyor was introduced for moving containers from one machine to another. Second conveyor, roller conveyor is used to transfer the pallets with bottles.

The main parameter of the belt conveyor while choosing was its width. Conveyor was needed of a certain width, so that the bottle could fit perfectly into it. Speed of the conveyor are relatively the same and in the production line of this paper high speeds are not required due to relatively low production rate, approximately 83 liters per hour or 27 bottles.

There is a big variety of the belt conveyor on the market which fit the requirements quite well. Very good example of such conveyor is Feeding conveyor / belt / for packaging lines produced by Imanpack company (directindustry). This particular conveyor is sold with photocells which can detect presence or absence of the object in the beginning and in the end of the conveyor module. This feature helps to almost exclude additional sensors in the system.

**Flow meter:**

Flow meter in case of the described system was used as a sensor, detecting the flow and adjust the torque of the motor of the pump. Considering that relatively simple flow meter was needed.

Overall, three types of flowmeters were suitable for the introduced system. They are: magnetic flowmeter, ultrasonic, coriolis mass flowmeter.

| | **Magnetic** | **Ultrasonic** | **Coriolis** |
|---|---|---|---|
| **Availability on the market** | 3 | 2 | 2 |
| **Ease of maintenance** | 3 | 2 | 3 |
| **Ease of installation** | 2 | 1 | 2 |
| **Ease of collecting the information about the change of flow** | 3 | 3 | 1 |

Table 8 Comparison of the flowmeters

Numbers from 3 to 1 in Table 4 show how good the sensor fits the parameter. 3 is considered as a perfect match. All the parameters are the same importance, expect availability on the market, it is not critical. From Table 4 it can be seen that magnetic sensor is the best option in this particular case.

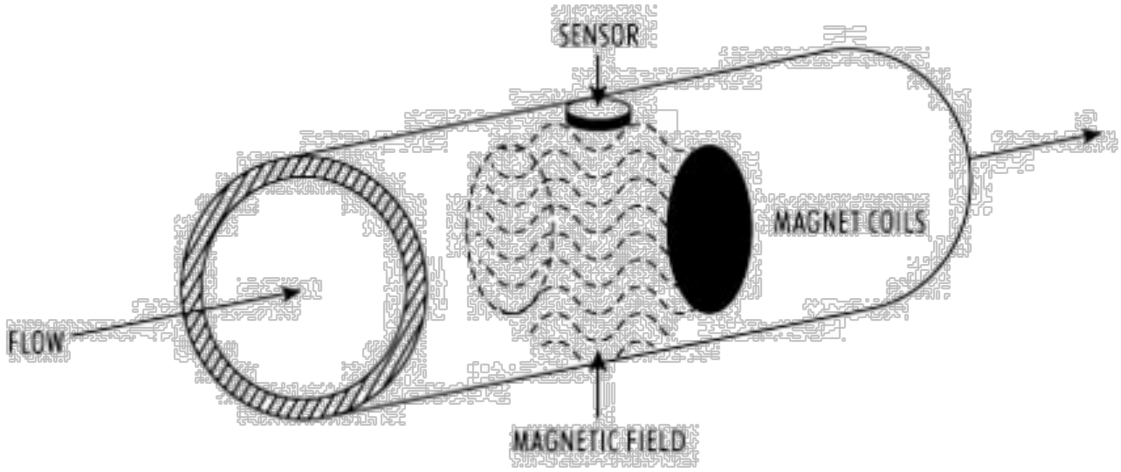


Figure 17 Magnetic flow meter

**Manipulator:**

It was supposed that the 2D linear movement manipulator should be used, because of the high working speed, accuracy and relative simplicity of programming.

The L70 series linear manipulator of MOOG Animatics is designed with mounting holes for easy X-Y setup (MOOG Animatics). After adding grabbing jaws this manipulator was inserted into the system.

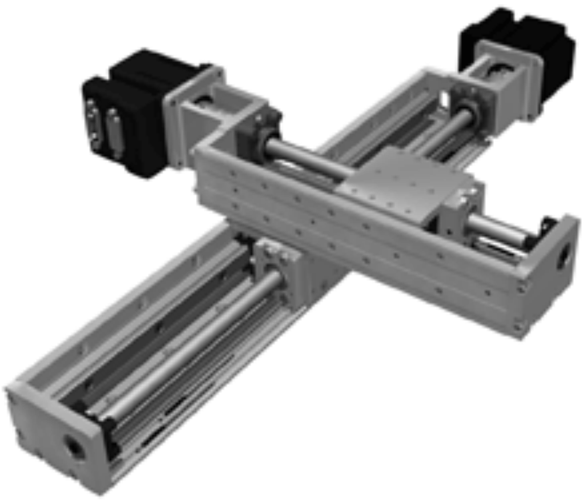

Figure 18 Two-axis manipulator

## 5.2 PLC program

SIMATIC MANAGER was used as a software for writing the program for the system. It was done this way for several reasons:

- Easy and good working communication with SIEMENS PLCs.
- Possibility of using all the existing PLC programming languages.
- Online monitoring feature.
- Helpful guidebooks.
- Big supporting online community, uploading ready programs for all kinds of automation problems.

The program for the system was written using FBD language. FBD is easier to learn, compared to ST, due to its interactivity. In addition, with FBD more complex programs can be written and more situations described compared to LAD.

# 6 Analyzing

Analyzing is an important part of design process. It helps a person to understand whether or not all the aspects, which were worth mentioning, were covered. Also final analyzing helps to identify the weak points in the system and which can be eliminated in the future.

## 6.1 Relevance of the project

Completion of the project was important because at the moment there is no such a system which could fit the given constraints. That is why the only choice was to design new manufacturing line.

Most of the systems deal only with one type of the product and one specific type of the container. Using such kind of the manufacturing process was not possible due big variety of the detergent variants and bottles.

## 6.2 Use of components

Taking into account that it was needed to find a compromise between the price and the quality, the chosen machines and equipment fits well. Even though the quality of the system elements was in the prior, cheap price of the components makes the system a bit less reliable than it could be. Otherwise, components which were chosen fit the system perfectly and cause no troubles.

## 6.3 Future expansion

Presented system is not capable of higher production rates, because at the moment it is not needed, but in the future, when the customer company will seek for higher amount of product manufactured the expansion or changes will be necessary to be done.

The most problematic part of the system is the manipulator. The production speed of the system is mainly defined by it. It should be changed to be able to fit in the process with higher production rate. One of the solutions which seems to be relevant is adding more grabbing devices on the manipulator. It will increase the amount of bottles transferred into the box at once.

Another troublesome stage is bottling/filling machine. In the project system the conveyor has to stop for a while to ensure that the bottle is filled completely. But it is impossible to stop the movement when production rate is high. That is why filling machine with several moving nozzles should be introduced. It is the only possible solution in this case.

Different shapes of the containers in the conditions of high production rates may cause problems in the system. Timing is very important part of the automation, but with various volumes and shapes of the bottles calculating the very precise time of the whole bottling process for each of them is a very complicated task. That is why it would be a nice idea to either leave a single type of the bottle or build more production lines for all of them.

Production of different detergents on the same line creates some troubles as well. The time for cleaning mixing machine, pipelines, filling machine, pump is useless and cause loss of money of the company. To avoid that, new manufacturing lines should be introduced.

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# 8 Figures and tables