Capítulo 2 Diseño e implementación de un dispositivo para Ablandamiento de Tubería Automotriz PA6 con base en la Norma DIN 16773-1

Chapter 2 Design and implementation of a device for Automotive Pipe Softening PA6 based on DIN 16773-1

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Abstract

In the automotive industry, standardization is vital to guarantee the quality of your products. In the manufacturing processes where the same conditions are measured and maintained, it is possible to generate the same results. This rule applies to many industries in the automotive industry, where; they make and assemble different parts for the fuel tank, the engine and the interior. In the task of continuous improvement, the quality of the company detected that, in the process of softening the PA6 pipe for the assembly with filters and couplings that counts the gas tank and the engine of the car, there is no system to measure the following variables: temperature, time and length of exposure of the pipe, which caused that the mechanical properties of tension and crystallization of the pipe are not for the assembly with the filters and couplings. In the internal analysis carried out by the quality department, the need to implement a system that certifies that each pipeline is exposed to the same working conditions, to ensure that the mechanical properties of the pipe are adequate, guaranteeing the performance of the pipe at the time of its assembly in different sections of the car. Exposed the above, a device was designed and implemented that softens the PA6 pipe, achieving the control of temperature, time, and the exposure length of the pipe, preserving its mechanical properties of tension and crystallization in a temperature range from 0 to 500 ° C. In addition to covering the variables detected by the quality department, it was possible to reduce 14.3% in the time of softening and assembly of the pipe, resulting in 20 more assemblies during a day of one hour. As a result of the characteristics of the device, it provides the heating reliability for ducts of different types of polymers such as: polyethylene (PE), polystyrene (PS).

Science of the plastics, Standardization, Polyamide PA6, Thermal systems, Automation

1. Introduction

The automotive industry since its inception has been in constant technological growth, according to the new requirements of quality and standardization, in order to meet the demand of its market. Many of these companies dedicated to the automotive sector have been since 1960, which has led them to have a technological development and update within their manufacturing processes, and thus be able to compete in the market. As a result of this technological growth and quality standards, which have been made to this industrial sector is the process of assembly of filters and couplings for engines, radiators, air systems, etc., which does not cover the product specifications required by the company's quality department. This process begins with the softening of polyamide PA6 pipe ends, whose diameters vary from 1 cm to 3cm. For softening in conventional mode, the operator uses a BOSCH GHG DCE heat gun of 1500 W, with electronically constant predetermined temperature at 450 ° C, where the operator exposes the ends of the pipe to the heat gun, this exposure is It performs approximately in intervals of 2 to 5 seconds depending on the type of polyamide (PA6), geometry and its diameter, later they are assembled with the corresponding filters or couplings with the help of a pneumatic press. From the above, the process of softening the polyamide pipe that is carried out with the BOSCH heat gun is highlighted. According to the observations made by the quality department of the company, 3 important points that should be covered in the softening of the PA6 pipeline are highlighted:

1. **The exposure temperature of the duct:** it is necessary to visualize and control a range of multiple temperatures ranging from 0 to 500 ° C, which, with said heat gun used in the current process, does not comply with this section**.**

2. **The exposure time of the conduit:** you need to have a control of the time where the operator knows how long the pipe should be exposed**.**

3. **Exposure length:** in the pipeline it is required to have the exposure of the pipeline controlled.

The implications that have no control of these three variables, fall in the non-standardization of the process and also in the mechanical properties of tension and crystallization of the pipeline due to heating, which later affect the assembly with filters and Due to the lack of adequate mechanical properties in the pipe, it will cause excessive deformation, will not fit the filter or coupling and will even break and become unusable.

As a consequence of the foregoing, an automotive pipe softening device was designed, which covers all the requirements mentioned above. In section 2, we will review the theory that is necessary to support the design of the softening device and the standards corresponding to the handling of the PA 6. Section 3 explains the development of the methodology used to determine the design factors and characteristics, the measurements and the materials used for the design and manufacture of the softening device. Later in section 4 explains the development, design and manufacture of the softening device, where the analysis of modeling in the thermal calculations of the heating chamber, the design of the control system, the design of the control program and the manufacture of said device, also shows the calibrations, specifications of use and field tests carried out in one of these companies of automotive turn, in relation to this section are attached data sheets of the electronic elements for the control of the softening system. Section 5 shows the results obtained. It compares the points that are judged in the audits carried out with the softening method used with the BOSCH heat gun, and with results achieved with the softening device.

2. Theoretical Review

2.1 Polyamide (PA6)

Polyamides are manufactured on an industrial scale since 1937 and first appeared on the market as synthetic fibers, under the names of Nylon (PA 66) and Perlon (PA 6). Polyamides are suitable for injection and extrusion of technical parts.

Synthesis

The polyamides are mainly semicrystalline thermoplastics, produced from the polycondensation or ion polymerization of caprolactam. The different types of PA are differentiated by the components introduced in the synthesis. Its identification is made by number representing the amount of carbon atoms between "foreign" atoms (nitrogen) within the chain. There are two possibilities to produce polyamides, from two different components or one component with two different reactive groups. PA model masses are classified as DIN 16773 or ISO 1874-1 equivalent.

Properties

The more often the amide groups appear in the chain, the greater the intermolecular attractive forces and the more water the PA will absorb. The absorption of water is what provides the polyamide with note tenacity through its high impact resistance, high abrasion resistance and good sliding properties. In turn, it is a disadvantage that the mechanical properties and their dimensional stability depend on the moisture content.

PA can be strongly demanded in a dynamic way and show little signs of fatigue after continuous efforts. The high resistance of the PA decreases with a longer duration of the effort.

Other PA properties:

- High damping capacity
- High resistance to heat deformation
- The electrical properties are influenced by the absorption of water. However, in general they are sufficiently resistant to leakage currents.
- The different types of PA absorb different amounts of water, from 1 to 3.5%, PA 66 absorbs the maximum and PA 12 the minimum.
- The chemical resistance of PA is very good. Above all, the resistance to gasoline, oils and fats, which allows its use in the manufacture of vehicles.
- They are not especially resistant to weather or light.

Influence on the properties of PA through the actions described below

The degree of crystallization can vary significantly (up to 40%) by means of the cooling rate. With high degree of crystallization decreases water absorption, improves mechanical and electrical properties, as well as dimensional stability and abrasion resistance.

Applications

In particular, PAs find application in:

- **Construction of machines and devices:** Gears, rollers, screws, nuts, bearings, ball bearing caps, coupling parts, and self-lubricating sliding tracks made with graphite types**.**
- **Electrotechnical:** Coil reels, housings for electrical appliances, (eg hand drills), abrasion resistant cable sheaths, cable couplings and connectors, photography flashes**.**
- **Vehicle manufacturing:** Fan wheels, oil filters, locks parts, carburetor parts, cams, brake fluid containers, fuel tank floats, oil and fuel hoses, (Schwarz, 2002).

2.2 DIN 16773-1 or ISO 1874-1 equivalent

Scope

This part of ISO 1874 establishes a designation system for polyamide (PA) thermoplastic materials, which can be used as a basis for the specifications. Covers polyamide homopolymers for molding and extrusion based on PA 6, PA 66, PA 69, PA 610, PA 612, PA 11, PA 12, PA MXD6, PA 46, PA 1212, PA 4T, PA 6T and PA 9T and copolyamides of various compositions for molding and extrusion. The types of polyamide plastic differ from each other by a classification system based on appropriate levels of the indicative properties.

a. Viscosity number,

b. Module of elasticity to the traction and

c. Presence of a nucleating agent, and information on the chemical structure, the intended application, the processing method, important properties, additives, color, fillers and reinforcement materials.

The designation system is applicable to all polyamide homopolymers and copolymers. Applies to materials ready for normal use, unmodified and modified by dyes, additives, fillers, reinforcing materials, modifying polymers, etc., this part of ISO 1874 does not apply to PA 6 and PA 12 cast monomer type polyamides. It is not intended to imply that materials with the same designation necessarily give the same performance. This part of ISO 1874 does not provide engineering data, performance data or data on the processing conditions that may be required to specify a material for a particular application and / or a processing method. If such additional properties are required, they shall be determined in accordance with the test methods specified in ISO 1874-2, if appropriate, (International Organization for Standardization, 2010).

- **ISO 1874-2**
- **ISO 1874-2: 2012,** specifies the methods of preparation of the test samples and the test methods that will be used to determine the properties of polyamide molding and extrusion materials. Requirements are given to handle the test material and to condition both the test material before molding and the samples before the test.

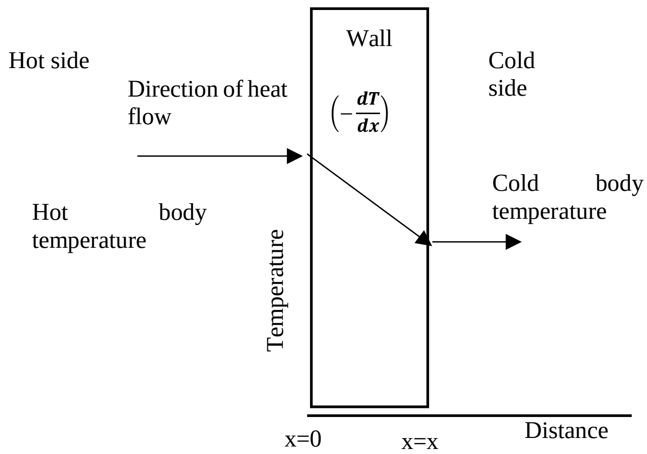
The procedures and conditions for the preparation of the test samples and the procedures to measure the properties of the materials from which these samples are made are given. The properties and test methods that are suitable and necessary to characterize polyamide molding and extrusion materials are listed. The properties have been selected from the general test methods in ISO 10350-1. Other test methods of wide use or of particular importance for these molding and extrusion materials are also included in ISO 1874-2: 2012, as well as the properties indicative of the viscosity number and tensile modulus given in ISO 1874-1, (International Organization for Standardization, 2012).

2.3 Heat Transfers

Mechanisms of heat transfer. There are three different ways in which heat can pass from the source to the receiver, even though many of the applications in engineering are combinations of two or three. These are, conduction, convection and radiation.

Conduction. The conduction is the transfer of heat through a fixed material such as the stationary wall shown in Fig. 2.1. The direction of the heat flow will be at right angles to the wall, if the surfaces of the walls are isothermal and the body is homogeneous and isotropic. Assume that a heat source exists to the left of the wall and that there is a heat sink on the right surface. It is known and then confirmed by a derivation, that the heat flow per hour is proportional to the change in temperature through the wall and the area of the wall A**.** If t is the temperature at any point on the wall and x is the thickness of the wall in the direction of heat flow, the amount of heat flow dQ is given by Eq. (1.1.).

Figure 2.1 Heat flow through a wall



Source: (Kern, 2013)

$$dQ = kA\left(-\frac{dT}{dx}\right) \qquad (1.1)$$

The term -dt / dx is called a temperature gradient and has a negative sign if a higher temperature was assumed on the face of the wall where x = 0 and smaller on the face where x = X. In other words, the instantaneous amount of heat transfer is proportional to the area and the temperature difference dt that drives the heat through the wall thickness dx. The proportionality constant k is peculiar to the conduction of heat by conductivity and is known by thermal conductivity. This conductivity is evaluated experimentally and is basically defined by Eq. (1. 1).

The thermal conductivity of solids has a wide range of numerical values depending on whether the solid is relatively a good conductor of heat, such as a metal, or a bad conductor such as asbestos. The latter serve as insulators. Even though heat conduction is usually associated with the transfer of heat through solids, it is also applicable to gases and liquids, with its limitations, (Kern, 2013).

Convection. Convection is the transfer of heat between relatively hot and cold parts of a fluid by mixing. Assume that a container with a liquid is placed over a hot flame. The liquid that is in the bottom of the container heats up and becomes less dense than before, due to its thermal expansion.

The liquid adjacent to the bottom is also less dense than the cold upper portion and rises through it, transmitting its heat by means of mixing as it rises. The transfer of heat from the hot liquid from the bottom of the container to the rest, is natural convection or free convection. If any other agitation occurs, such as that caused by an agitator, the process is forced convection. This type of heat transfer can be described in an equation that mimics the shape of the driving equation and is given by:

$$dQ = hAdT \qquad (1.2)$$

The proportionality constant h is a term over which the nature of the fluid and the form of agitation have influence and must be evaluated experimentally. It's called heat transfer coefficient. When Eq. (1.2) is written in its integrated form, Q = hAΔT, it is known as Newton's law of cooling, (Kern, 2013).

Radiation. Radiation involves the transfer of radiant energy from a source to a receiver. When radiation is emitted from a source to a receiver, part of the energy is absorbed by the receiver and part is reflected by it. Based on the second law of thermodynamics, Boltzmann established that the speed at which a source gives heat is:

$$dQ = \sigma * \varepsilon * dA * T^4 \quad (1.3)$$

This is known as the law of the fourth power, T is the absolute temperature. σ is a dimensional constant, but ε is a factor peculiar to radiation and is called emissivity. The emissivity, like the thermal conductivity k or the heat transfer coefficient h, must also be determined experimentally, (Kern, 2013).

3. Methodology

The activities and procedures that are necessary to carry out the design and implementation of this softening device are summarized in eight stages, which can be observed in Figure 2.1.

Figure 2.1 Methodology used for the design of the PA6 pipe softening device

START	
Analysis of the process	The process that is currently carried out for the softening of PA 6 ducts and evaluation of the requirements that must be modified was analyzed to cover the quality standards marked by the audits carried out in the company, which stand out in 3; control of temperature, time and position of the duct.
State of the art	State of the art about the methods and standards applied in the handling and work of PA polymers, as well as the latest technologies developed for this purpose.
Best alternative evaluation	Evaluation of the best alternative solution according to the requirements that are necessary to correct the shortcomings of the current process. Where it was decided to design a device that completely replaces the part of the process that was carried out for the softening of the PA ducts.
Design factors	Factors and characteristics that must be taken into account for the design and manufacture of the device, according to the requirements and signations by the audits.
Design	Design of the PA duct softening device, where the manufacturing materials are chosen according to the: • Structural CAD design and softening chamber • Design of the control system for temperature, time and positioning of the duct • Design of the control program system
Manufacture	Manufacture of the softening device, where the materials contained in Table 3.1 are used, and thus manufacture the softening chamber and the control circuit.
Calibrations	The calibrations corresponding to the softening equipment were made with respect to the quality parameters required in the final product by the audits and the client.
Field tests	The corresponding tests of the softening device in the PA pipe assembly process were carried out and the results of production and quality of the previous process compared to the current one.
END	

Source: Self Made

Materials

Table 2.1 Materials used for the construction of the softening device

Electronic, Electrical and Control Elements		
No.	**Quantity**	**Description**
1	1	14 gauge polarized cable meter
2	1	12 gauge polarized cable meter
3	1	Voltage source of 24V-3A
4	1	Solid state relay 250VA-50A
5	1	J type thermocouple
6	1	5 positions selector
7	1	Pin 127VAC - 15A
8	1	Arduino UNO microcontroller with protector
9	1	Module of 4 SRD relays - 5VDC - 1A (5W), optocoupler drive
10	2	12 gauge cable meter
11	2	18 gauge cable meter
12	2	22 gauge cable meter
13	2	22 gauge wire meter
14	1	Micrometers
15	1	Temperature indicator
16	1	Voltage regulator Lm7805
17	2	3 way clemas
18	10	Resistors 10K ohm.
19	1	Thermostat
20	1	GLCD 128x64 graphing screen
Thermal and pneumatic materials		
1	½	One square meter of ceramic fiber sheet
2	1	Kilogram of refractory mortar
3	1	Smooth steel sheet Cr 20% - Ni 15% - 0.45mm - 100cm x 200cm
4	1	Pneumatic actuator with connectors No. 6 - Internal diameter 32mm - stroke 100mm - stem diameter 12mm - air consumption per cycle 1.141 L Brand: FESTO
5	1	Annealing refractory block
6	1	Valve 5/2 stable mono with solenoid drive and pilot return with No. 6 connectors. Brand: FESTO.

Source: Self Made

4. Development
4.1 Process Analysis

The analysis of the process that is carried out for the heating of the polyamide PA 6 conduits, is of great importance to find the factors and design characteristics that must be considered for the manufacture of this softening device. Operators work with BOSCH guns, they generate hot air through a fan that is inside the gun and an electrical resistance. The air that is expelled by the gun is not controlled or visualized according to the strict parameters required of the product.

The operators must use thermal gloves of security to be able to work with the pistol, since the heat that gives off has a very high temperature. Subsequently place the ducts (Figure 2.2) on the nozzle of the gun, the duct is introduced approximately 3 cm to 6 cm, since that is the distance in which the couplings and filters are assembled, then the operators freely manipulate the duct to be able to heat its diameter trying to cover the entire surface, and leave it approximately 2 to 5 seconds. Once the duct is heated it is placed in a manually operated pneumatic bench to be assembled, the mentioned procedure only depends on the skill and experience of the operator, which implies a very large margin of error in the result of the final product.

Figure 2.2 PA6 polyamide conduit

Source: (Kayser, 2018)

Figure 2.3 Measurement of temperature with NI equipment

Source: Self Made

After analyzing the process that takes place to heat and assemble the ducts, we proceeded to measure the temperature generated by the BOSCH gun, to carry out this task the tests were carried out with two teams to have reliable readings, the first of which was carried out I end up with the help of LabVIEW software and the National Instruments team, specifically the NI cDAQ-9174 chassis, (see Figure 2.4), and the NI 9219 data acquisition card with a J-type thermocouple (see Figure 2.3), shown the gun that is used to heat the ducts, this is attached to a steel base, since the guns must be fixed to avoid accidents.

The NI-9219 is designed for multipurpose testing, (National Instruments, 2018), can measure signals from sensors such as voltage meters, resistance temperature detectors (RTD), thermocouples, load cells and other triggered sensors, as well as perform bridge quarter bridge signs, etc. For the measurement of the temperature, only the first channel was used, since only one card needed to receive the temperature variable was needed, in addition to this procedure, the temperature measurement process was also performed with a thermal imaging camera (see Figure 2.5), FLIR E60 (Silva JA, Salazar P., Ponce M., & Herrera S., 2017) for the acquisition and analysis of information of non-contact thermal imaging devices and thus perform an effective calibration of the parameters in the system design (see table 2.2). The data obtained with both equipment in real time of the measurements under normal operating conditions yielded values of ± 1% error in the accuracy.

Figure 2.4 NI 9219 Card

Source: (National Instruments, 2018)

Figure 2.5 NI Cdaq-9174 chassis

Source: (National Instruments, 2018)

Figure 2.6 Camara FLIR E60

Source: (Silva J. A. , Salazar P., Ponce M., & Herrera S., 2017)

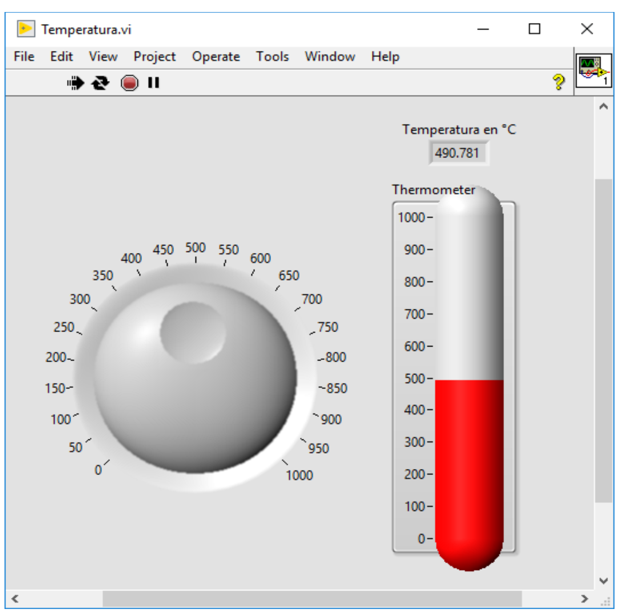
Table 2.2 Parameters for Flir

Parameters for measurement with thermal imager	Units
Emissivity	0.95
Reflected temperature	+20 °C
Distance	1 metro
RH	50%
Atmospheric temperature	+20 °C
Window temperature	0.95

Source: (Flir,2018)

With the LabVIEW 2018 software, the program was designed to visualize and acquire the temperature variable (see Figure 2.7). In the interface was incorporated a graphic and an indicator, to visualize the temperature that was generated from the gun, the results obtained showed that the temperature that was generated with the BOSCH gun was 490ºC and also the block diagram. Which indicates that the temperature obtained with the gun is not adequate to meet the quality standards needed in the process of assembly of the conduits, since it is required to have a temperature and a variable exposure time in function to the type of duct that is heating up, and that is also required to have a fixed standard of exposed duct distance at high temperature.

Figure 2.7 Heat flow through a wall



4.2. Factors and Design Characteristics

4.2.1. Exposure and softening temperature

Depending on the temperature specifications required by the duct manufacturing process, the exposure temperature of the ducts, to which it must be subjected, will depend on the dimensions of each one, which vary in diameters, thicknesses and alloys of the Polyamide PA 6 with other polymers. Based on the conduit that requires greater heating, the maximum operating temperature of 500 ° C was taken as reference, the most suitable thermal chamber for the application can be designed, denoting that the 500 ° C is the maximum operating temperature, based on design a margin of + 10% (50 ° C) is left at the maximum operating temperature. Therefore, the softening chamber can reach a maximum temperature of 550 ° C.

Another important point to analyze is the softening temperature, since for obvious reasons it can not exceed the melting temperature of the material, for the development of this project this softening temperature is 75 ° C according to procedure A ISO 75-1, (International Organization for Standardization, 2004). Among the most relevant characteristics in the design of the softening device are summarized in Table 2.3 (Inalcoa, 2018), (Sanmetal, 2018).

Table 2.3 Technical characteristics of the PA6 polyamide conduit

Mechanical characteristics	Method / Test (DIN / ASTM)	Value	Unit
Density	53479	1,14	g/cm^3
Stretch point elongation	53455	85	MPa
Resistance to breakage due to elongation	53455	70	%
Module of elasticity to the traction	53457	3200	MPa
Thermal characteristics	**Method / Test (DIN / ASTM)**	**Value**	**Unit**
Melting temperature	53736	220	ºC
Dynamic vitrification temperature	53736	40	ºC
Resistance to deformation	ISO 75 ISO 75	75 190	ºC ºC
Procedure A		160	ºC
Procedure B		0,23	W/ (m.K)
Temperature of use for a short time		1,7	J/ (g.K)
Specific heat conductivity capacity		7	10(-5) /k

Source: (Sanmetal, 2018)

4.2.2 Exhibithion time

Because the automotive sector manufactures different types of conduits with different geometries and alloys, the exposure time becomes a function of these. Based on the characteristics of the ducts that require higher and lower temperatures, it can be deduced that the shortest exposure time is 1 sec. and the highest 3 sec. Because you need to change the time to different values, you need to have a control whose readability is 200 msec. Having a control range of exposure time of 200 msec. to 3 sec.

4.2.3. Exposure length

The exposure length of the ducts is a standard parameter for all duct models, which is defined by the manufacturer's specifications, which in many cases is **5 cm** for all ducts.

4.2.3.1. Positioning and detection system

Due to the high temperatures that are generated inside the softening chamber, it is necessary to take into consideration the positioning system of the duct, because, if this positioning system is heated to the high temperatures of the chamber, it can burn the surface In addition, it must be ensured that when placing the duct in the heating system, the 5 cm already specified above is exposed to the duct.

4.2.4. Work area for the device

According to the dimensions of the work stations, where the softening and the assembly of the conduit takes place. The section where the softening device is intended to be placed must take care of the size and weight. The space available for mounting the camera both width, length and height is of; 20 x 80 x 40 cm respectively, see Figure 2.8 and 2.9

Figure 2.8 Available width of for the softening chamber

Source: Self Made

Figure 2.9 Available length of for the softening chamber

Source: Self Made

The maximum permissible weight for the softening chamber is 10 kg. Because it must be fastened in the structure of the work station, with this reference it has to be designed with light materials, but strong enough to operate at temperatures of 500 ° C.

4.3 Design

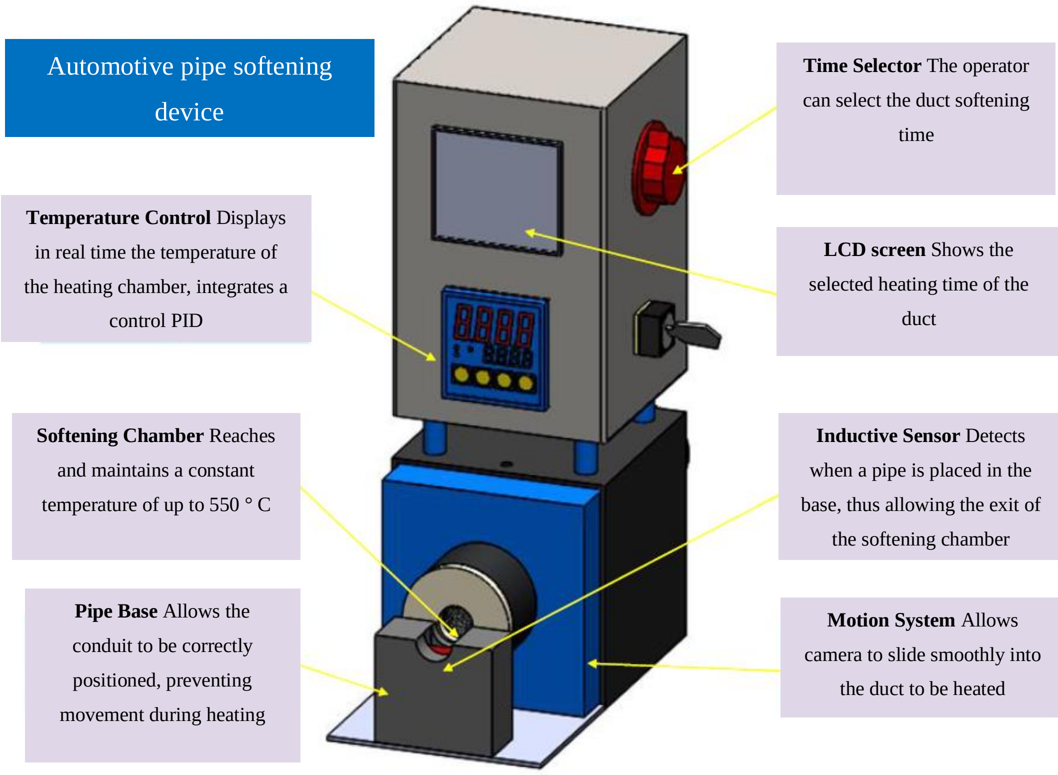
4.3.1 CAD Design Structural and Softening Chamber

4.3.1.1 CAD Design Structural

With the help of CAD design software, Solid Works, the design of the heating system was carried out to have the structural plans of the same, which has a 128x64 LCD screen to visualize the time in which the duct is exposed to heat, time selection has a readability of 200 ms and a maximum range of 3 sec. The process temperature measurement procedure was carried out in the first instance using infrared thermography (Silva JA, Salazar P., Ponce M., & Herrera S., 2017) to ensure the calibration and specify the parameters to be used in the mathematical model of the system.

It also has a PID temperature controller, which shows the temperature generated in the device and the maximum temperature that must be inside, with it we can vary the temperature we want to have in the chamber with a range from 0º to 550ºC, since the maximum temperature at which the pipes must be subjected is 500 ° C for a time of 1s to 3s, depending on the dimensions thereof. To measure the internal temperature of the chamber, a J type thermocouple was placed in the central part of the heating chamber in order to receive the temperature signal, it was ensured that the thermocouple was not close to the resistance, since in this way the signal of temperature that it would receive would be greater due to the radiation that it emits, (see Figure 2.10).

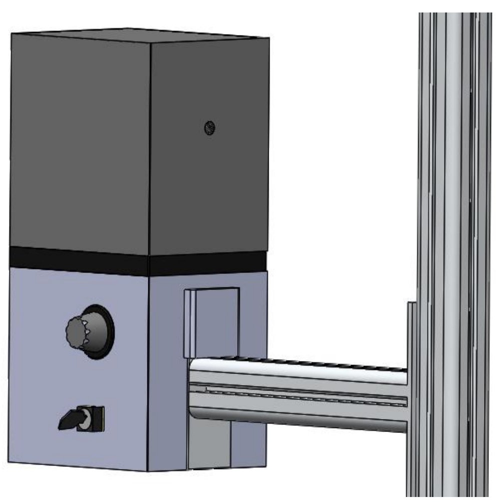
Figure 2.10 Design of Heating System in Solid Works



Source: Self Made

At the bottom of the design is the heating chamber, which has a pneumatic actuator that moves the camera 5cm towards the base where the duct is placed, this chamber is designed to generate a maximum temperature of 550ºC. The heating chamber has insulations with low conductivity coefficient, to avoid energy losses in the system and an external coating of stainless steel to avoid the least heat loss by radiation. In the back of the heating system there is a tab to be able to attach it to an arm that is at the base of the work table, this helps the equipment does not move and is a danger for operators, based on the oscillatory mechanical behavior of the pneumatic cylinder that controls the displacement of the linear movement, the analysis of the magnitude of the signal of the vibration spectrum and the phase angle was performed to ensure the minimum imbalance of the equipment while it is in operation (Silva J., Salazar P., Ponce M., & Herrera S., 2016). Figure 2.11 shows the rear view of the camera which has an entrance to attach it to an aluminum arm. In this way the camera will be fixed helping it to be manipulated in a more comfortable and safe way for operators.

Figure 2.11 Warming camera tab



Source: Self Made

Table 2.4 Heating system specifications

Specifications		
Physical	High	318 mm
	Width	170 mm
	Background	141 mm
	Weight	7000 gramos (+/- 200g)
Counters / Timers	Logical Levels	TTL
	Accountants	1
Digital I / O	Bidirectional Channels	12
	Maximum Voltage Range	0 V – 5 V
	Entry resolution	12 bits
Timing - Accountants	Shooting	Digital
	Accountants	---
Temperature 1	Maximum temperature	550° C
	Readability	1° C
Consumption Energy	Power	1000 W

Source: Self Made

4.3.1.1.1. Dimensions of the softening chamber

Once the CAD design was finished, according to the required specifications, the dimensions of the camera were designed and specified. To start the camera, the largest size of duct was taken as reference, which has 3.5 cm outside diameter, which by entering 5 cm into the chamber occupies a volume of 48.1 cm^3. Taking as margin 1.5 cm in diameter and 1 cm in depth, and considering 1 cm of thickness in the block results in a volumetric figure of 7cm x 7cm x 10cm, and as an inner chamber a cylindrical geometry of 5cm in diameter and 6cm background, giving as inner volume 117.8cm^3. The cylindrical figure of the inner chamber was taken as a consequence of the geometry of the body to be heated, because it is required to heat the duct uniformly around its diameter, and to achieve this, it is required that the heat transfer from the walls from the inner chamber to the surface of the body must meet the perpendicularity.

4.3.1.2 Design of the Softening Chamber

Returning to what was analyzed in chapter 4.1 and 4.2, it is taken as a reference in this chapter, because depending on these aspects we can start with the thermodynamic design of the softening chamber, as is the thickness of the insulation necessary to have the losses of allowable energy, in addition to determining the adequate resistance for the system, thus avoiding an excessive consumption of energy and increasing operating costs.

4.3.1.2.1 Calculation of the energy balance of the system

In any thermal design it is necessary to determine an energy balance, since in real life there are energy losses that are not thoroughly analyzed in an empirical problem. Given as a guideline, the energy balance for this thermal system is denoted by Eq. (1), (Faires, 1982).

$$Q_T = Q_s + Q_p \tag{1}$$

Where:

Q_T = *Total heat supplied to the system*
Q_s = *Heat absorbed by the body to be heated*
Q_p= *Lost heat of the system*

4.3.1.2.1.1. Calculation of heat losses (Q_P)

In the first instance, the heat losses due to the heat flow in the insulator and the environment are calculated, which can be denoted by Eq. (2).

$$Q_p = Q_k + Q_{cv} + Q_r \tag{2}$$

Donde:
Q_k = *Heat losses by conduction*
Q_{cv} = *Convective heat loss*
Q_r = *Heat losses by radiation*

4.3.1.2.1.1.1. Calculation of the coefficient of heat transfer by convection

According to the norm NOM - 009 - ENER - 1995 and NOM - 018 - ENER - 2011, (National Secretariat of Energy, 1995), the coefficient of heat transfer by convection or also denoted by the film coefficient (h_{cv}) in flat surfaces, is given by the following mathematical relationship, see Eq. (3).

$$\boldsymbol{h_{cv}} = 3.0075C\left(\frac{1.11}{T_{sup}+T_{amb}-510.44}\right)^{0.181} * \left(\frac{1.18}{(T_{sup}-T_{amb})^{-1}}\right)^{0.266} * (1 + (7.9366 * 10^{-4})(v))^{0.5} \tag{3}$$

where:
$\boldsymbol{h_{cv}}$ = *Coefficient of film by convection* $\left(\frac{W}{m^2K}\right)$
$\boldsymbol{C}$ = *Coefficient of form, 1.79 for flat surfaces and 1.016 for pipes (dimensionless)*
$\boldsymbol{T_{sup}}$ = *Assumed temperature of the outer surface of the insulation, (K)*
$\boldsymbol{T_{amb}}$ = *Ambient temperature, (K)*
$\boldsymbol{v}$ = *Wind speed* $\left(\frac{m}{h}\right)$

According to a study carried out by (Soler & Palau Ventilation Group, 2015), the wind speed scale is proportional to the force of the wind, and this scale is called the Beaufort scale, see Table 2.5 measured values at 10 m height. The value of the wind that was taken for the purposes of Beaufort scale calculations is "0"

Table 2.5 Beaufort scale

Beaufort scale	Name of the wind	Speed	
		m/s	Km/h
0	Calm	0.5	2
0	Calm	0.5	2
1	Light air	1.5	5
2	Light breeze	3	11
3	Soft breeze	6	22
4	Moderate breeze	8	30
5	Fresh breeze	11	40
6	Strong breeze	14	50
7	Moderate wind	17	60
8	Fresh wind	21	75
9	Strong wind	24	87
10	Great Wind	28	100
11	Storm	32	115
12	Hurricane	36 or more	130 or more

Sourcee: Soler & Palau Ventilation Group

Replacing the particular values to Eq. (3), we obtain:

$\boldsymbol{C}$ =*1.79*
$\boldsymbol{T_{sup}}$ =*378.15 (K)*
$\boldsymbol{T_{amb}}$ = *298.15 (K)*
$\boldsymbol{v} = 1800 \left(\frac{m}{h}\right)$

$$\boldsymbol{h_{cv}} = 3.0075(1.79)\left(\frac{1.11}{378.15+298.15-510.44}\right)^{0.181}\left(\frac{1.18}{(378.15-298.15)^{-1}}\right)^{0.266}(1 + (7.9366 * 10^{-4})(1800))^{0.5}$$

$$h_{cv} = 12.714234 \left(\frac{W}{m^2K}\right)$$

4.3.1.2.1.1.2. Calculation of heat transfer coefficient by radiation

In the same way the norm NOM - 009 - ENER - 1995 and NOM - 018 - ENER - 2011, (National Secretariat of Energy, 1995), the coefficient of heat transfer by radiation (h_r) in flat surfaces, is given by the following mathematical relationship, see Eq. (4).

$$\boldsymbol{h_r} = 0.9824 * 10^{-8} * \varepsilon * \frac{{T_{amb}}^4 - {T_{sup}}^4}{T_{amb} - T_{sup}} \quad (4)$$

Where:

$\boldsymbol{h_r}$ = *Radiation transfer coefficient* $\left(\frac{W}{m^2K}\right)$
$\boldsymbol{\varepsilon}$ = *Emissivity of the radiant surface (Adimensional)*

Taking the emissivity value of polished stainless steel ε = 0.074 and substituting the values corresponding to Eq. (4), we obtain:

$$\boldsymbol{h_r} = (0.9824)(10^{-8})(0.074)\frac{298.15^4 - 378.15^4}{298.15 - 378.15}$$

$$h_r = 0.11401\left(\frac{W}{m^2K}\right)$$

To determine the global heat transfer coefficient (h_g) and then use it to obtain the total heat losses per unit area, Eq. (5) is used.

$$h_g = h_{cv} + h_r \quad (5)$$

Substituting the corresponding values you get:

$$h_g = 12.828244\left(\frac{W}{m^2K}\right)$$

4.3.1.2.1.2. Calculation of the total heat flow lost per unit area in the system

To determine the total heat losses in the system, Fourier's Law (Kern, 2013) is used, which states that the heat flux per unit time (q) (W) passing through a flat wall is directly proportional to the area (A) (m^2) of the wall, to the temperature change (dT) (K) and to the $(k)(\frac{W}{m\,K})$, denominated thermal conductivity of the material of the wall and inversely proportional to the thickness of the wall (dx) (m), see Figure 11. The equation that relates this process is the Eq. (6).

$$dq = kA\left(-\frac{dT}{dx}\right) \quad (6)$$

Solving the differential equation is obtained Eq. (7), the sign agreement will be a function of the direction of heat flow that one assumes.

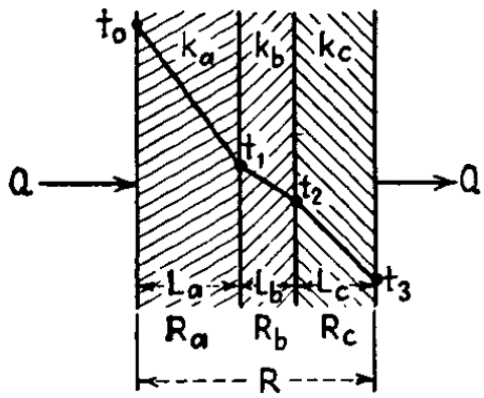
$$q = kA\frac{\Delta T}{\Delta x} \quad \rightarrow \quad q = kA\frac{T_2 - T_1}{\Delta x} \quad (7)$$

Where:

$\boldsymbol{T_2}$ = *Warmer face temperature*
$\boldsymbol{T_1}$ = *Temperature of the least hot*
$\Delta\boldsymbol{x}$ = *Wall thickness*

For the case of composite walls, the analogy of the law of ohm is used (see Figure 2.12). Where Eq. (7) is modified to Eq. (8) and the heat flow will be given per unit area $(\dot{\boldsymbol{q}})$ $(\frac{W}{m^2})$.

Figure 2.12 Heat flow through a composite wall.



Fuente: (Kern, 2013).

$$\dot{q} = \frac{q}{A} = \frac{T_0 - T_i}{\sum_{i=0}^{i} R_i} \quad \rightarrow \quad R_i = \frac{\Delta x_i}{k_i} \tag{8}$$

Where:
T_0 = *Warmer face temperature*
T_i = *Temperature of the last face*
R_i = *Thermal resistance*
k_i = *Thermal conductivity of each material of the composite wall*
Δx_i = *It is the thickness of each material of the composite wall*

For our particular case, Eq. (8) is modified to Eq. (9), this is due to the fact that, by combining heat transfers by convection and radiation, thus obtaining the global transfer coefficient, we can combine the transfer of heat by convection, radiation and conduction in a single equation thus obtaining the total heat losses per unit area of the system, (Holman, 1996).

$$\dot{q_T} = \frac{q}{A} = \frac{T_{int} - T_{amb}}{\frac{1}{h_g} + \frac{\Delta x_0}{k_0} + \frac{\Delta x_1}{k_1} + \frac{\Delta x_2}{k_2}} \tag{9}$$

Where:
T_{int} = *Temperature of the inside of the wall of the softening chamber 823.15 (K)*
T_{amb} = *Ambient temperature 298.15 (K)*
h_g = *Global coefficient of heat transfer* 12.828244 $\left(\frac{W}{m^2 K}\right)$
k_o = *Thermal conductivity of the refractory block* 1.04 $\left(\frac{W}{m\,K}\right)$
k_1 = *Thermal conductivity of ceramic fiber* 0.12 $\left(\frac{W}{m\,K}\right)$
k_2 = *Thermal conductivity of stainless steel* 15.1 $\left(\frac{W}{m\,K}\right)$
Δx_0 = *Thickness of the refractory block 0.01 (m)*
Δx_1 = *Thickness of ceramic fiber 0.0508 (m)*
Δx_2 = *Thickness of ceramic fiber (0.002) (m)*

Substituting the particular values of our problem to Eq. (9) we obtain:

$$\dot{q_T} = \frac{823.15 - 298.15}{\frac{1}{12.828244} + \frac{0.01}{1.04} + \frac{0.0508}{0.12} + \frac{0.002}{15.1}} \quad \rightarrow \quad \dot{q_T} = 1027.3285 \ \frac{W}{m^2}$$

To determine the flow of heat lost q_{pT} due to the conduction, convection and radiation of the walls, multiply the $(q_T)^{\cdot}$, between the area or exterior surface of the heating chamber, which has dimensions of 0.206529 m^2, from the above you get:

$$q_{pT} = \left(1027.3285 \ \frac{W}{m^2}\right)(0.206529\, m^2) = \mathbf{212.1740\ W}$$

To verify if our calculations were correct, the norm NOM - 009 - ENER - 1995 and NOM - 018 - ENER - 2011, suggests to use the Eq. (10), which relates the real temperature of the exterior surface (T_{reals}) and the heat per unit area (q_T'') lost in the system with the assumed temperature (T_{sup}).

$$T_{reals} = T_{amb} + \frac{\dot{q}_T}{h_g} \tag{10}$$

If T_{reals} = T_{sup}, then the heat losses are equal to q_T'' and therefore the temperature of the isolated surface is T_{reals}, otherwise T_{reals} = T_{sup} is taken and the calculations made previously are repeated, from Eq. (3).

$$T_{reals} = 298.15 + \frac{1027.3285}{12.828244} \quad \rightarrow \quad T_{reals} = 385.05\, K$$

$$T_{reals} = 378.23.05K \cong T_{sup} = 378.15\, K \ \therefore \ T_{sup} = T_{reals}$$

Recalling the value of the assumed temperature and buying its value with the actual temperature of the calculated surface, no significant difference is noted, so the assumed temperature is correct and in the same way the calculations made previously.

4.3.1.2.1.3 Calculation of the heat flow provided to soften the duct

For the total calculation, Eq. (11) is used for the effective heat flow (q_{AT}) provided to heat the duct.

$$q_{AT} = q_{rT} + q_{cvT} \tag{11}$$

Where:
q_{rT} = *It is the flow of heat provided by radiation from the inner wall of the chamber (W)*
q_{cvT} = *It is the flow of heat by conduction due to the air staked inside the inner chamber (W)*

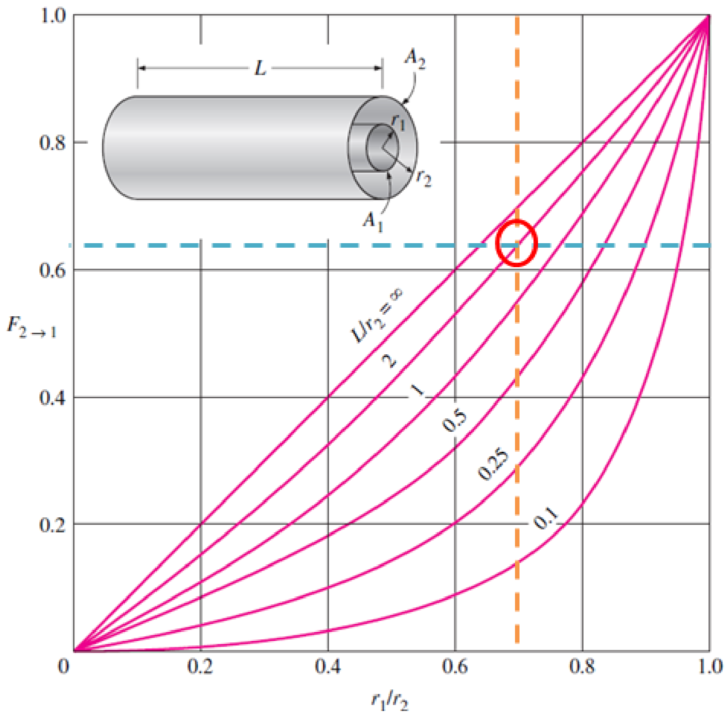
For the analysis of the total heat of heat supplied by radiation (q_{rT}), Eq. (12), (Holman, 1996), which is a particular derivation of the Stefan-Boltzmann radiation equation for surfaces, is used cylindrical concentric between them.

$$q_{rT} = \frac{\sigma({T_{int}}^4 - {T_{cd}}^4)}{\frac{1-\varepsilon_1}{\varepsilon_1 A_1} + \frac{1}{A_1 F_{12}} + \frac{1-\varepsilon_2}{\varepsilon_2 A_2}} \tag{12}$$

Where:
σ = *Constant of Stefan-Boltzmann* $5.6703 * 10^{-8} \left(\frac{W}{m^2 K^4}\right)$
T_{cd} = *Initial temperature of the duct 298.15 (K)*
A_1 = *Radiating area of the camera 0.00785398 (m^2)*
A_2 = *Area of the radiation absorbing duct 0.00549778 (m^2)*
ε_1 = *Emissivity of the irradiating surface - chamber with mortar coating (0.93)*
ε_2 = *Emissivity of the absorbent-conductive surface of polyamide PA6 (0.94)*
F_{12} = *Form or vision factor for concentric cylinders*

In order to determine the form factor (F_{12}) for our particular case, the relationship given in Figure 4.1 is used, (Gengel, 2007).

Grafico 2.1 Form or vision factor for concentric cylinders



Source: Calorie and mass transfer, a practical approach, Yunus A. Cengel 2007

Where:
$\boldsymbol{L}$ = *Conduit length 0.005 (m)*
$\boldsymbol{r_1}$ = *Conduit radius 0.0175 (m)*
$\boldsymbol{r_2}$ = *Camera radio 0.025 (m)*
$\boldsymbol{r_1}/\boldsymbol{r_2}$ = *0.7 (dimensionless), denoted by the dashed orange line.*
$\boldsymbol{L}/\boldsymbol{r_2}$ = *2 (dimensionless)*
$\boldsymbol{F_{12}}$ = *Form factor ≅ **0.65**, denoted with the dashed line blue.*

Substituting the particular values in Eq. (10), we obtain:

$$q_{rT} = \frac{5.6703*10^{-8}*(823.15^{\ 4} - 298.15^{\ 4})}{\frac{1-0.93}{0.93*0.00785398} + \frac{1}{0.00785398*0.65} + \frac{1-0.94}{0.94*\ 0.00549778}} = \mathbf{117.86218\ W}$$

To determine the flow of heat by conduction due to stagnant air inside the chamber (q_rT) Eq. (6) is used, and solving the differential equation for our particular case, where we have heat exchange by conduction between cylindrical walls, (Incropera & Witt, 1999), you get:

$$q_{cvT} = \frac{2\pi L(T_{int} - T_{cd})}{\ln\frac{r_2}{r_1}} \qquad (13)$$

Substituting the corresponding values you get:

$$q_{cvT} = \frac{2\pi*0.005*(823.15-298.15)}{\ln\frac{0.025}{0.0175}} = \mathbf{25.47471\ W}$$

Using Eq. (11) and replacing the values already calculated, there is a total heat flow provided to the duct:

$$q_{AT} = 117.86218 + 25.47471 = \mathbf{143.3369\ W}$$

Once calculated the total heat flow that the duct receives, we can determine if this heat flow is enough to heat the largest duct in the required time, these parameters can be consulted in chapter 4.2. To calculate the heating time of the duct with the total heat flow (q_{AT}) determined with Eq. (11), Eq. (14) is used.).

$$q_{AT} = \frac{dQ}{dt} = \rho_c V_c C_p \frac{dT}{dt} \quad (14)$$

Solving the differential equation for our particular case we obtain:

$$q_{AT} * t = \rho_c V_c C_p (T_{bl} - T_{cd}) \quad (15)$$

Where:
$\boldsymbol{t}$ = *Time used for the softening of the duct*
$\boldsymbol{\rho_c}$ = *Density of the duct to be heated, in this case PA6* $\left(1.14 \ ^{gr}/_{cm^3}\right)$
$\boldsymbol{V_c}$ = *Volume of the section of the duct to be heated (*$4.0349\ cm^3$ *)*
$\boldsymbol{C_p}$ = *Specific heat of the duct to be heated, in this case PA6* $\left(1.7 \ ^{J}/_{grK}\right)$
$\boldsymbol{T_{bl}}$ = *PA5 duct softening temperature (348.15 K)*

Clearing the time (t) of Eq. (15) and substituting the corresponding values, we have:

$$\boldsymbol{t} = \frac{1.14*4.0349*1.7*(348.15-298.15)}{143.3369} = \mathbf{2.7277}\ \boldsymbol{seg}$$

$$\boldsymbol{t}_{\boldsymbol{expuesto}} = \mathbf{3}\ \boldsymbol{seg}. \cong \boldsymbol{t} = \mathbf{2.7277}\ \boldsymbol{seg}$$

Deducing that the calculated time (t), for practical purposes, is equal to the necessary exposed time ($t_{expuesto}$), it has an effect that the total heat flow provided to the duct, is adequate to meet the necessary characteristics of duct softening. Therefore, the flow of heat q_s supplied is double to q_{AT}, because q_{AT}, is the flow of heat that is generated every second, from the walls to the duct. From the above, the heat necessary to soften the pipe to the desired temperature and in the required time must be considered independently, therefore the heat flow q_s, is equal to:

$$q_s = 2 * 143.3369\ W = 286.6738\ W$$

4.3.1.2.2 Calculation of the total heat supplied to the system ($\boldsymbol{Q_T}$)

Taking as reference Eq. (1) and for practical defects, the total heat needed in the system, is taken as heat flow, q_T, the previous as a result of which the previous calculations are simplified determined the total heat flow of the system.

$$Q_T = Q_s + Q_p \quad \rightarrow \quad q_T = q_s + q_{pT}$$
$$q_T = 286.6738\ W + 212.1740\ W = 498.8478\ W \cong 500\ W$$
$$q_T \cong 500\ W$$

4.3.1.2.3 Calculation of resistive elements

Applying the law of electric power, Eq. (16), to calculate the power dissipated by an element that adds a certain current I is obtained

$$P = VI \quad (16)$$

Where, V is the supplied voltage and I is the current that the system consumes, as, V is equal to 127 V and the power P is equal to q_T, replacing and clearing the current value I is obtained:

$$\boldsymbol{I} = \frac{500\ W}{127\ V} = \mathbf{3.937}\ \boldsymbol{A} \cong \mathbf{4}\ \boldsymbol{A}$$

Applying the law of ohm and the Eq. (15), we obtain the Eq. (17), where the power that dissipates a resistance of value R and that consumes current I is obtained.

$$P = RI^2 \quad (17)$$

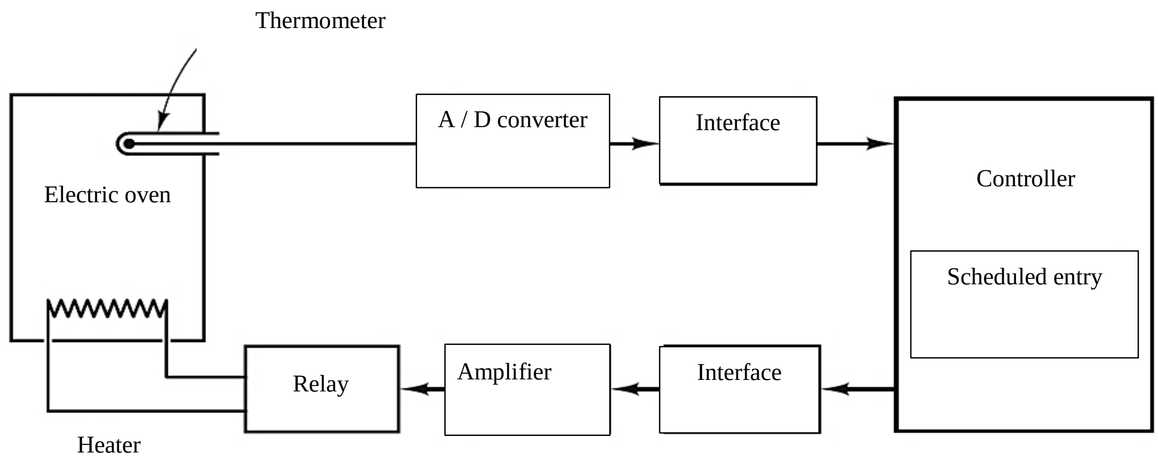
Clearing R of Eq. (17) and substituting values, we obtain the value of the resistance in Ohms that our resistance must have in order to dissipate the heat q_T.

$$\boldsymbol{R = \sqrt{\frac{P}{I}} = \sqrt{\frac{500}{4}} = 11.1803\ \Omega \ \cong 12\ \Omega}$$

4.3.2 Design of temperature control, time and position of the duct
4.3.2.1 Design of the temperature control system

En la figure 2.13 muestra un diagrama esquemático de lazo cerrado del control de temperatura de un horno eléctrico, (Ogata, 2010).

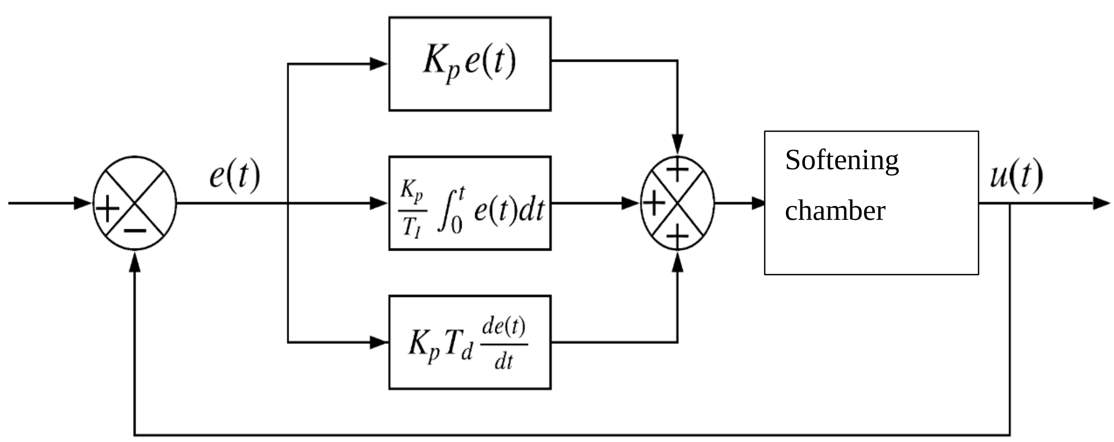
Figure 2.13 Temperature control system.



Source: (Ogata, 2010)

For our particular case, the control system that was used for the temperature control in the heating chamber, follows the same structure as in Figure 2.13, having a PID controller, whose synthesis can be seen in the block diagram shown in the figure 2.14.

Figure 2.14 Diagram of temperature PID system blocks.

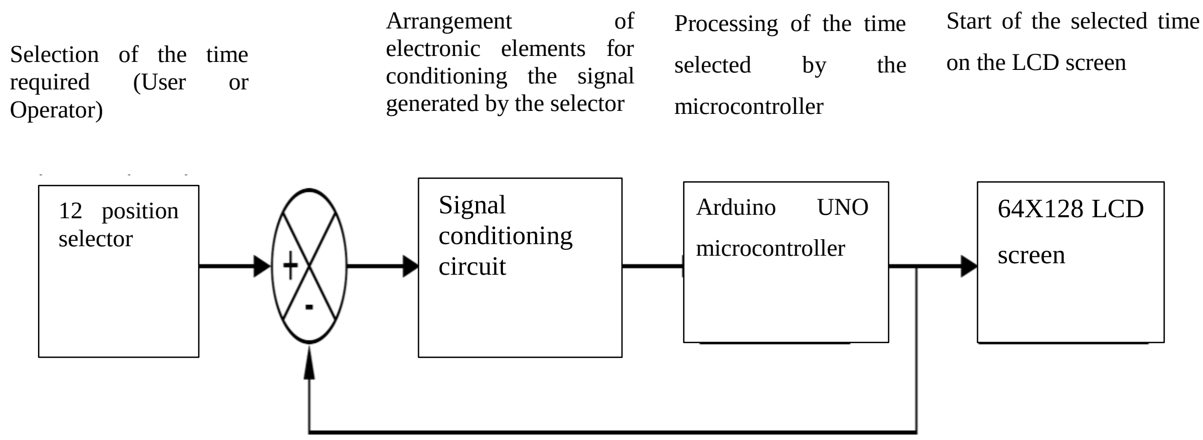


Source: (Ogata, 2010)

4.3.2.2 Design of the visualization and time control system

En función a los factores de diseño que se analizaron en el capítulo 3 y 3.1, se empleó un microcontrolador Arduino UNO, el cual nos permite seleccionar y visualizar el tiempo exposición del conducto por medio de un selector y una pantalla LCD de 64x128 pixeles. En la figure 2.15 se muestra un diagrama esquemático del funcionamiento.

Figure 2.15 Diagram de bloques del sistema de visualización.



Source: self made.

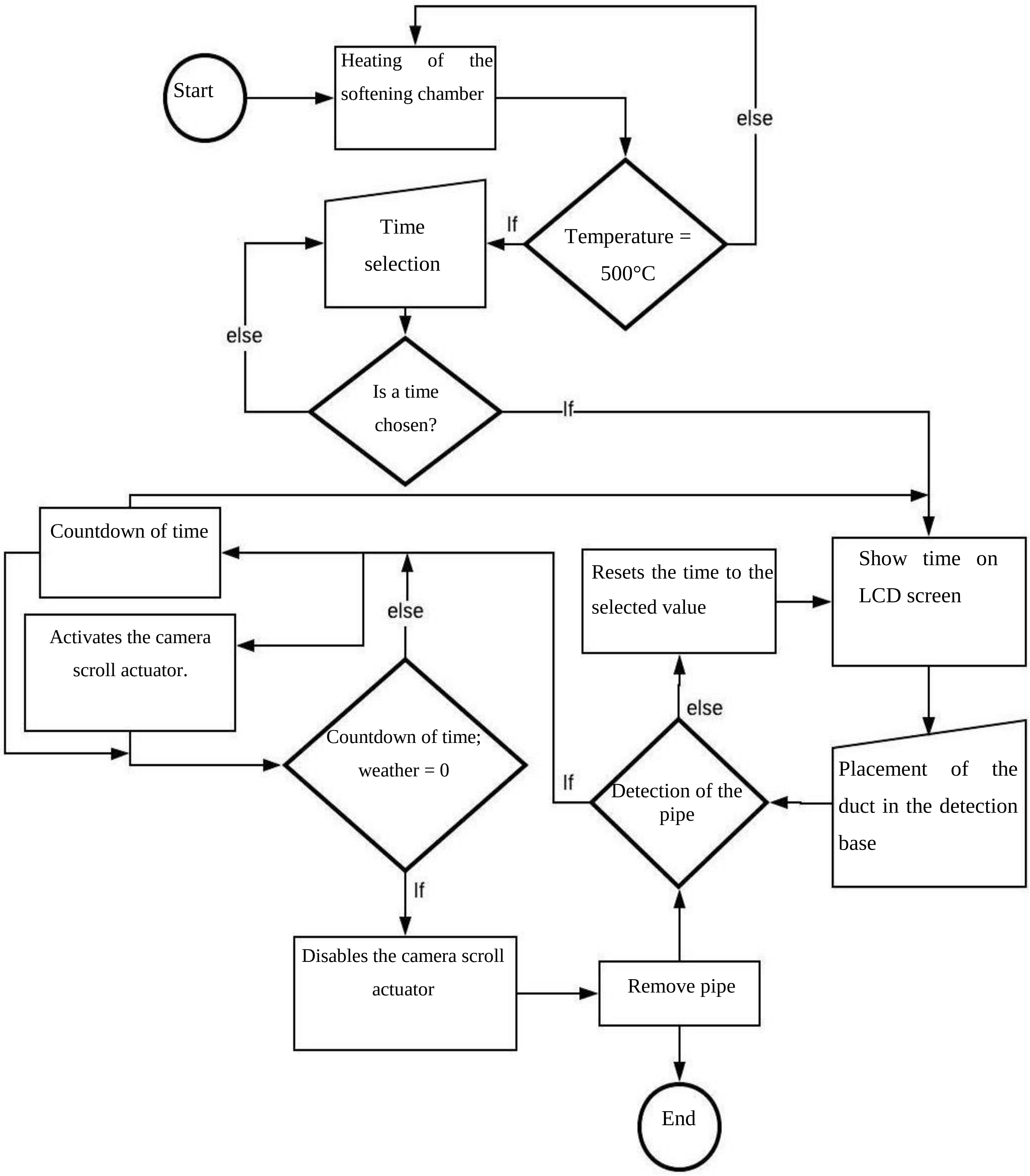
4.3.2.3 Design of the positioning and duct detection system

Returning to the design factors of chapter 4.2, it is required that this heating system has a mechanism for movement and detection of the pipeline, since, with this, it will be possible for the time counting system to detect the pipe, this is achieved due to that on the basis of detection where the duct is placed, there is an inductive sensor, thus allowing the detection of the duct and start of the heating of the duct. See figure 4.9 For the movement of the camera there is a pneumatic actuator that facilitates the movement of the heating chamber towards the pipe.

4.3.3 Control Program Design

In Figure 4.15, a flow diagram is shown where the program was designed, which was developed in the Arduino programming platform.

Figure 2.15 Diagram of flow of the designed program.



Source: Self Made

4.3.4 Selection of Materials

The selection of chose according to all the parameters and designs already analyzed in the previous chapters. You can see a list of the materials that were used for the manufacture of the softening system in the Table 2.2.

4.4 Manufacture

4.4.1 Manufacturing of the Softening System and Structure

In the design of the chamber a circle was drawn in the center of the square with a diameter of 5cm, once the hole of 5 cm was made, points were marked every 45 ° in the entire circumference. After having marked all the necessary points, with the help of a table drill and a drill for concrete, the block was drilled at each point.

After finishing the holes in the block, a nichrome resistor was placed, this was placed in a spiral around the circumference of the block, taking care that each spiral of the resistance did not have contact with each other, since when the material expands, the material expands and if there is contact of two spirals the electric current that flows would increase twice, which would cause a break in the electrical resistance. (Ver Figure 2.17 y 2.18).

Figure 2.17 Refractory block with mortar and ceramic fiber coating.

Source: Self Made

Figure 2.18 Structure of the softening system

Source: Self Made

4.4.2 Manufacturing of the Control System

For the implementation and manufacturing of the control system, a signal conditioning circuit was implemented for the inductive sensor, a position selector was placed on a side wall for different time intervals and for the 164x128 LCD screen, in addition to this circuit the necessary electronics were included to implement an Arduino UNO microcontroller, this device will have the task of acquiring and processing the signals sent by the inductive sensor and the time selector, to later process this information and send it to the LCD screen. From the above according to what was analyzed in chapter 4.3.2 and 4.3.3.

4.5 Calibrations

Once the performance tests were made and verify that the requirements are satisfactory, we proceeded to calibrate the measurements of time, temperature and distance that are required. The time required for the operation of the machine is 3s, 4s and 5s for the different types of ducts, all at a distance of 5cm. What was done to develop the appropriate calibrations was the following:

1. The temperature of 500 ° C was adjusted
2. The time was adjusted according to the type of conduit.
3. The stop of the pneumatic actuator was adjusted to be able to leave a standard length for a stroke of 5 cm.

Once the calibration of the different parameters was completed, the corresponding tests were carried out. In order to know if the calibrations are adequate, the quality department of the company provided us with samples of how the different conduits that are manufactured and assembled in the process should be, this to be able to compare them with what was obtained in this softening system.

4.6 Field Installation and Testing

The heating chamber was presented to one of the companies in the automotive sector, to start its operation and perform tests (See Figure 2.19). Once the camera was installed, tests were carried out for a period of one hour, where the operators who were in that module expressed that the method to soften and assemble the pipeline was approximately 4 to 5 sec. faster, these data were verified with a stopwatch, giving an average of 4.6 seconds, which was valid what the operators reflected, besides, they expressed that this new softening system was much more comfortable, since they only had to introduce the conduit by the mouthpiece of the camera and did not have to manipulate or make any movement with the conduit, as they did with the heat gun BOSCH. When removing the conduit, the operators observed that there was no detachment of material or excessive deformation, due to the heat that was inside the chamber, (See Figure 2.20).

Figure 2.19 Camera installation inside the Kayser facilities

Source: Self Made

Figure 2.20 Operator inserting the conduit in the chamber

Source: Self Made

5. Results

The implementation of the softening device to the assembly line obtained the following results:

- **Exposure temperature control:** as a result of implementing a PID temperature control, it was possible to manipulate this variable in a range of 0 to 500 ° C with a readability of 1 ° C, it is also possible to visualize in real time the temperature which covers with the requirements indicated by the quality department**.**

- **The exposure time:** because in this system the distribution of heat is uniform throughout the circumference of the duct, it prevents the operator from having to manipulate the duct in order to achieve complete softening. The system performs the process of softening the pipe in a time of 2 to 4 seconds, previously was done in a time of 3 to 6 seconds per conduit, which gives a total of 30 seconds for each assembly that is made with the system traditional using the BOSCH heat gun, with the new system is performed in a total of 25.71 seconds approximately in each assembly see Table 2.6**.**

- **Exposure length:** with the electronic motion control system of the softening chamber, an error of ± 3 mm was achieved in the measurements of the exposure length of the pipe.

The statistics were carried out with a sample of 140 PA6 pipe assemblies, where one out of every 20 assemblies had an error of 3% difference in the execution time of the assembly, thus giving ± 0.58 seconds of error in each assembly.

Table 2.6 Comparison in times of the conventional vs. automated system

Production system with heat gun BOSCH	Production system with softening device
Number of heated ducts in a working day of one hour an average of 120. Giving a total of 30 sec. of time used for each conduit, from the softening with the BOSH gun, to the assembly with the filter or coupling.	Number of heated ducts in a workday of an hour an average of 140. Giving a total of 25.71 sec. of time used for each conduit, from the softening with the gun, to the assembly with the filter or coupling.

Source: Self Made

6. Conclusions

The design and implementation of a control system that meets an imperative need in a manufacturing process of the automotive sector, specifically in the design of an automated PA6 pipe softening device and developed based on the Standard, has been presented in this paper. DIN 16773.

The development of the PA6 polyamide pipe softening system satisfactorily covered the following points, which were technically analyzed in depth in chapter 4.1 and 4.2.

1. The exposure temperature of the duct: PID temperature control in the range of 0 to 500 ° C.
2. The exposure time of the conduit: where the operator selects the exposure time depending on the type of pipe material with a control range of 0 to 4 sec.
3. Exposure length: in the pipe it is required to have controlled the exposure inside the softening chamber, which covers a value of 5 cm.

As it could be analyzed in the previous section (results), the proposed purpose was satisfactorily achieved by covering the critical points requested by the quality department, in addition to improving the time in which the process was carried out manually, reducing by 14.3. %, resulting in 20 more assemblies in a day of one hour. As a result of the results obtained, and the research carried out, we can say that the type of conventional procedure carried out by the automotive sector for the softening of its ducts affected the mechanical properties of the same, did not meet the required quality parameters and reduced the production of pipe assemblies with filters and couplings. As discussed in Chapter 4, the softening design that was chosen was based on DIN 16773-1, (German Institute for Standardization, 2010), using the specified parameters allowed the pipe to soften uniformly, thus avoiding crystallization of it and the excessive deformation due to heat.

Based on the above, the appropriate design of the softening chamber was the most complex point in the development of the softening system, since it required a very broad analysis about heat transfer, thermodynamic systems and properties of thermoplastics. Automotive companies are not the only sector, where this type of process is used, as a consequence of this, the application of this type of softening system is not limited to this sector, but also in systems where control is required precise heating and softening of an object, piece or product. Some of the points that are recommended to other research work related to this, is to take into account the type of material to be heated and how its mechanical properties are affected when heated, in the same way take into account the type and dimensions of the material that is going to be used for the insulation of the softening chamber, the latter as a result of what was analyzed in chapter 4.1 and 4.2, in our case in particular the dimensions of the chamber could not be adequate to isolate the heat properly As a consequence, the chamber walls are heated to 105 ° C, which is a high temperature for this type of system, but this can be sacrificed depending on the operating conditions and the installation location, this can be consulted In more detail in standard NOM-009-ENER-1995 (National Secretariat of Energy, 1995), for our case, the temperature of the walls was not a risk for the operator, because The design of the structure and movement of the duct prevents the operator from being in contact with the heating chamber.

7. References

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