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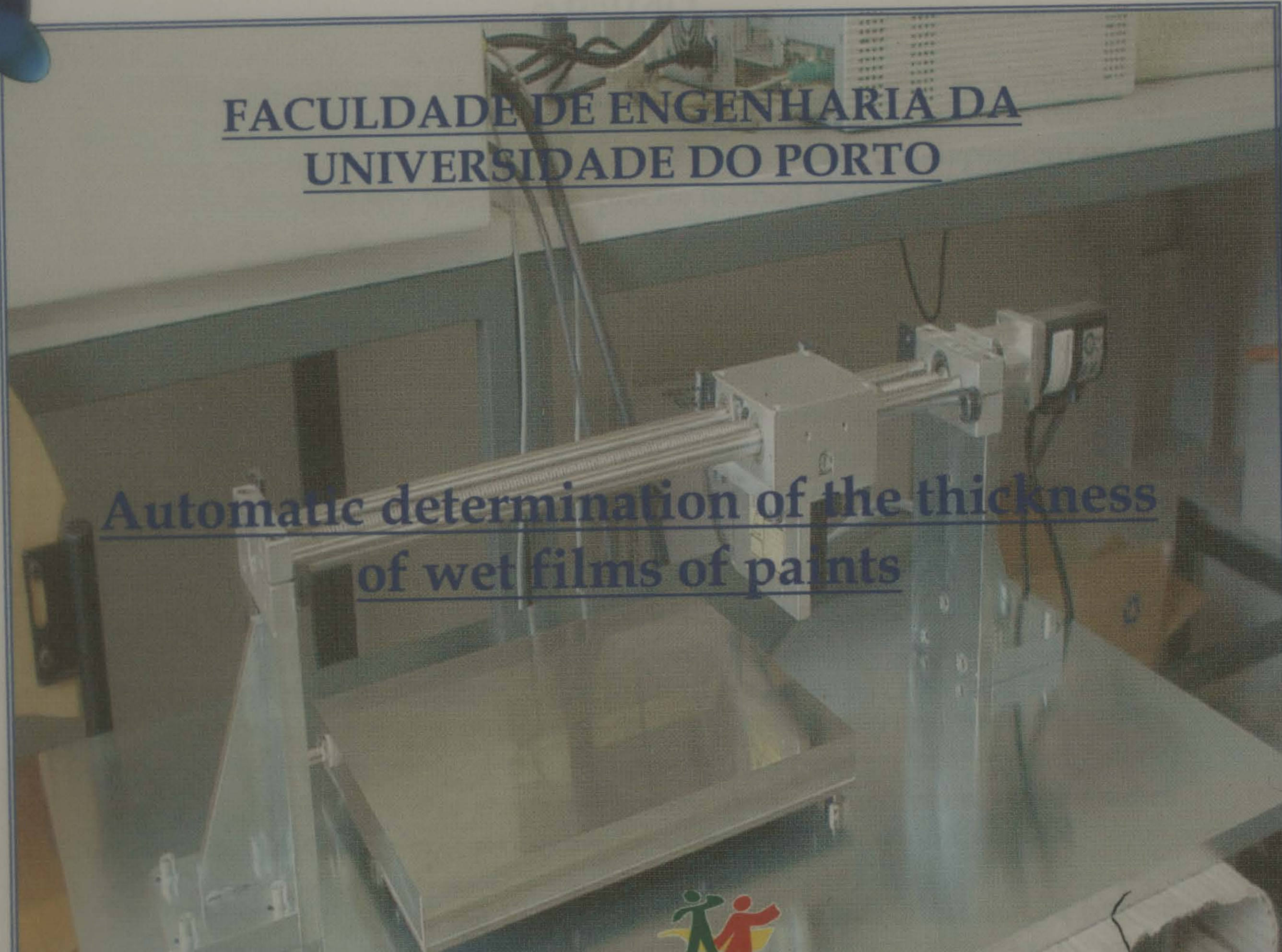

Automatic determination of the thickness of wet films of paints

Ministério da Educação
prodep III
PROGRAMA DE DESENVOLVIMENTO EDUCATIVO PARA PORTUGAL

Author
Ana Alexandra Pereira

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Abstract

The determination of the opacity is a test performed to evaluate the quality of paints. This test is done by spreading a film of paint into a card and evaluating spectrophotometric parameters of it. The opacity is dependent on the film thickness. Currently there isn't a precise method to determine the wet film thickness of the paint.

The objective of this project is to develop a device capable of reading the thickness of wet films of paint without damaging its surface. High accuracy of results is required in order to improve the assessment of the opacity.

This work was divided into two parts.

The **first part** was named: *Development and testing of the thickness reading unit*. In this stage of the work it was defined that an optical sensor would be used - a laser - to measure the thickness of the paint; it was also designed and implemented the control unit and the mechanical elements. These three elements and the laser allow the unit to have its desired performance: to read the thickness of the paint with high accuracy. Once the unit was ready it was time to perform some tests to see if it was measuring as it was desired. Those tests led to the conclusion that the reading of the thickness is independent of the paint colour, but is slightly dependent of the transparency of the spread paint. Some studies were done to define the best procedure for using the reading unit.

The **second part** of the work consisted of the *Study of the relation between the opacity and the wet film thickness*. A study of how does the contrast ratio varies with the wet film paint thickness was done. Mathematical relations between these two quantities resulted from this study for three different paints (*Vinyl Matt, Vinyl Silk* and *Vinyl Soft)*. The best correlation proposed is presented next:

$$Contrast\ Ratio(\%) = a \times e^{\frac{-b}{Thickness\ (\mu m)}}$$

The results showed that *Vinyl Silk* is the most opaque of the paints tested, followed by *Vinyl Soft* and *Vinyl Matt*.

Acknowledgments

This project was only possible due to the financial support of the PRODEP III program, for which I am very grateful.

I recognize the excellent work of Eng. Rui Almeida (*Tecnogial*) on manufacturing the mechanical components, essential part of the project.

I am grateful to Eng. Hugo Machado (*CIN*) and Eng. Vasco Lopes (*CIN*) for their contribution to the work.

I express my thanks to Eng. Adélio Mendes (*Chemical Engineering Department, FEUP*) and Eng. Fernanda Oliveira (*CIN*) for their helpful suggestions and guidance.

I express special gratitude to Eng. Joaquim Mendes (*Mechanical Engineering Department, FEUP*) for his enthusiasm and total dedication to the project. The chance to work with him was one of the biggest compensations of this work.

Finally I wish to thank *CIN* for this opportunity that allowed me to earn a helpful experience for becoming a better engineer in the future.

Contents

1. Introduction

1.1. Context

The main purpose of paint is to protect surfaces, as well as to decorate them. **Paint** is usually the most cost-effective way of changing the look of a space for the better.

A good paint is characterized by some parameters such as be washable, crack resistant and also be stain and microbial resistant. The thin film has to adhere to the surface it is assumed to protect, and provide a decorative aspect as well as retaining its initial colour and gloss for a long time.

To guarantee that the paint has the required properties, which are different from paint to paint, many laboratory tests are made.

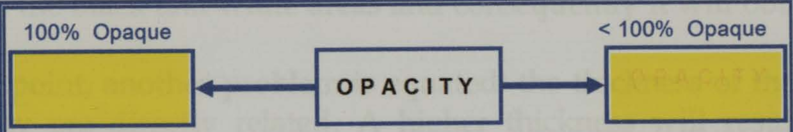


Figure 1: scheme that compares a total opaque coating (100%) with a non one (<100%).

One of the most important characteristics of paint is its opacity. The **opacity** of paint, also referred to as the *hiding power* or *contrast ratio*, is a measure of how effectively will cover or hide the surface over which it is applied. In other words, opacity measures the ability of a coating to prevent the transmission of light. One simple and practical example of this is the case where a white wall with black sayings is painted using a yellow paint. As can be seen in Figure 1, when the opacity of the coating that covers the referred wall is greater, less of the letters can be seen. The incident light is either returned to the surface by scattering within the film or absorbed without reaching the underlying material. Usually the thickness of a coat of paint is in the micrometers order.

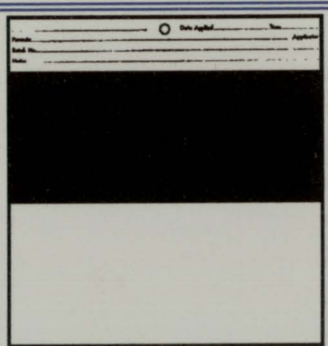


Figure 2: card where the paint is going to be spread.

There are several ways to measure the opacity, however the simplest process to do that, is to measure the 'contrast ratio'. This is the quotient between the reflectance over a black and a white substrate. In fact, this is the process that is used at CIN. The reflectance is measured using a spectrophotometric method, in a process ruled by the NP-2402 standard (*Appendix A*). This standard describes how a wet film of the paint under test is applied to a black and white card (Figure 2). The application that is done consists on the spreading (application) of the testing paint into a card using a special device – a draw down bar. The result is a wet film of paint. A **draw down bar** - Figure 3 - is an apparatus specially designed for this purpose, and debits a chosen thickness of paint.

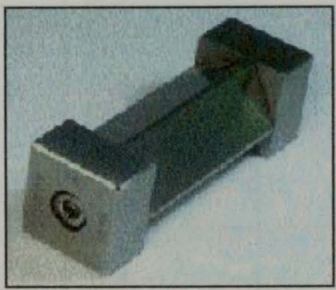


Figure 3: draw down bar.

Then, the paint should be left for drying at the ambient temperature. Before twenty four hours, when the paint is completely dry, a spectrophotometer is used to measure the amount of light that is reflected from the black and white areas of the substrate. The contrast ratio is the quotient of these two quantities of reflected light.

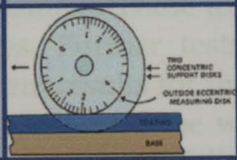
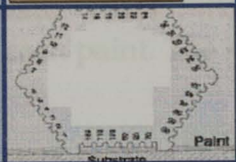
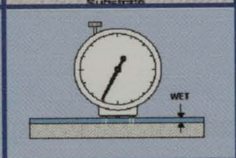
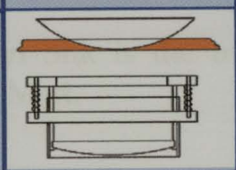
A paint which is highly opaque will cover the black and white areas to an equal extent. In this situation, equal amounts of light will be reflected from the black and white areas and consequently it will obtain an opacity value of 100%.

At this point, another problem is equated: the thickness of the spread paint and its opacity are directly related. A higher thickness will result in a higher opacity. The thickness of the spread paint depends on various factors that cannot be controlled or accounted for, such as the temperature, the paint itself, the application velocity, the person who is spreading and specially the draw down bar used.

It is important to measure correctly and with high precision the thickness of the wet paint. Nowadays, there are several mechanisms used to determine the thickness of wet films of paint, but all demand contact with the surface of the film, disabling the reading of the opacity. A list of these instruments and a brief explanation of how they work is presented in Table 1*.

* Adapted from www.elcometer.com.

Table 1: Exemple of some instruments that can measure thickness of wet films of paint

Picture	Technique	Type of measurement	Functioning principles
	Wheel gauge		**Implies contact**. The measurer is wheeled on the coating and then it's seen until where the central cylinder is wet by the paint.
	Comb Gauge		Has the functioning principle of the previous one. The plate is put over the paint and the thickness value corresponds to the last hole that had been wetted.
	Gravimetric		It's like a micrometer, adapated to this situation.
	Lent		The thickness of the film of paint is determined by the diameter of the mark created on the semi-spherical and transparent lent.

As one can see in the previous table, there are not methods capable of reading wet thicknesses of coatings, without damaging the surface of the sample to be characterized. All these methods do not have high accuracy, and some are even rudimentary, with a lot of subjectivity in it.

Hence, this work intends to develop a precise device able to measure without contact the thickness of wet paint with high accuracy, improving the opacity assessment. This work also enlaced the first practical application of the system: the study of the relation between the opacity and the thickness of the wet film of paint, for three different paints.

1.2. Major results

All the objectives proposed were achieved. A system for reading thicknesses of wet films of paint was designed and assembled. The tests conducted show that this system has high accuracy and high precision, proving to be a major improvement on the opacity assessment. These tests revealed some problems on the reading of transparent substrates. Further tests should be made to determine precisely the deviation of the system results for these sort of substrates.

The relation between the opacity and the wet film thickness was studied for three different paints (Vinyl Matt, Vinyl Silk and Vinyl Soft). Mathematical expressions were determined for each paint. The best correlation proposed is:

$$CR(\%) = a \times e^{\frac{-b}{Thickness\ (\mu m)}}$$

The results prove that the previous mathematical relation is a good fitting curve for the experimental data.

It was concluded that Vinyl Silk is the most opaque of the paints tested, followed by Vinyl Soft and Vinyl Matt.

1.3. Report outline

The present report is divided into two major parts, corresponding to the two subjects of the project. Hence, after this *Introduction,* where the work is contextualized, the objectives are set and the major results are referred, the first part of the work is presented.

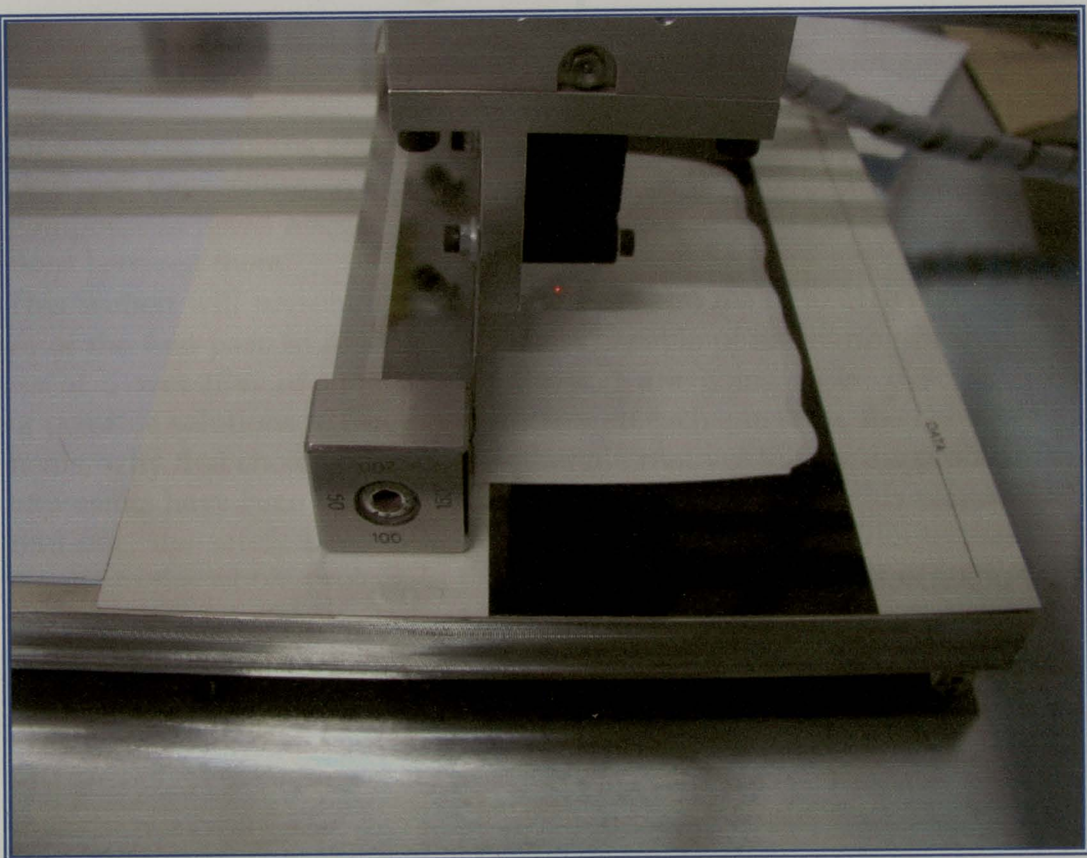
The first part is named *Development and testing of the thickness reading unit* and comprehends chapters 3 to 12. In chapters 3 (*The sensor)* and 4 (*Control Unit)* the components chosen are presented and compared with the alternatives. Chapter 5 (*Unit assemble*) presents the final state of the Control Unit. Next, in chapter 6 (*Motor and laser's transportation*) and in chapter 7 (*Mechanical components*) the remaining elements are presented. Chapter 8 (*Software*) shows some considerations about the software created. Chapter 9 gives an idea of the *Final unit* that was built. Chapter 10 refers the tests made for the *Unit evaluation* and in chapter 11 the problems detected with the *Cards* are explained. Finally, chapter 12 is the last of the first part of the report and establishes some *Unit usage considerations.*

The second part of the work was named *Study of the relation between the opacity and the wet film thickness*. On chapter 14 the *Method* used in the experiments performed is explained. The *Results* obtained are showed on chapter 15 and are analyzed on chapter 16 (*Results analysis*). The *Discussion* is made on chapter 17, and the *Conclusions* are drawn on chapter 18. The conclusions are in common for both parts of the report. Some *Future developments* are suggested on chapter 19 and important data is presented on *Appendixes.*

Appendix A shows the standard NP-2402 that rules the process for determining the opacity of paints. *Appendix B* presents general information on the devices and sensors that potentially could be used in this work. *Appendix C* enumerates the suppliers where the components of the system were bought. *Appendix D* presents the technical drawings made for the mechanical components.

PART 1

Development and testing of the thickness reading unit



2. Introduction to part 1

As described in section *Context*, the purpose of this work is to measure precisely and fast the thickness of wet films of paint, to afterwards correlate it with the opacity of this paint.

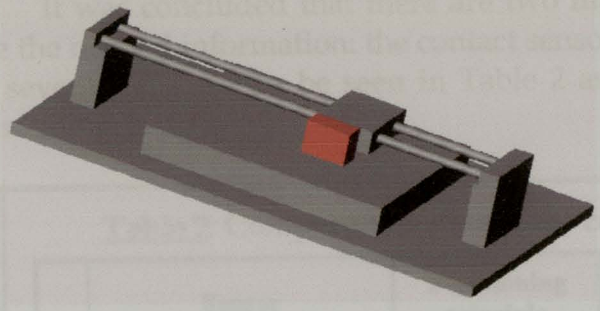


Figure 4: original idea of the system appearance.

With this in mind, the kind of sensor that was most suitable for this project and the kind of system which had to be conceived had been defined. The first idea of the system came around the third week of work and looked like what is present in Figure 4. In fact, a lot of big modifications and work have been done, to put this original idea working.

This first part of the work lasted for almost six months and moved around four main areas: the electrical, the mechanical and the sensing. In fact, the work has not been only dealing with each of the components listed above independently but also with the restrictions and interactions between them.

This section will present each step that has been made to arrive at the final objective of the first part: to assemble a system capable of measuring precisely the thickness of a wet film of paint. The following are going to be described: the different possible solutions to face each problem in each situation, the choice of the components, why that choice and not the other alternatives to face the problem; the way components have been assembled, why they have been done this way and not a different one, the safety procedures taken in care and the contribute that each element gave to the whole project. In the final part of this section it is going to be presented and discussed the tests that have been done to guarantee that this is a trusty system, and the features and the limitations that it presents.

3. The sensor

3.1. The alternatives

It was done a market search on measuring instruments that could be used to determine the thickness of paint. This transducer should be able to give thicknesses in the order of micrometers with high accuracy and without damaging the surface of the film of paint.

It was concluded that there are two main groups of transducers that could give the needed information: the contact sensors, and the non-contact ones. A list of the several sensors can be seen in Table 2 as well as a short description of their operation principle.

Table 2: Comparison between the contact and non-contact sensors.

	Sensor		Functioning principle	Advantages	Disadvantages
Contact	Wet film comb		Geometric	Cheap Easy to use	With contact Discontinuous scale
	Wet film wheels		Geometric	Cheap Easy to use Continuous scale	With contact
	Wet film gauge		Geometric	Easy to use Continuous scale	With contact
Non-contact	Capacitive		Electric Storage Capability	Any kind of solid or liquid Good resolution	Dependent of the composition Dependent of the water content
	Optical		Triangulation	Any solid or liquid Excellent resolution	Errors with transparent surfaces
	Inductive		Eddy Currents	Very reliable	Metallic Materials Bad resolution
	Ultrasonic		Signal's speed	Any kind of solid or liquid	Bad resolution

The analysis of the two groups of sensors led to the conclusion that the **contact sensors** were not appropriated to this project once they demand contact between the paint surface and the sensor, as can be seen in Figure 5. This is impossible to do since the paint is wet and it contact with the sensor would damage it.

The **inductive sensors** are non-contact. They only work with metallic objects. In order to be able to measure the thickness of paint films these sensors had to work with contact. The paint would have to be applied over a metallic substrate, and the sensor would be placed just contacting with the surface of the paint. The distance between the sensor and the metallic substrate is the thickness of the film. Evidently, this procedure is inadequately for this project.

Figure 5: example of a contact sensor.

The **non-contact sensors** can be divided in optical and non-optical sensors. For the non-optical there is the **capacitive**, which is inadequate for this application once it is dependent on the paint's composition and water content. The **ultrasonic** is independent on the composition and on the water content, but the maximum resolution is not enough for this project. This way it was concluded that an optical sensor is the most appropriated solution, once it is the only one capable of achieving the desired accuracy and is independent on the composition and water content of the paint.

The characteristics that determine that the **optical sensor** is a good choice are: high accuracy and precision, the non-dependency on material properties or water content, and the fact that it is efficient on the reading of wet materials.

A more detailed presentation of the characteristics of the sensors is made in *Appendix B*.

3.2. The sensor that was chosen

Figure 6: the chosen sensor.

Figure 6 shows the sensor that was chosen. This sensor is commercialized by OMRON®, under the name of **Z4M-N30V**: "Regular Reflective Displacement Sensor".

It is an optical distance measurer, which has a maximum resolution of 0.4 μm, can acquire up to 100 points per second, and has a filter that annuls the possible influence of the environmental light. This laser determines the distance to the object, by emitting a red laser light (on the visible spectrum, λ=670 nm) and measuring the reflected light. It uses a **triangulation method** to calculate the referred distance.

It can be seen in Figure 7 that the main components of the sensor are: two lenses, signal processor, detector and diode. According to the distance at which the surface is from the laser, the reflected beam will strike the detector on a different point, from which it is known the correct distance at which the surface is from the laser. Trigonometric relations allow the calculation of the distance between the laser and the surface: knowing the length of the reflected beam and the angle formed between the incident and the reflect beams, it is easily determined the length of the emitted beam, and so, the distance at which the laser is from the surface. This kind of sensor is widely used in applications involving the measurements of position or displacement.

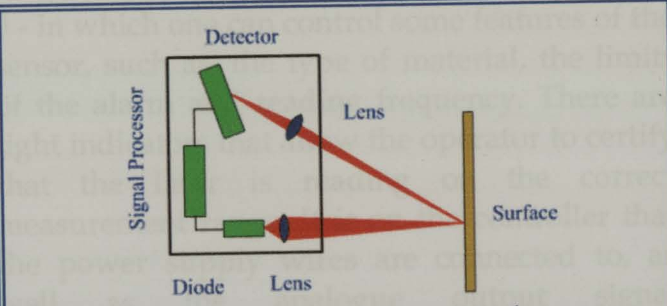


Figure 7: components of the optical sensor.

3.3. The thickness reading

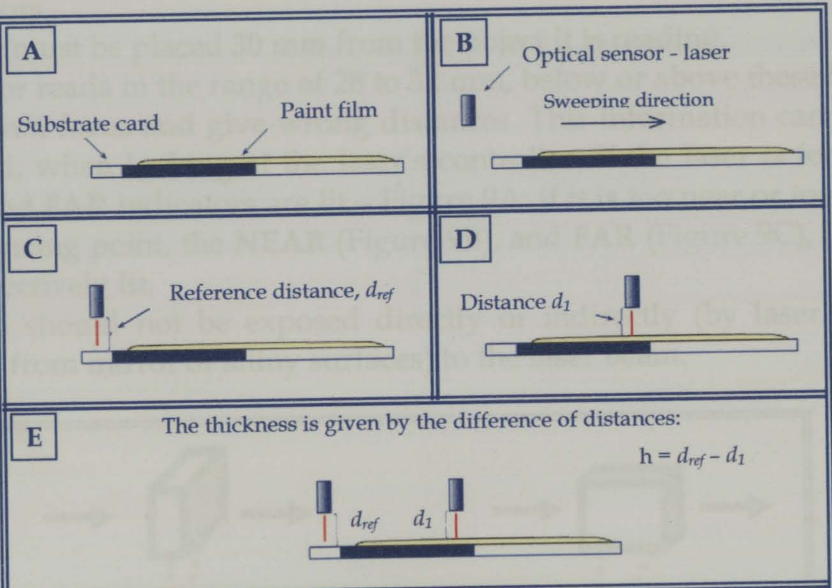


Figure 8: the principles used to measure thicknesses.

There are not lasers capable of reading thicknesses of materials directly, but there are ones capable of measuring distances. These lasers are used for the precise detection of distances or values deduced from these distances, for example, filling level or position.

The process to determine the thickness from the distance measurement is easy. As it can be seen in Figure 8, the sensor measures two different areas: the distance to the reference (d_{ref}) (step C), and the distance to the paint (d_1) (step D), the difference between these two measures (d_{ref} - d_1) gives the thickness of the spread paint (step E).

3.4. The laser's controller

The laser came with a controller – Figure 9 - in which one can control some features of the sensor, such as, the type of material, the limits of the alarm and reading frequency. There are light indicators that allow the operator to certify that the laser is reading on the correct measurement range. It is on the controller that the power supply wires are connected to, as well as the analogue output signal corresponding to the laser reading.

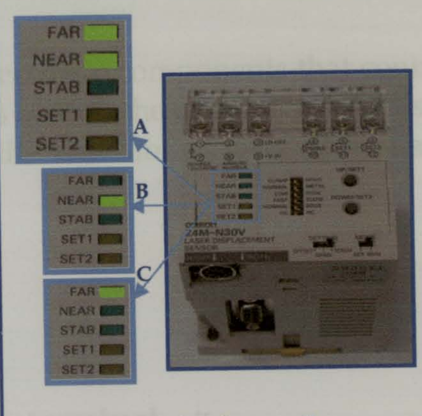


Figure 9: laser's controller.

3.5. Precautions on the assembling and use of the laser

In order to assure that the laser is reading correctly and with the best accuracy possible there are some measures that must be attended to.

- The laser must be assembled according to Figure 10, to minimize colour effect errors.
- The laser must be placed **30 mm** from the object it is reading.
- The sensor reads in the range of 28 to 32 mm, below or above these limits the laser cannot focus and give wrong distances. This information can be easily perceived, when looking at the laser's controller. If the laser is focused the **NEAR** and **FAR** indicators are lit – Figure 9A; if it is too near or too far from the measuring point, the **NEAR** (Figure 9B), and **FAR** (Figure 9C), indicators will respectively lit.
- The eyes should not be exposed directly or indirectly (by laser radiation reflected from mirror or shiny surfaces) to the laser beam.

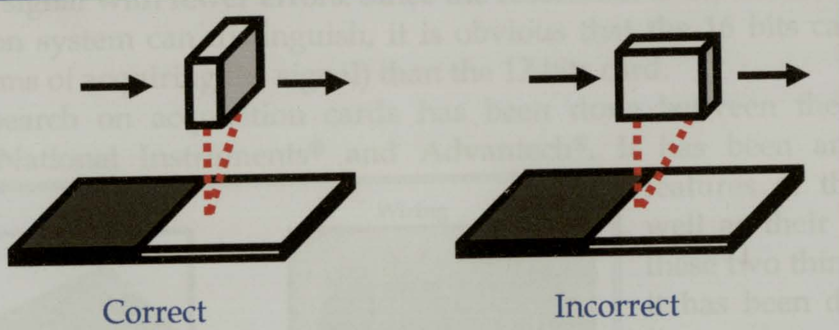


Figure 10: laser's assembling position.

4. Control Unit

The control unit is the set of electrical and electronic components that control the equipment and process the laser's signal. In this section the main components of the unit are going to be described as well as the assembling procedures and precautions that have been taken in care.

4.1. Material's choice

4.1.1. Data acquisition card and wiring terminal

One of the tasks of the data acquisition card is to convert the analogue signal emitted by the laser to a digital value, which can be processed by the computer. The number of bits of this conversion is a crucial factor. Before looking for the best acquisition card, it was defined that a **16 bits** card would be the ideal for this project because a highest resolution would be obtained. If the 12 bits card was used then the resolution of the analogue to digital conversion would be worst than the laser's resolution. In this sense it was concluded that it was worth to invest on a better acquisition card in order to get the best use of the laser. Let's compare the resolution obtained for 12 and 16 bits, for an input range of 5 V:

For 12 bits: $\frac{5}{2^{12}} = 1.22\ mV$

For 16 bits: $\frac{5}{2^{16}} = 0.08\ mV$

The analysis of the two resolutions shows that, naturally, the 16 bits card acquires the signal with fewer errors. Since the resolution is the smallest value that an acquisition system can distinguish, it is obvious that the 16 bits card is much better (in terms of acquiring the signal) than the 12 bits card.

The search on acquisition cards has been done between the two main producers: National Instruments® and Advantech®. It has been analysed the features of the cards as well as their price. With these two things in mind, it has been decided that the most suitable card was: **PCL - 1716** from Advantech® (presented in Figure 11A). Each card requires a wiring terminal, that does the connection between the card (that is connected inside the computer) and the other components (for example, the laser and the motor) of the control unit. The wiring

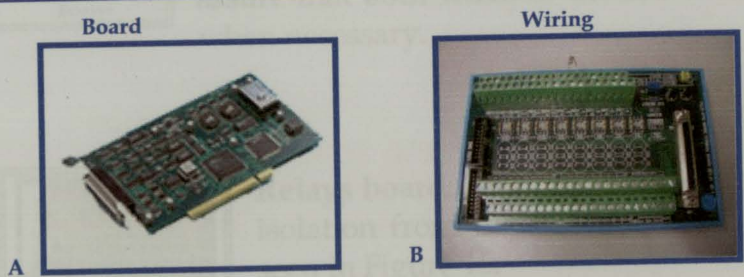


Figure 11: Board acquisition and wiring terminal.

terminal suitable for this card is **PCLD - 8710** also from Advantech® (see Figure 11B). The wiring terminal includes a circuit that allows direct measurements of the temperature.

4.1.2. Electrical material

Below it can be seen a list of the most important electrical material that have been used to implement the necessary connections between the different components, to provide safety and control of the unit.

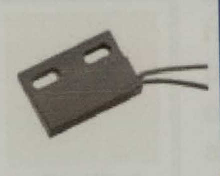


Figure 12: end-course sensor.

End-courses sensors: these are two sensors placed on the laser's transportation car which have the function to stop the whole system when the laser passes a defined zone. This is important to avoid the laser to crash to the extremes of the laser's transportation system, causing possible damages on the motor or on the transportation car itself – Figure 12.

Figure 13: eletric fuse and its enclosure.

Electric fuse: to protect the electrical circuit on situations of short-circuits with the consequent overcharge. The indicated fuse (1 Ampere) is determined by the normal consumes of the components of the electrical circuit (motor, laser, power supply).

Figure 14: circuit Breaker.

Circuit breaker: As can be seen on Figure 14, this device has an on /off button that allows the operator to turn the system on and off. In addition, this device turns the system off when there is an over voltage caused by the malfunctioning of one component. This way it protects all the components from damage caused by extended over voltage. The indicated type of circuit breaker is the bipolar to assure that both wires of the 230 V supply are actually turned off when necessary.

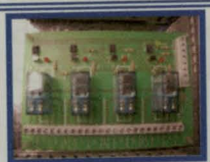


Figure 15: relay board.

Relays board: This card provides a set of relays and the optical isolation from the relays to the computer. This device can be seen in Figure 15.

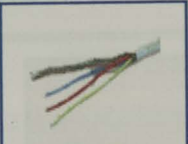


Figure 16: conductors.

Conductors: these are simple connecting wires – as can be seen in Figure 16, coated with a metallic mesh to minimize the electromagnetic interferences.

Figure 17: 230 V terminals.

Terminals of the 230 V: these electrical components – Figure 17 – are secure to the DIN rail and are connected to the 230 V wire; the distribution of the 230 V inside the control unit is made from these terminals.

Figure 18: rail.

Simple rail: as is shown in Figure 18, these plastic rails have the function to take inside the conductors wires that have been previously mentioned. These rails have two functions: to create an organized look of the control unit (in spite of the numerous wires) and to protect the circuit (one connector in touch with a component that heats with functioning can cause a fire). This way, the control unit presents itself organized and safe.

Figure 19: DIN rail.

DIN rail: this is a standard rail in which some equipment are ready to be set on. As can be seen in Figure 19, this is made of metal so, when connected to a ground source it can provide a way to discharge the system. Here it is going to be set: the wiring terminal of the acquisition card, the laser's amplifier, the electric fuse, the circuit breaker and the terminals of the 230 V.

Electrical box: this is the container where all the equipment and material mentioned are going to be stored. As can be seen on Figure 20, this is an ordinary electrical box, with a dimension of 600x400x200 mm. This model was chosen because it was the only electrical box that could handle all the components, and have a free space that allows a future scale-up. This box has light indicators in the front door that show the current state of the system, the turn on/off button and the emergency button of the system.

Figure 20: electrical box – inside and outside view.

The electrical box also includes a metal plate where the electrical components are going to be screwed. This way one does not have to screw the equipment directly on the box making therefore the assembling of the circuit a much more comfortable work, since one does not have to work directly inside the box.

Figure 21: buttons and indicators.

Buttons and indicators: these can be divided into three different sets, as can be seen on Figure 21, from the outside view of the electric box: the **light indicators** that provides the information about the state of the system and the laser (if those are turned *on* or *off*), and about the laser's movement (if it is moving or not) – these indicators are respectively named: ***On*** and ***Laser***. In the middle of the door of the electrical box it can be seen the **emergency button**, that allow the operator to stop the whole system if anything goes wrong. The inferior part of the door presents an **on/off switch button** that has the function of turning *on* or *off* the system.


Figure 22: power supply.

Power supply: it was chosen according to the laser's necessity (24 V, 1 A). It is of the linear type to guarantee maximal stability of the output voltage. This power supply has a current feedback system to assure the voltage is constant, and independent of the circuit's consumption.

Rest of the material: it has been listed above the most important material that has been used, but besides those it was used material to improve safety and organization on the electrical unit. In this extra material can be found: cable ties, thermo-contractile sleeves, terminal blocks, among others.

A table with the component supplier in which each component have been bought, is presented in *Appendix C*.

5. Unit assemble

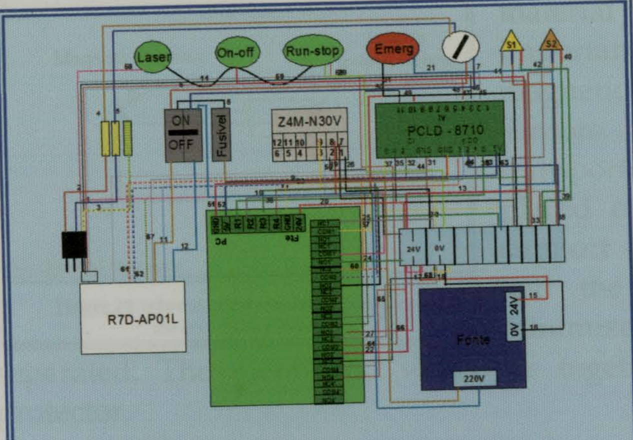


Figure 23A: scheme of the connections that have been made.

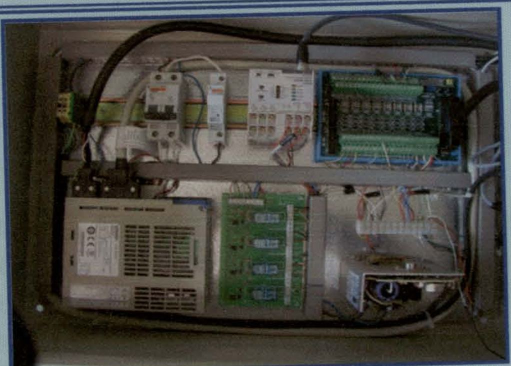


Figure 23B: real appearance of the connections made.

Now that the electrical components are chosen, it is time to assemble the control unit, that is what it is going to be described on this section.

Before starting with the assembling properly said, it has been done a study about the best way to place things on the control unit box in order to: minimize electromagnetic influences and optimize the space and cable length.

In Figure 23A it is shown a scheme of the connections that have been made, and in Figure 23B it can be seen the real aspect of those connections. In *Appendix F* it is shown a detailed scheme of the 75 connections that have been made, as well as a list with those connections and another one with every used pin in each connector.

In order to minimize the electromagnetic influences of the motor, which could increase the electrical noise of the laser's signal, the motor and the terminal board are placed in the extremes of the box. This concern has also been taken in care when placing the power supply.

As it can be seen in Figure 22, the power supply is limited by two metal plates (which are an integrating part of the power supply). These metal plates minimize the electromagnetic influence of the power supply to the wiring terminal of the acquisition board, and are a free surface from where the heat (from the power supply) can be dissipated, improving this way the safety of the system.

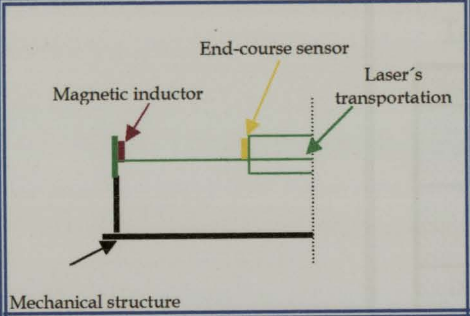


Figure 24: scheme of the mounting positions of the end-course sensors.

End-course sensors: as mentioned on the material choice, the end-course sensors have an important role on this project. There are two magnetic pieces that induce the end-course sensors. The sensors are placed on the laser's transportation, and the magnetic inducers are placed on the lateral part of the mechanical support (see Figure 24). This way, the laser's and the sensors wires are together which minimize the number of possible wires separated. The mentioned wires are together with the help of a plastic wire protector.

6. Motor and laser's transportation

The two items that are going to be discussed are treated on a different section, once that they do not belong to the electrical part neither to the mechanical one. So, because of their importance and particular characteristics they are going to be discussed separately.

6.1. Motor

Figure 25: motor.

The chosen motor - Figure 25 - is a very sophisticated one that combines the precision of a stepping motor with the soft dislocation of a linear one. In fact, as it is pretended for the system to read with very high accuracy it is imperative that the motor has a soft displacement in order to not affect the reading.

The motor came with a driver that is an interface from which the operator can control some characteristics of the motor's operation. This motor has high precision, high velocity and high torque. It can achieve up to 3 000 rotations per minute. This is an ONROM® motor commercialised under the name of ***Smartstep R7M-A05030-ST***, and the driver under the name ***Smartstep R7D-AP01L***. The driver is installed in the electric box, and has a cable with 42 conductors which of it induce a specific function to the motor. From these 42 conductors in this project it is only been used 6 of them that are shown in Table 3.

Table 3: the 6 motor connectors used.

Function	Connector colour
Velocity	White
	White with grey spots
Run/Stop function	Yellow with back spots
	Grey
Displacement Direction	White with blue spots
	White with yellow spots

Each of these connectors is linked to a specific pin according to what is its function. This can be seen in *Appendix F*.

6.2. Laser's transportation

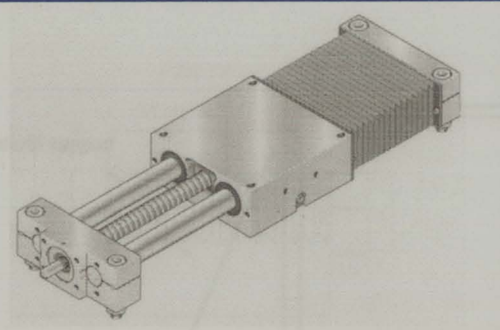


Figure 26: laser's transportation.

This is a component, shown in Figure 26, that plays an important role once it allows the laser to move above the vacuum table (see section *Mechanical components*) along the horizontal direction. It is composed of two spindles and in the middle of those a spiral spindle. It moves according to the orientations of the motor. The motor and the laser's transportation are connected by a coupling that does the junction of the transportation spindle with the motor's vein. This component has a high precision which is also required for the system accuracy.

7. Mechanical components

This section includes, as the name indicates, the design and concretization of the mechanical elements.

The laser needs to have a mechanical support, which must allow the sensor to move along the card and to measure the required thickness. The work on the mechanical part consisted most of all on the analysis of the system requirements to respect the electrical and laser's restrictions and to give the system the functionality and robustness that was needed. On parallel with this, it has been done the drawings of the mechanical components – these detailed technical drawings are presented in *Appendix D* and in the next paragraphs it is going to be discussed some of the considerations that have been taken in care when the drawings were done.

Before describing each mechanical component separately, in Figure 27 is shown the lateral view of the mechanical system with its components on the correct assembly position.

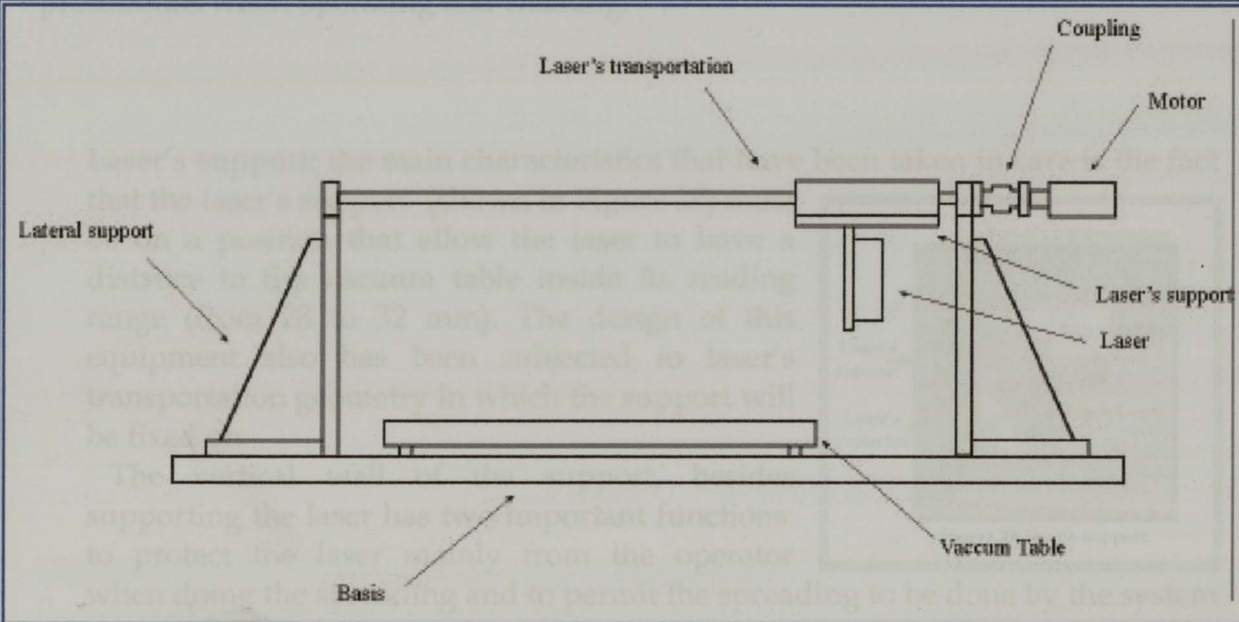


Figure 27: lateral view of the mechanical system.

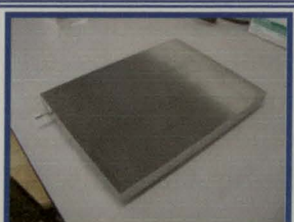


Figure 28: vacuum table.

Vacuum table: the main function of the vacuum table - Figure 28 - is to guarantee that the card in which the paint is going to be spread is correctly and completely preyed to allow the operator to do the application. The vacuum table is an equipment that was already used at CIN. In spite of this, a new vacuum table has been designed to this system.

The new vacuum table that has been made, visually, is very similar to the old one. Besides that some alterations have been made in order to improve the functionality of this equipment and to adapt it to the system, as can be seen below.

The new vacuum table instead of four has only **three supporting feet**, which allow the operator to easily level the table. In fact, it is very important that the vacuum table is perfectly levelled, once that the laser has an action range well defined, and because the operator needs a horizontal support to do correctly the spreading. To level the new vacuum table one only needs to move one foot at a time, while on the eldest one you always need to move two feet.

The **construction material** of the old vacuum table is aluminium and the new table is made of stainless steel. This material change is due to the stiffness and weight characteristics of the stainless steel. In fact, the new vacuum table is heavier (confers higher stability to the system), and has a surface more resistant to scratches, which is one of the major problems of the eldest table requiring greater precautions when operating and cleaning.

Laser's support: the main characteristics that have been taken in care is the fact that the laser's support (shown in Figure 29) must be on a position that allow the laser to have a distance to the vacuum table inside its reading range (from 28 to 32 mm). The design of this equipment also has been subjected to laser's transportation geometry in which the support will be fixed on.

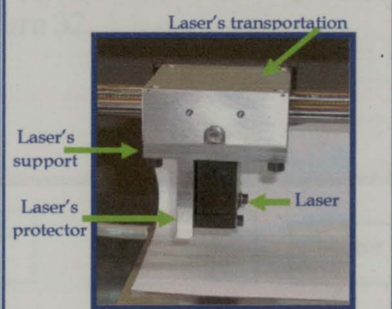


Figure 29: laser's support.

The vertical wall of the support, besides supporting the laser has two important functions: to protect the laser mainly from the operator when doing the spreading and to permit the spreading to be done by the system – as can be seen in section *System's features*.

Lateral support: these apparatus, shown in Figure 30, supports the setting: laser's transportation, laser's support and laser. The laser's transportation is directly linked to this device. In fact, these two structures have a primordial importance on the system, once that they provide the stability of it. They were constructed in order to eliminate possible horizontal moving of the laser's transportation.


Figure 30: lateral support.

Figure 31: motor coupling.

Motor coupling: this is a structure that makes the link between the laser's transportation and the motor. It has a hole, as can be seen in Figure 31, to permit to accede easily to the laser's transportation and motor guiding.

Systems base: it is a stainless steel base that supports the whole system. Its dimensions are 750x500 mm, and is considerably heavy once more to provide the required stability. Besides that, these large dimensions allow a future installation of an automatic spread system.

Once every mechanical components has been described it is time to show the final aspect of the mechanical system with each of the elements characterized previously in its proper place.

In Figure 32 it is shown the real aspect of the system. It is important to mention one more time that for each of the previous mechanical elements characterized a technical drawing has been made (see *Appendix D*). It is important to notice the correspondence between Figure 27 and Figure 32.

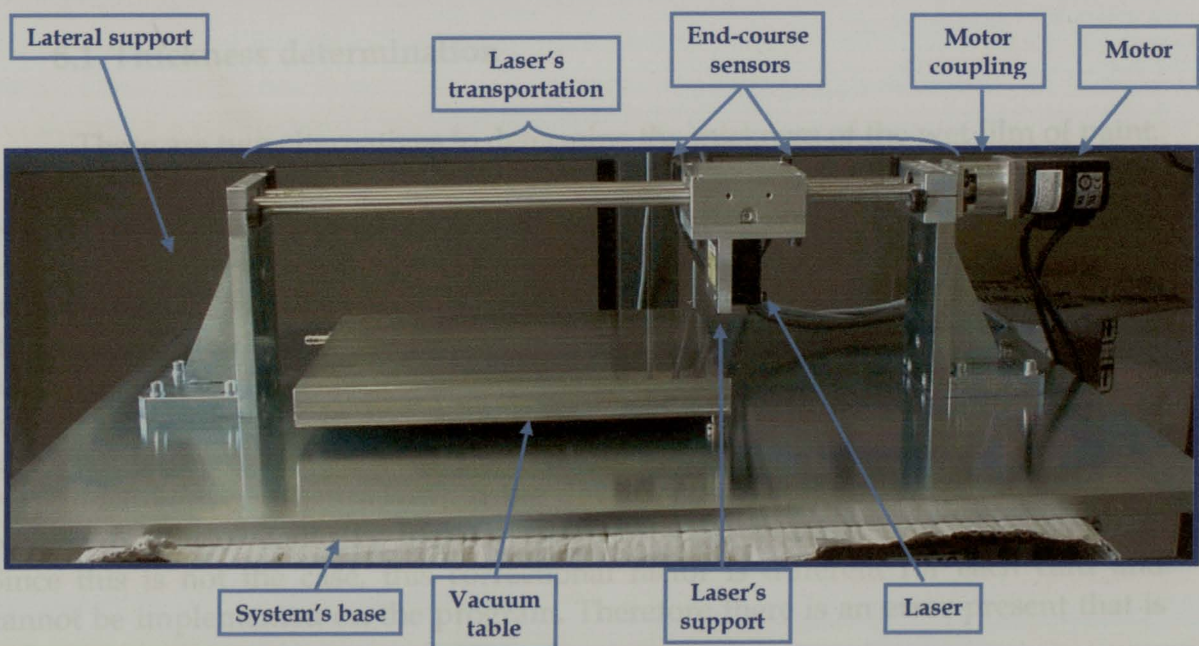


Figure 32: general view of the mechanical components.

8. Software

This is a fundamental part of the work developed, in which a significant amount of time was invested. The software has been continuously improved and changed since the beginning of the project. A program was developed to establish the communication between the operator and the control unit (through the computer). The program was created with Labview® 6.1, an application developed by National Instruments® (www.ni.com). Labview® was specially designed for dealing with data acquisition.

Labview® implements a graphical programming language, contrary to a traditional language with commands and syntax. The programming is made with symbols (icons) and connections between those icons.

To develop a program one has to work in two different windows: the **interface window** (where are placed the elements that will be visible to the operator) and the **diagram window** (where all the actual programming is made). For engineers, the diagram window can be seen as a flux diagram, where the icons are process units that transform the variables and the lines connecting the icons represent the flux of the variables between the different process units. In general, the variables connected to the left of the icon are inputs and the ones connected to the right are output variables.

The program has to perform some of the following tasks: allow the operator to define the key parameters of the operation, control the motor and simultaneously acquire the laser's signal, process the generated data and write the processed data to a file. For further details on the program developed consult the program's Manual.

8.1. Thickness determination

There are two alternatives to determine the thickness of the wet film of paint. The first is the less accurate. It calculates the thickness as being the difference between the average distance to the reference area (the header of the card, which as no paint) and the average distance to the reading area (more or less the center of the card) (see Figure 8). This difference gives a measure of the thickness of the film, but it has a problem: there is no guarantee that the card is perfectly flat. If there is a difference on the thickness of the card from the header to the center areas, then the results are influenced. In fact, testing this method led to the conclusion that the cards not only are not perfectly flat, but are also very heterogeneous (they differ very much between themselves). If the deviation was constant for all the cards, a correctional factor could be implemented on the program to minimize the error. Since this is not the case, this correctional factor is different for each card and cannot be implemented on the program. Therefore there is an error present that is unknown.

The second method to determine the thickness of the film of paint consists in two steps: place the card on the vacuum table and memorize the vector of distances to this card; without moving the card, spread the paint and read the distance again. The difference between the two vectors gives directly the thickness at each point. This second method is more accurate because it does not work with a reference that introduces errors. It has the disadvantage that it requires more time: it has to do two readings instead of one for the first method, so the time spent is approximately twice.

8.2. Program Structure

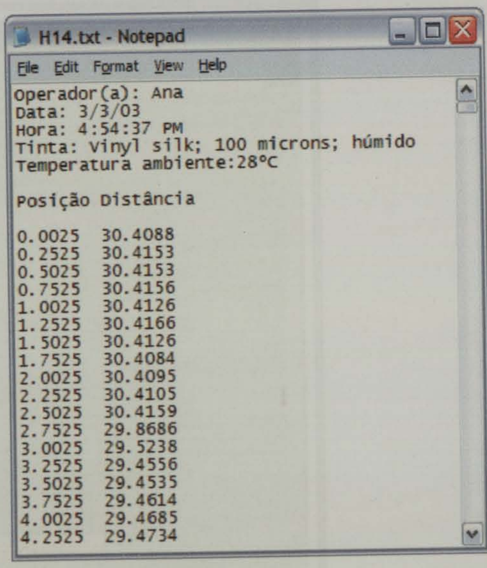
The basic structure of the program consists on a sequence of operations:

1. The operator starts the program;
2. The operator chooses the desired option;
3. The operator types her / his name;
4. The operator types the paint specification and / or any comment;
5. The file is created and the header is written;
6. The laser is aligned with the top of the vacuum table;
7. The laser moves along the card, reading the distance;
8. The data is processed;
9. The data is saved into the file;
10. The laser returns to its initial position.

The core of the program is a cycle where the motor is being moved and the signal of the laser is being read. In fact, the program acquires one reading from the laser for each step that the motor takes. Since these steps are in fact very small, the program does not save all the points. It creates two vectors: the distance of the laser to the surface and the displacement of the laser. One can see these two vectors combined as a silhouette of the surface. As explained, proper processing of these vectors by the program gives the average thickness of the wet film of paint.

8.3. File created

As it was mentioned, a file is created for each reading, where the data is stored. Additionally to the two referred vectors (the distance versus the displacement), this file contains information such as the date and time of operation, the operator's name



H14.txt - Notepad

File Edit Format View Help

Operador(a): Ana
Data: 3/3/03
Hora: 4:54:37 PM
Tinta: vinyl silk; 100 microns; húmido
Temperatura ambiente:28°C

Posição	Distância
0.0025	30.4088
0.2525	30.4153
0.5025	30.4153
0.7525	30.4156
1.0025	30.4126
1.2525	30.4166
1.5025	30.4126
1.7525	30.4084
2.0025	30.4095
2.2525	30.4105
2.5025	30.4159
2.7525	29.8686
3.0025	29.5238
3.2525	29.4556
3.5025	29.4535
3.7525	29.4614
4.0025	29.4685
4.2525	29.4734

Figure 33: file created.

and the specification of the paint or any detail or comment that the operator wants to keep. This way it is easy to control the stored files and relate them to the readings performed. An example of a typical file is presented in Figure 33.

8.4. Subroutines

One can create subroutines to be used in the program. These subroutines appear like an icon. The icon can be changed to make it simple to understand what the subroutine does, specially for those that did not participate on the development of the program. The purpose of creating subroutines is to simplify the look of the diagram, leaving visible only the essential. In this sense, one can easier realize what the program does in each step. It makes easier the maintenance of the software because one knows where each operation is performed.

8.5. Interface

This is the only thing that the operator will see during his work. There is a main interface which is the menu from where the operator chooses the mode of operation (automatic / manual, wet /dry films). Each mode has its interface. In Figure 34 the main menu is shown and in Figure 35 the interface of the automatic wet film thickness reading mode.

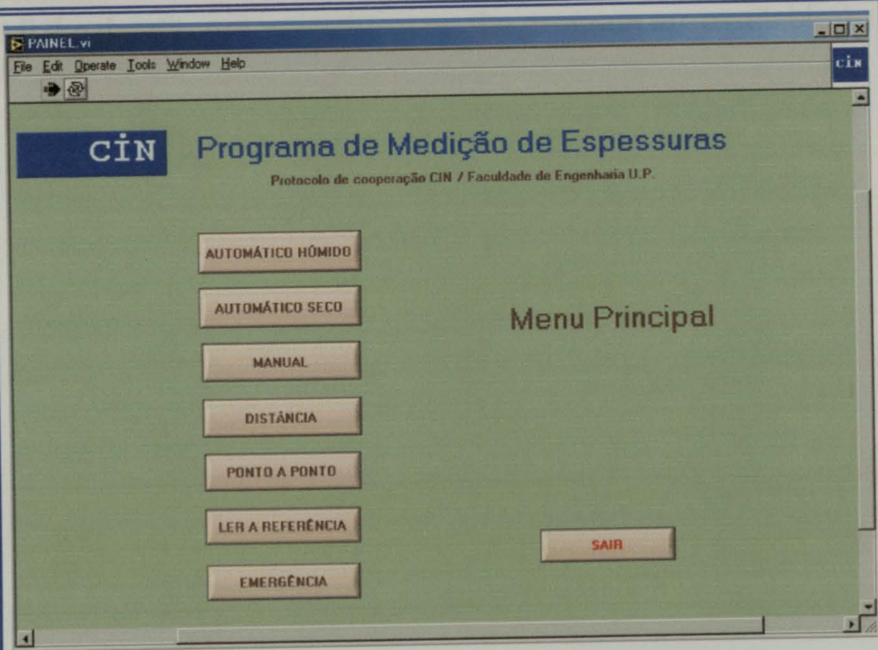


Figure 34: interface of the main menu.

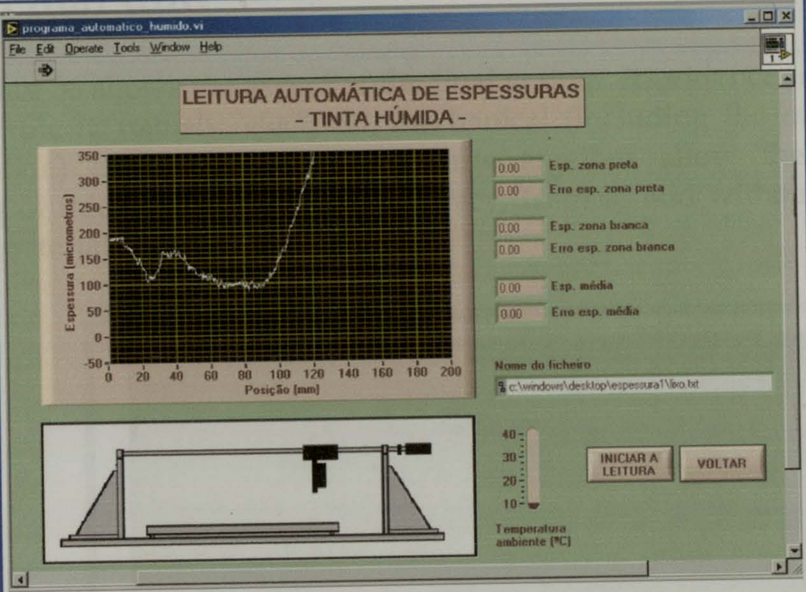


Figure 35: interface of the automatic program.

There are some fields where the operator can make some options related to the operation. These are the fields that the operator can change according to what is wanted. Additionally, there are two fields where the results are presented: the graphical display and the average thickness as well as its respective standard deviation. The graphical display corresponds to the profile of the film of paint. The results are only updated on the end of the reading, before the laser returns to its initial position.

All the details and procedures on the program are available on the program's Manual.

9. Final unit

Figure 36 shows the aspect of the final system. It evidences each of the parts that constitute it, namely: electrical, mechanical (including the motor and laser's transportation) and software. These parts together allow the system to do measuring of thicknesses with high accuracy, fastness and without destroying the analyzed material.

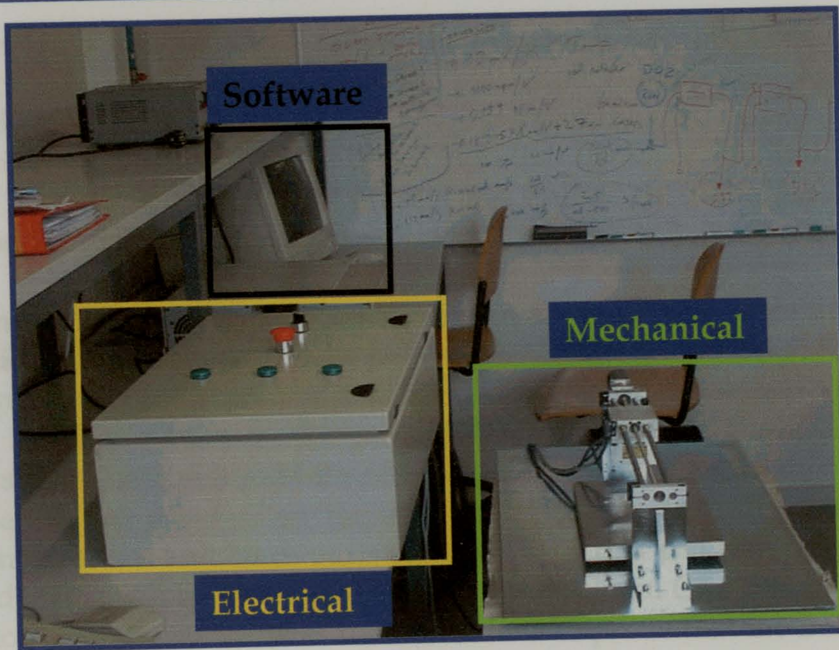


Figure 36: the thickness measuring system.

10. Unit evaluation

Some tests were done in order to validate the measuring system. These tests focused mainly on the accuracy, precision and limitations of the setup. Now, it is going to be described some of the tests that have been done, and the results they led to.

10.1. Non-influence of the substrate color

Before the start of the tests to validate the system, it had been seen a big difference on the profile of the cards between the black and white parts – Figure 2. The difference of thicknesses on the black and white parts of the card can achieve 14 μm. A first analysis to this fact, led to the conclusion that the laser was influenced by the color of the material on study. A lot of tests and studies about the sensor and the cards were performed and it was concluded that this hypothesis was not correct.

The color influence would have been a problem to the system, once that it is supposed to do thickness determinations of paints of various colors. At that time, to face the possible influence of the color calibration methods were developed (one for dry and another one for wet film thickness determination), to guarantee the accuracy of the system. These methods are not going to be discussed on this report once that the laser is not affected by the material color. In fact, the thickness difference between the white and black parts of the cards is real and was proved by alternative methods. This will be explained with detail on section *Card*.

It is going to be presented the tests that were done to prove that the thickness determination is not influenced by the subtract color.

✓ As mentioned, the laser gave for a particular card a difference of about 14 μm between the black and white parts. The same card was analyzed with a contact probe. The results with this method gave a difference of about 12 μm. The disparity of results can have two explanations: there is an actual influence of the color and the real difference of thicknesses is 12 μm or the contact method causes a small deformation on the card and the real difference of thickness is about 14 μm. Even if the first case is true, the color has much less influence than the 14 μm that at first was believed. Nevertheless, the second explanation is more reasonable since the contact method is very likely going to cause deformation on the card on the moment of reading.

10.2. Accuracy

The accuracy of a system is the agreement of a measured result or the medium of measured results of a propriety and its real value (the correct value). This parameter is very important to the system once that it will assure that the system is reading the correct value instead of any other. For proving that the system is accurate some tests have been performed and are going to be described following.

✓ It has been done determinations of thicknesses of standards. These were plastic standards with dimensions of about 50 x 70 mm, and as it is easy to understand with thickness values known. It has been done ten measurements of the thickness of each standard on different areas; the determined thickness corresponds to the average of those values. The standards had different thicknesses and colors. It was only the thinner standard that the read correctly: the standard value was 120.4 ±1.0 µm and the determination by the laser was 123.0 ± 1.8 µm. The results are very near. The thicker standards were not as flexible and did not stay completely flat on top of the vacuum table; the results was not as near as for the thinner standard.

✓ The draw down bar needs to be sometime calibrated in order to assure that it debits the same amount of paint. The company that usually does this calibration process is *CATIM* and gives the average level difference shown in Figure 37, and the error associated with that measurement. So, the same way, it had been done the same measurement with the laser system and the results were compared. In fact, the level difference obtained with the system was in the interval considered by the company that does the calibrations. This way, it was proved that the system reads correct values and it can be said that the system is accurate. Besides that, the results show that the surface of the draw down bar is not perfectly flat, which can influence the thickness of the wet film paint. This difference on the draw down bar may cause different thickness on the wet film paint from the center to the sides.

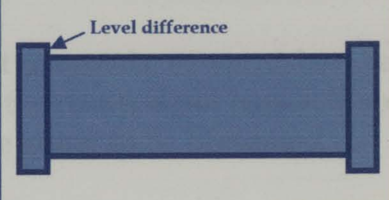


Figure 37: draw down bar and the level difference.

10.3. Repeatability

The repeatability measures the capacity of the system to read the same sample various times on the same measuring condition, providing the same result. This section shows the procedures that have been taken in order to quantify this parameter.

✓ For the standards mentioned previously the repeatability of the measurements cannot be evaluated because the standard was moved manually and one could not guarantee that it was on the exact same location as the previous reading. The repeatability cannot be evaluated on these determinations.

✓ The main test consisted on reading a card with paint applied. The paint was completely dried, and ten readings were made, without moving the card. The results are shown in Table 4.

Table 4: results for the repeatability test.

Trial	Thickness (μm)
1	27.9
2	28.3
3	28.4
4	28.8
5	28.5
6	28.4
7	28.4
8	28.4
9	28.3
10	28.2

The average thickness for this set of values is 28.3 μm and the standard deviation is 0.4 μm. With 95% of trust the error is ± 0.2 μm, so one can say with 95% of certainty that the actual thickness of the film paint is 28.3 ± 0.2 μm. As one can see, 8 out of 10 determinations are within the trust interval. This accuracy is very good, and represents a great feature of the system.

10.4. Transparent materials

The laser system when reading over transparent materials, as varnishes, has difficulties to determine the correct focusing point and the result is not trusty. Some tests have been done to study this problem and they are going to be presented.

✓ Determination of the thickness of standards similar to those mentioned before (with a smaller area and transparent) was performed. The results were compared with the standard value. On this experiment, as already referred, the standards are transparent. Two different determinations of thickness were made: the first with the standards placed on a paper sheet on top of the vacuum table and the other with the standard placed directly on the vacuum table.

The results are presented in Table 5, and it can be seen that the global results are quite different from the standard values. One more time, a deviation is introduced by the small area of the standard which increases the errors. Nevertheless, the difference between the results and the standard values cannot be explained only based on the small area of the standards. In fact the error is also due to the fact that the object measured is transparent. Maybe the laser does not detect the surface of the transparent object and it reflects directly on the object beneath. Even so, the laser does not read the same distance as with no transparent object. Possible refraction phenomena explain why the laser does not detect the surface of the object beneath (see Figure 38). It is notorious from Table 5 that the results show problems when operating with transparent objects.

Table 5: measurements of transparent standards.

Standard	Standard thickness (µm)	System thickness (µm)	
		White sheet	Vacuum table
S1	50.0 ± 1	55.3 ± 3.1	24.9 ± 2.7
S2	31.0 ± 1	43.6 ± 2.9	16.8 ± 2.6
S3	120.4 ± 1	154.4 ± 2.8	119.4 ± 2.9

✓ An additional test was done: determine the thickness of an opaque standard on top of a mirror. The reference distance to the mirror was measured and memorized then with the standard placed on the mirror the distance was read again. The difference between those two distances gave the read thickness of the standard. In fact this thickness was over two times the standard value. This fact indicates that the laser was not able to identify correctly the surface of the mirror and the distance read corresponds to a surface somewhere inside the mirror – this phenomena is shown in Figure 38.

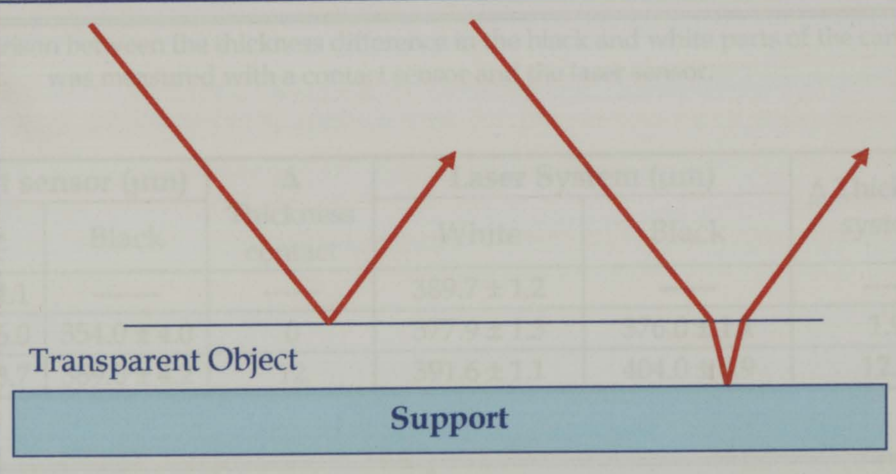


Figure 38: representation of refraction phenomena with transparent objects.

11. Cards

Although the title of this section could seem a little out of context, it is not once that a lot of work had been done in order to find out the motive of the difference between the black and white parts of the cards.

The first explanation, and probably the most complicated one, was that the laser is influenced by the material color. A first approach with the cards supplier revealed that the cards should have a black and white thickness difference in the order of the 5 micrometers. The laser system found differences up to 14 µm, which is considerably high and is a big error attending that the measures are usually in the same order. As described before, a lot of tests have been done in order to find where the real problem is: in the cards or in the system.

The cards production is essentially done by painting a black band on the original card (only white), and only then a varnish is applied, to provide that the surface does not absorb the paint humidity.

The cards producer provided cards on different stages of production: the original cards (everything white) - A, the white card with the black band on it (without the varnish) - B, and the final card (with a white and black bands on it, and with varnish) – C. These samples have been submitted to three different kinds of tests. Those tests are going to be described below.

✓ With the same method described for the reading of the thickness of the standards (in Section *System validation: non-influence of the substrate color*), there had been done thickness measurements of the cards on different stages of production. The results are presented in Table 6.

Table 6: comparison between the thickness difference in the black and white parts of the card. It was measured with a contact sensor and the laser sensor.

Card	Contact sensor (µm)		Δ Thickness contact	Laser System (µm)		Δ Thickness system
	White	Black		White	Black	
A	361.0 ± 4.1	-------	------	389.7 ± 1.2	------	-----
B	354.0 ± 6.0	354.0 ± 4.0	0	377.9 ± 1.3	376.0 ± 1.1	1.9
C	357.0 ± 3.7	369.0 ± 4.2	12	391.6 ± 1.1	404.0 ± 0.9	12.4

Note:

A - The original card
B - The original card with a black band
C - The final card with the varnish

Δ thickness = thickness on the black part – thickness on the white part o There is a difference on the measures made by the contact sensor and the laser's one that are related with the facts referred in section *System validation: non-influence of the substrate color*. One more time, the results allow concluding that the laser's system is accurate.

o From Table 6 one can conclude that independently of the method used to determine the thickness difference of the black and white parts, the referred difference is the same.

o It is interesting to note that the card without the varnish - card B, does not show a thickness difference from the black to the white parts of the card. Although analysis of the card C (card with varnish), demonstrates the appearance of a difference on the order of the 10 μm.

o With this experiment two things can be concluded: first of all, the independency of the laser's measures from the subtract color; secondly, that in deed the cards have a real thickness difference from the back to the white parts, and that difference only appears on the final card - the one varnished.

✓ Another test that has been done was to compare the normal cards (the one previously analyzed) with the *Leneta* ones. The *Leneta* is a different brand of cards. These cards are used when working with UV radiations, because the *Leneta* cards are not affected by this radiation.

Leneta cards do not show any difference between the white and black parts. There had been done comparisons of the measures with the contact and laser sensors. Both the results reveal that in fact, there are not significant differences on this card morphology.

✓ In order to improve the understanding of this problem one more experiment has been done. The normal cards (A, B and C) and the *Leneta* one have been sent for a different analysis: taking microscope photography in order to understand why the normal cards present a thickness difference so high, why the *Leneta* does not show that difference and why the difference only appears on the card C (the final stage) and not on the previous stages of the manufacturing process. The methodology is now going to be described.

o Analysis of these cards was made with an electron microscope on the *Centro de Materiais da Universidade do Porto* (*CEMUP*). Additionally to the images observed, element spectrums were obtained, and these two elements together enabled drawing some important conclusions.

The analysis on *CEMUP* began by observing the surface of the original card (with no black band or varnish) - card A. There is actually a pre-treatment of the paper because the front of the original card is different than its back. As is

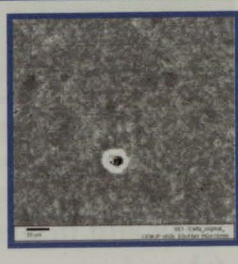


Figure 39: card A.

shown in Figure 39 the surface is very porous. On the center of the picture a large pore can be seen. Two kinds of pores were identified: the smaller that are present all over the surface and are very numerous and the larger pores which appear occasionally.

The element spectrum detected a great percentage of silicium and calcium. This indicates that there is, in fact a previous treatment of the paper. The backside of the card was also analyzed and the principal element detected was carbon.

- Afterwards the surface of the original card was compared with the surface of the card with the black band – card B. As one can see in Figure 40, the porosity is much reduced with the application of the black band. The structure of the original card is still visible beneath the black band, but the majority of the pores are covered. The larger pores are still present (see the bottom of Figure 40). The element spectrum detected mostly carbon, which is present due to the black pigment applied.

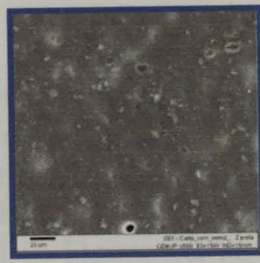


Figure 40: card B.

- The final stage of the card – card C was observed (the final stage is the card with the black band and with the varnish). The top of the Figure 41 corresponds to the black part of the card and the bottom to the white part. An important conclusion can be taken by looking at Figure 41: the varnish is not perfectly spread all over the surface on the white part of the card. There are some areas were it lacks varnish (whiter areas). The varnish is also very rich in carbon.

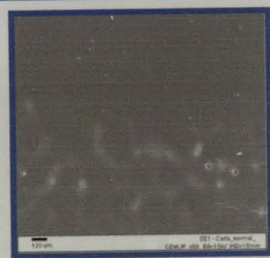


Figure 41: card C.

In Figure 42 can be seen an amplification of the areas where there are lacks of varnish. In this image the porosity of the original paper is perfectly visible (left side of the image).

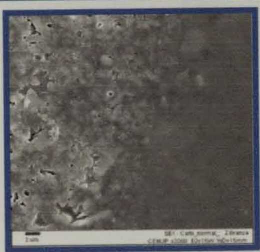


Figure 42: card C, lacks of varnish.

- The *Leneta* card was also observed. With this card the laser never detected significant differences of thickness between the black and the white parts, as already referred. Figure 43 shows the transition from black (top) to white (bottom). As one can see in this figure, the surface of the *Leneta* cards is very homogeneous; there is not any visible difference from the black to the white areas. It is not visible any lack of varnish on the surface. Also, the varnish used on the cards analyzed is quite different (even in a visual analysis). Perhaps the varnish used on the *Leneta* cards has better coverage. The elements present in this varnish are carbon and a little of titanium (not present on the varnish of the normal cards).

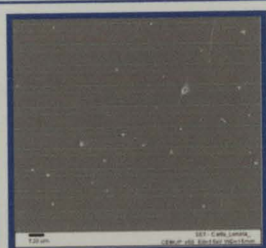


Figure 43: *Leneta* card.

One cannot conclude on the reason why the *Leneta* cards never have different thicknesses and the normal cards some times have. Maybe it is the varnish or perhaps the treatments before the application of the varnish.

❍ A different kind of analysis was made. It is very difficult to cut the cards in order to observe them by side. The *CEMUP* does not have the appropriated technique to perform a cut that does not damage or change the real profile of the card. Nevertheless some images were obtained, but nothing could be concluded to the real reason for the difference of thicknesses of the card.

The following images are of a different kind. The color gives an idea of the atomic number of the elements present. The whiter the color, the greater is the atomic number. Naturally, the majority of the thickness of the card is due to the paper fibers. The whiter area corresponds to the pre-treatment which is rich on silicium and calcium. The last section corresponds to the varnish.

An amplified image of the top of the card is presented in Figure 44. After that the same kind of image is presented for the *Leneta* card (Figure 45). There are not significant differences between the two cards that may explain the different quality of the cards especially because when the cards are cut there can be some damages.

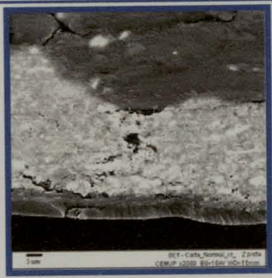


Figure 44: card C.

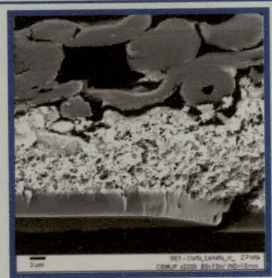


Figure 45: *Leneta* card.

12. Unit usage considerations

A lot of experiments have been done to find out the best way to use the system, in order to guarantee the highest accuracy and repeatability. Additional tests have been done to improve the systems features and to enhance the results. What is expected the system to do, is to determine the correct thickness of wet or dry films of paints.

✓ It was found that the system can do the application of the paint over the card itself and at the same time read the paint thickness. As can be seen in Figure 46, a metal plate can be assembled in the laser's support that can push the draw down bar in the application direction. The application made by the system is more uniform, and does not cause problems arising from the evaporation of the water in the paint, once the determination of the film thickness is made simultaneous with the application of the paint.

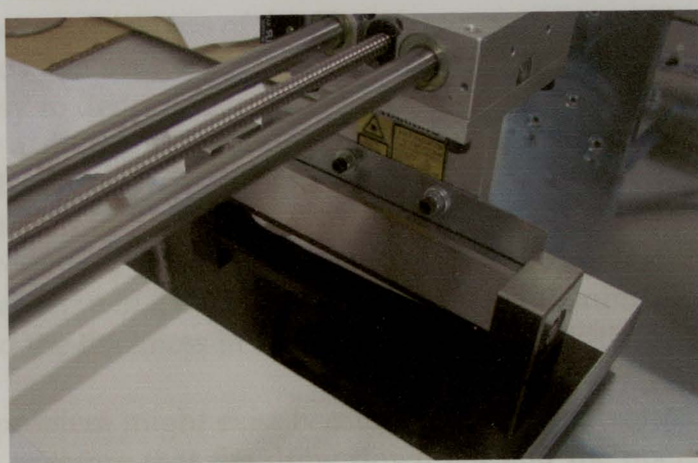


Figure 46: automatic application of the paint.

✓ The reading of wet films of paint can bring problems. A wet film of paint has a given water content, that as time goes by diminishes (the water evaporates). This implies that the thickness of paint tend to be smaller. This way, it is important to define the time after the application is done, in which the measurement of the thickness can be done without introducing much errors. In order to answer that question it has been done an application and the thickness had been read in a function of time.

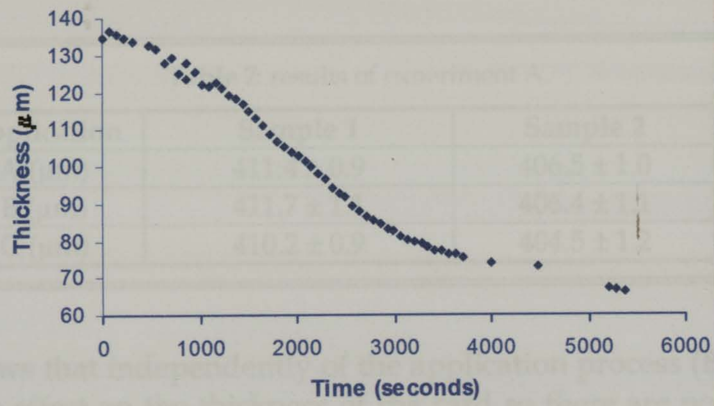


Figure 47: thickness evolution with time.

Figure 47 shows the variation of the thickness with time: there is a diminution of the wet thickness of the film of paint with time. This diminution after a given time tends to a stationary thickness that represents the thickness of the dry coating. As is easy to deduce, depending on the time that the measuring is done, it will correspond a different thickness. Much time after the application implies a much different thickness (from the initial one).

As can be seen in Figure 47 in 10 minutes, there is a diminution of about 7 µm, which represents a thickness variation of 5%. For smaller thicknesses the percentage variation will be superior. In order to minimize these errors it is suggested to read the thickness in the near **2 minutes** after the application.

✓ Another problem might exist because of possible deformations of the cards, related with the pressure that the draw down bar and the operator does over the card when the application is done. To find out if that was truth, it has been done a measurement of a card before the application was done (original card) and then compared the result with another one, correspondent to the measurement of the same card after the spread (simulation of an application but without paint) had been done. With that in mind there have been done three different experiments that are going to be described.

Experiment A

It had been measured the thickness of the original card (A), and then compared to the card after the application (without paint) had been done (B). These results were also compared with the thickness of the same card when the measure is done at the same time of the application (automatic application) - C. The results are presented in Table 7, for two different samples.

Table 7: results of experiment A.

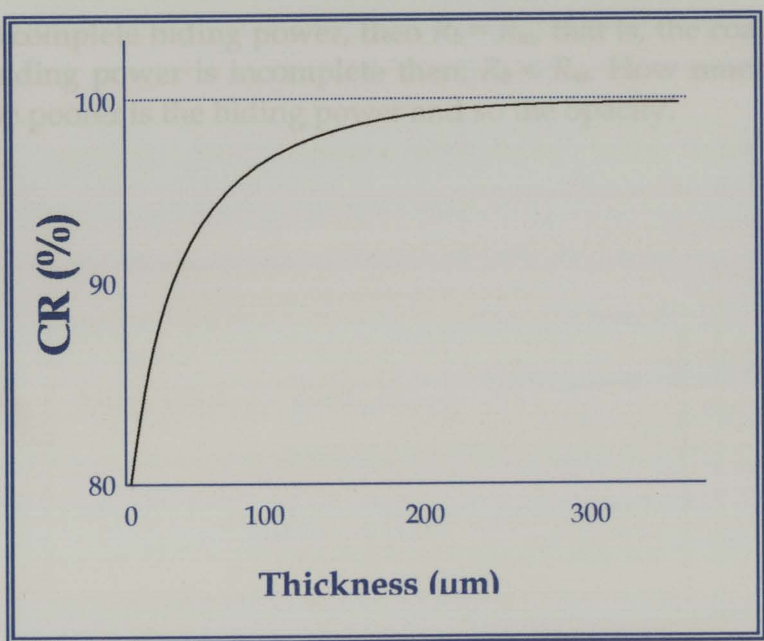
Application	Sample 1	Sample 2
A (µm)	411.4 ± 0.9	406.5 ± 1.0
B (µm)	411.7 ± 1.1	406.4 ± 1.1
C (µm)	410.2 ± 0.9	404.5 ± 1.2

Table 7 shows that independently of the application process (B or C), there is not a considerable effect on the thickness of the card so there are not errors on the measuring induced by the card deformation.

Experiment B

Another experiment had been done in order to find out if the cards are not really affected by the water of the paint. It has been put a water drop on the card and then the laser read the distance to a point near the drop during approximately 60 minutes. During that time, it had not been observed variations on the distance measured. That implies that the cards are not affected by the water of the paint, and do not suffer deformation with aqueous substances, at least on the considered time.

PART 2 –
Study of the relation between the opacity and the wet film thickness



13. Introduction to part 2

The objective of this part of the work was to obtain a mathematical relation between the thickness of the wet film paint and its contrast ratio when dried. The correlation was determined for three different paints: Vinyl Matt, Vinyl Silk and Vinyl Soft.

The opacity, can be measured by some parameters such as hiding power or contrast ratio. The opacity is a measure of how effectively a paint or coating covers or hides the surface over which it is applied. By measuring the reflectance of this coating over black and white areas (white does not absorb nothing and emits everything; black absorbs everything and does not emit anything), it is possible to have a measure of the opacity of the coating. By definition, contrast ratio can be calculated according to the following equation:

$$CR(\%) = 100\frac{R_b}{R_w}$$

where R_b is the reflectance over the black card, and R_w is the reflectance over the white one.

If there is complete hiding power, then $R_b = R_w$, that is, the coating has 100% opacity. If the hiding power is incomplete then: $R_b < R_w$. How much lower is the contrast ratio, the poorer is the hiding power and so the opacity.

14. Method

As previously referred, the objective of the second part of the work is to determine a mathematical expression between the thicknesses of wet films of paint and their dry opacity. Three different paints have been chosen: Vinyl Matt, Vinyl Silk and Vinyl Soft (specification of the paints can be consulted in Table 8).

Table 8: specification of the paints analyzed.

Paint	Specification
Vinyl Matt	10-250.0501 06
Vinyl Silk	10-220.0501 08
Vinyl Soft	10-240.0509 06

The adopted procedure considers a series of trials that will allow to obtain, to each paint, different thicknesses on the range of 50 to 200 µm. Different draw down bars have been used (their serial number is present in Table 9), as well as different quantities applied. The method that have been chosen to determine the wet thickness was the exact method that is described in section *Software*. This method is based on the difference between the reference vector (distance between the laser and the card, along its length), and the vector of distances to the paint. Each of these samples were clearly identified and dried for about an hour on an oven at 50 ºC. When this time passed, the contrast ratio have been determined on a spectrophotometer.

Table 9: draw down bars used.

Draw Down Bar	Serial Number	Gap dimension (µm)
A	981282	50, 100, 150, 200
B	5041909	100, 150, 180, 200
C	504053	200, 400, 600, 800

The implemented procedure next described was identical for all the paints.

A. Determination of the wet thickness

- Identifying clearly each card with: paint name, draw down bar used, gap dimension chosen and sample identification.
- Placing the card into the vacuum table;
- Cleaning the card surface with a smooth paper (for example cleaning paper);

- Starting the program to initialize the reading and saving of the reference vector (vector 1);
- Without moving the card, do the application of the paint (with a the chosen draw down bar and gap dimension) – the draw down bar have been aligned to the bottom of the vacuum table, and the paint was distributed uniformly on the draw down bar with the help of a syringe, Figure 48 shows this procedure;
- Asking the program to do the reading of the distance to the paint vector (vector 2);
- Reading the thickness given by the program (which is the difference between vector 1 and vector 2).

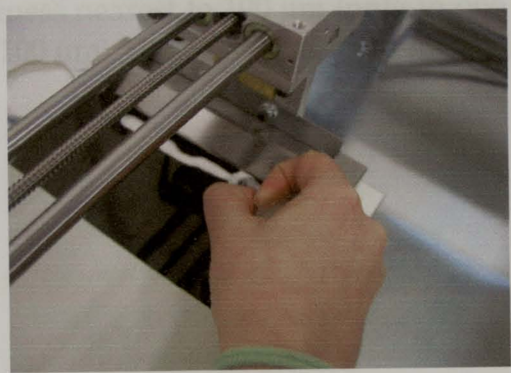


Figure 48: application of the paint on the card.

B. Drying

After reading the wet thickness the samples were dried, in order to do the determination of the dry contrast ratio. The NP-2402 standard (*Appendix A*) refers that the sample should be dried at ambient temperature over 24 hours. Although, to save time, the drying of the cards has been done on an oven at 50 ºC, over an hour. This procedure is used at CIN and guarantees that all the water content in the sample evaporates.

C. Opacity determination

The opacity determination has been made on a spectrophotometer, which determined the contrast ratio, by the quotient between the reflected quantity of light on the white band, and the reflected quantity on the black one. The places where the measures have been made were located near the center of the card, because it is where the errors are inferiors (and it is the zone where the thickness determination had been made). The zones where the readings were made, have been marked (behind the card) with a circle, in order to allow doing the reading again on the same point, to verify any result in doubt.

15. Results

The parameters that are important to analyze are: wet thickness of the coating, gap dimension, opacity (determined by a contrast ratio procedure).

The procedure that had been described in section *Method* was repeated, to each paint, fourteen times. Flowingly it is going to be presented the results obtained for the three paints analyzed. The results will be presented in a table, and the opacity versus thickness will be presented in a graph.

According to the NP-2402 standard (*Appendix A*), the opacity should be determined for a wet thickness of 100 µm. So, after each table it is presented the contrast ratio of the thickness nearest to 100 µm (only in one case it was possible to apply a real thickness of 100 µm) The draw down bar identification is in accordance to Table 9.

Results for Vinyl Matt

Table 10: results for of the wet thickness and respective dry opacity for Vinyl Matt.

Trial	Draw Down Bar	Gap dimension (µm)	Average Thickness (µm)	CR (%)
1	A	50	34.9	84.74
2	A	50	34.3	84.17
3	A	100	66.8	93.77
4	A	100	67.0	92.99
5	A	150	96.2	96.62
6	**A**	**150**	**98.0**	**96.62**
7	A	200	133.0	97.92
8	A	200	128.6	97.62
9	B	100	68.4	93.91
10	B	150	96.6	96.25
11	B	180	123.2	97.83
12	B	200	134.2	98.47
13	C	400	276.7	99.61
14	C	400	278.2	99.66

Contrast ratio for Vinyl Matt (thickness of 98.0 µm) = 96.62 %, the normalized contrast ratio (to a thickness of 100 µm) will be higher, once that the thickness is 2 µm below of the comparison term.

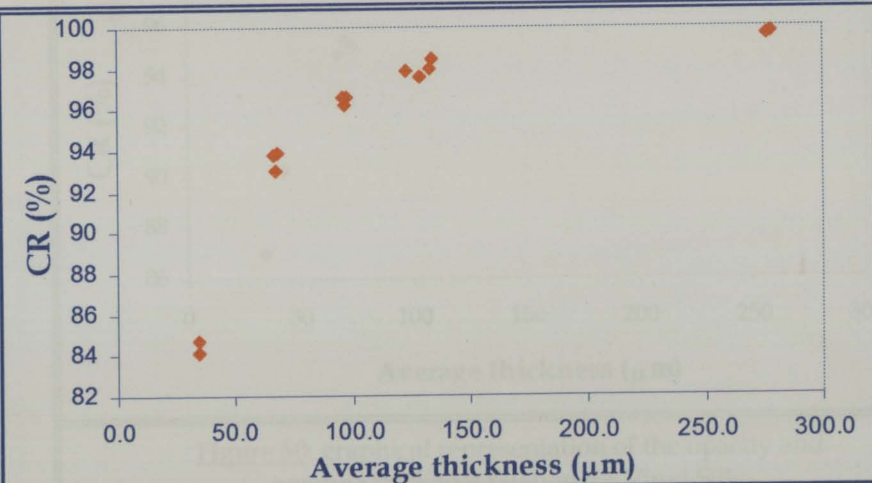


Figure 49: graphical representation of the opacity and average thickness relation for Vinyl Matt.

Results for Vinyl Silk

Table 11: results for of the wet thickness and respective dry opacity for Vinyl Silk.

Trial	Draw Down Bar	Gap dimension (μm)	Average Thickness (μm)	CR (%)
1	A	50	42.3	90.19
2	A	50	34.1	87.02
3	A	100	69.5	95.42
4	A	100	72.7	95.15
5	A	150	98.0	97.73
6	**A**	**150**	**100.3**	**97.85**
7	A	200	131.1	98.57
8	A	200	134.8	98.68
9	B	100	67.0	94.83
10	B	150	96.5	97.68
11	B	180	121.8	98.37
12	B	200	129.6	98.71
13	C	400	272.0	99.91
14	C	400	272.8	99.97

Contrast ratio for Vinyl Silk (thickness of 100.3 μm) = 97.85 %. The normalized contrast ratio will be a close to the one determined in trial 6

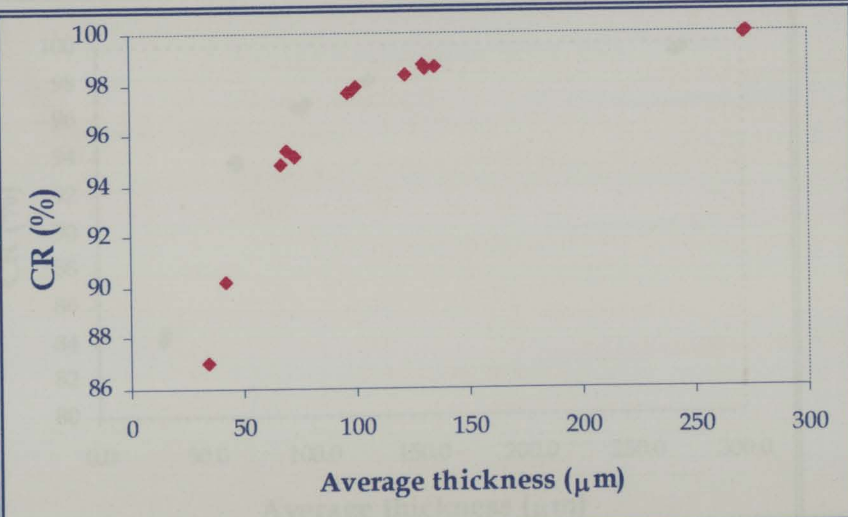


Figure 50: graphical representation of the opacity and average thickness relation for Vinyl Silk.

Results for Vinyl Soft

Table 12: results for of the wet thickness and respective dry opacity for Vinyl Soft.

Trial	Draw Down Bar	Gap dimension (µm)	Average Thickness (µm)	CR (%)
1	A	50	33.6	84.10
2	A	50	32.5	84.60
3	A	100	67.6	93.85
4	A	100	67.5	93.68
5	A	150	92.8	96.59
6	A	150	96.9	96.46
7	A	200	128.7	97.92
8	A	200	129.0	98.04
9	B	100	68.2	93.55
10	**B**	**150**	**97.8**	**96.75**
11	B	180	119.8	97.65
12	B	200	129.1	98.00
13	C	400	268.6	99.50
14	C	400	270.4	99.64

Contrast ratio for Vinyl Soft (thickness of 97.8 µm) = 96.75%, the paint will be more opaque, once that the thickness is 2 µm below of the comparison term.

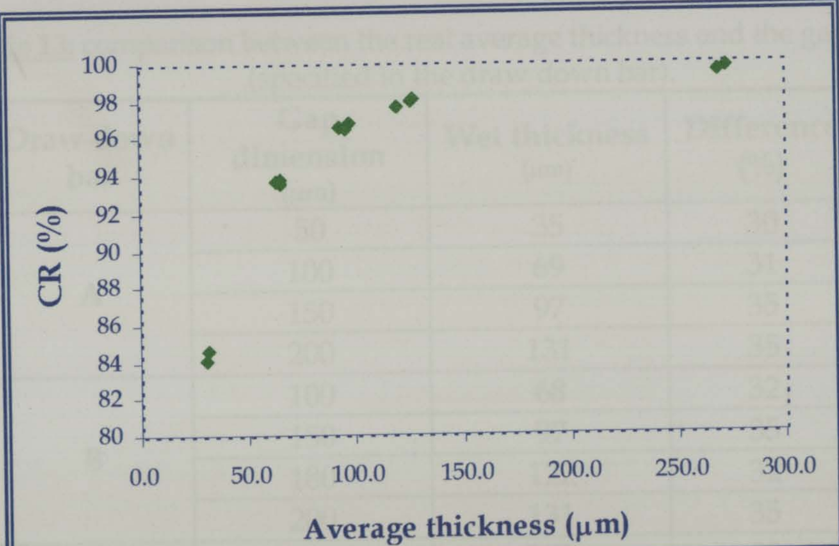


Figure 51: graphical representation of the opacity and average thickness relation for Vinyl Soft.

16. Results Analysis

It is important to find out a mathematical relation between the wet thickness and the dry opacity for each of the paints. As can be seen from the graphical representations of the contrast ratio versus wet thicknesses, for low thicknesses, the relation between them is linear. For high thicknesses a constant value between the two related parameters is observed. Contrast ratio cannot be higher than 100%. This corresponds to the limit situation, where the paint covers totally the surface beneath and no difference between the black and white parts of the card can be detected. Hence, the relation between opacity and wet thickness is similar to the one shown in Figure 52.

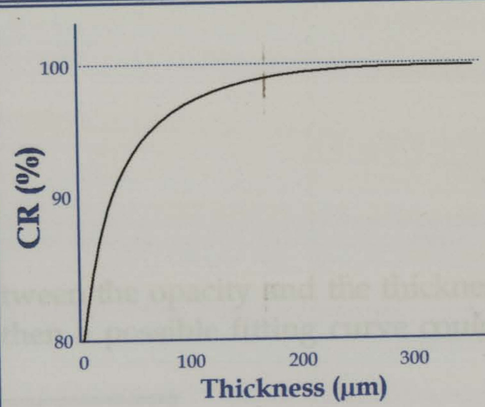


Figure 52: expected relation between opacity and thickness.

The observation of Tables 10, 11 and 12, allow to conclude that there is a substantial difference between the gap dimension of the draw down bar and the thickness of the wet film. In Table 13 the mean of real thickness of wet paint for each gap of each draw down bar is presented.

Table 13: comparison between the real average thickness and the gap dimension (specified in the draw down bar).

Draw down bar	Gap dimension (µm)	Wet thickness (µm)	Difference (%)
A	50	35	30
	100	69	31
	150	97	35
	200	131	35
B	100	68	32
	150	97	35
	180	122	32
	200	131	35
C	400	273	32

There is a more or less difference of 33% from the real average thickness and the draw down bar gap dimension. This must be paid in attention, because to have a real thickness of about 100 µm (the one specified on the NP-2402 standard for the determination of the contrast ratio), one has to use the draw down bar with a gap of about 150 µm. It is also important to note that the difference between the thickness and gap dimension can be bigger or smaller depending on the applied paint, and on the person that is doing the application.

Next it is going to be analyzed two different fitting curves that face the requirements previously described (linearity for low thicknesses, and constancy for high thicknesses).

16.1. Fitting curves

16.1.1. Correlation 1

So, if one assumes that the relation between the opacity and the thickness is similar to the one represented in Figure 52 then a possible fitting curve could be equation (1):

$$CR(\%) = \frac{Thickness}{a \times Thickness + b} \qquad (1)$$

Analyzing equation (1), it is observed for:

- **low thicknesses**, a linear relation is verified:

$$a \times Thickness + b \approx b \Rightarrow CR \approx \frac{Thickness}{b}$$

- **high thicknesses**, the contrast ratio tends to be constant:

$$a \times Thickness + b \approx a \times Thickness \Rightarrow CR = \frac{1}{a}$$

In order to test this fitting curve, and to easy the calculations, a linearization of equation (1) have been performed. This was achieved by inverting both terms of that equation:

$$\frac{1}{CR(\%)} = \frac{b}{Thickness} + a \qquad (2)$$

As it is presented in equation (2) the inverses of the contrast ratio and the thickness are directly proportional (the equation assumed a form of: y=ax+b). So a linear relation is expected for these two quantities.

For each paint it will be represented the inverse of the opacity versus the inverse of the thickness. Below each figure (that represents the linearization) is shown the mathematical equation of the trend line and in the figures is shown the correlation coefficient.

Vinyl Matt

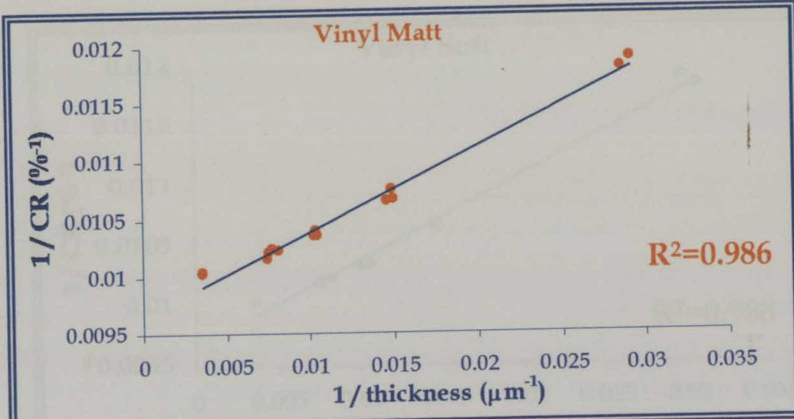


Figure 53: representation of the linearization of correlation 1 for Vinyl Matt and respective trend line.

$$\frac{1}{CR\,(\%)} = \frac{7.367 \times 10^{-2}}{Thickness\ (\mu m)} + 9.651 \times 10^{-3}$$

Vinyl Silk

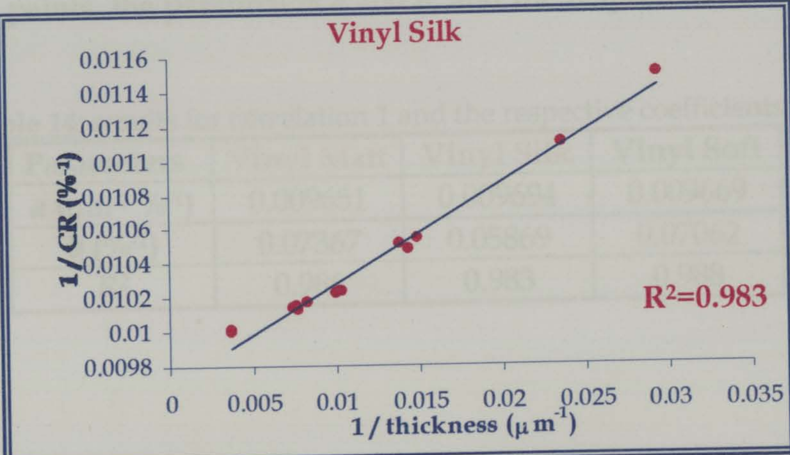


Figure 54: representation of the linearization of correlation 1 for Vinyl Silk and respective trend line.

$$\frac{1}{CR\,(\%)} = \frac{5.869 \times 10^{-2}}{Thickness\ (\mu m)} + 9.694 \times 10^{-3}$$

Vinyl Soft

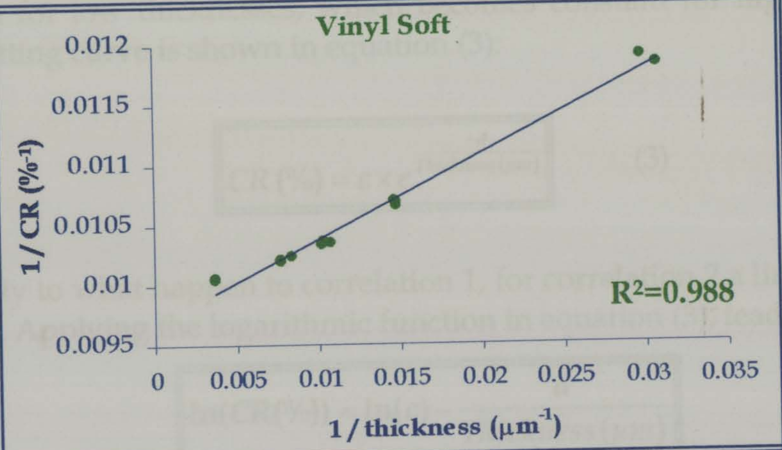


Figure 55: representation of the linearization of the correlation 1 for Vinyl Soft and respective trend line.

$$\frac{1}{CR\,(\%)} = \frac{7.062\times10^{-2}}{Thickness\ (\mu m)} + 9.669\times10^{-3}$$

A table with the results for correlation 1 is next presented, and shows for each of the paints, the parameters *a* and *b*, and the respective correlation coefficient (R^2).

Table 14: results for correlation 1 and the respective coefficients.

Parameters	Vinyl Matt	Vinyl Silk	Vinyl Soft
a ($\mu m^{-1}\ \%^{-1}$)	0.009651	0.009694	0.009669
b ($\%^{-1}$)	0.07367	0.05869	0.07062
R^2	0.986	0.983	0.988

16.1.2. Correlation 2

Another mathematical expression shows the behavior that is expected: a linear relation for low thicknesses, which becomes constant for high thicknesses. This second fitting curve is shown in equation (3):

$$CR(\%) = c \times e^{\frac{-d}{Thickness\,(\mu m)}} \qquad (3)$$

Similarly to what happen to correlation 1, for correlation 2 a linearization can be performed. Applying the logarithmic function in equation (3), leads to:

$$\ln(CR(\%)) = \ln(c) - \frac{d}{Thickness\,(\mu m)} \qquad (4)$$

Therefore, the logarithm of the contrast ratio is directly proportional to the inverse of the thickness.

For each paint it will be represented the logarithm of the contrast ratio versus the inverse of the thickness, the respective equation of the applied trend line and its correlation coefficient. It is important to note, that contrarily to what happen for correlation 1, here the parameters to be obtained are: *c* and *d*. One more time, the figures will represent the linear regression performed in accordance to equation (4), and below them are presented the equation of the linearization and the correlation coefficient, for each paint.

Vinyl Matt

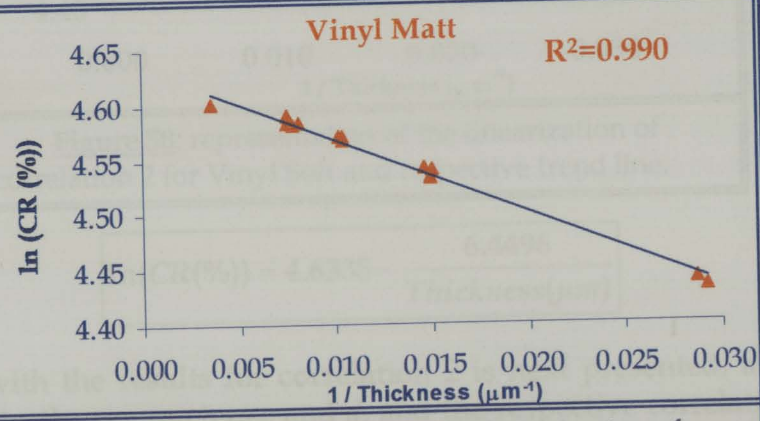


Figure 56: representation of the linearization of correlation 2 for Vinyl Matt and respective trend line.

$$\ln(CR(\%)) = 4.6352 - \frac{6.7388}{Thickness(\mu m)}$$

Vinyl Silk

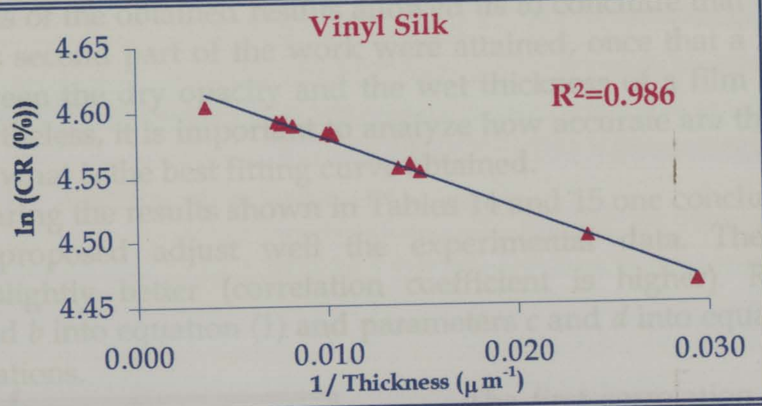


Figure 57: representation of the linearization of correlation 2 for Vinyl Silk and respective trend line.

$$\ln(CR(\%)) = 4.6329 - \frac{5.4977}{Thickness(\mu m)}$$

Vinyl Soft

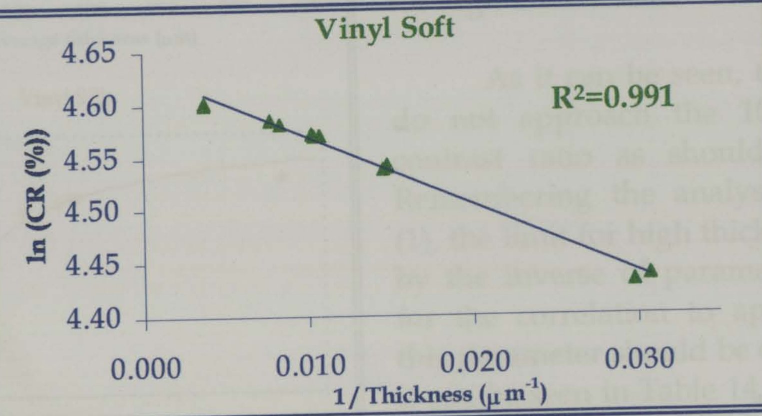


Figure 58: representation of the linearization of correlation 2 for Vinyl Soft and respective trend line.

$$\ln(CR(\%)) = 4.6335 - \frac{6.4496}{Thickness(\mu m)}$$

A table with the results for correlation 2 is next presented, and shows for each of the paints, the parameters *c* and *d*, and the respective correlation coefficient (R^2).

Table 15: results for correlation 2 and the respective coefficients.

Parameters	Vinyl Matt	Vinyl Silk	Vinyl Soft
c (%)	103.05	102.81	102.87
d (μm)	6.7388	5.4977	6.4496
R^2	0.990	0.986	0.991

17. Discussion

The analysis of the obtained results allowed us to conclude that the objectives proposed to this second part of the work were attained, once that a mathematical expression between the dry opacity and the wet thickness of a film of paint, was achieved. Nevertheless, it is important to analyze how accurate are these results as well as to study what is the best fitting curve obtained.

By comparing the results shown in Tables 14 and 15 one concludes that both fitting curves proposed adjust well the experimental data. The exponential correlation is slightly better (correlation coefficient is higher). Replacing the parameters *a* and *b* into equation (1) and parameters *c* and *d* into equation (2) gives the required relations.

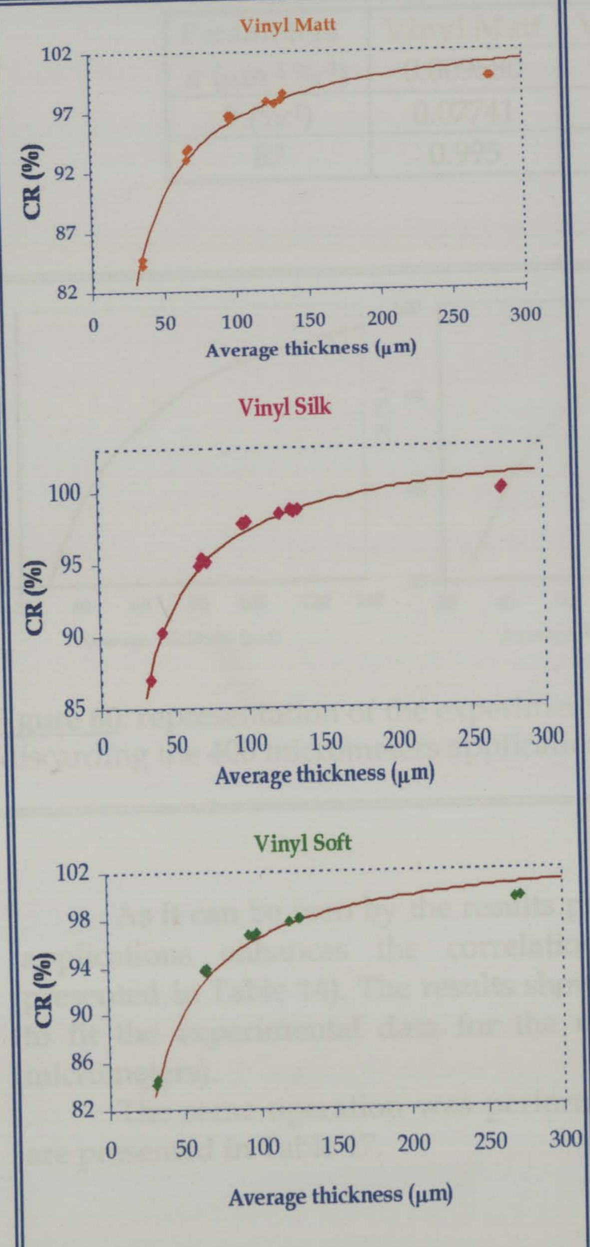


Figure 59: representation of the experimental data and correlation 1.

The first correlation is next going to be analyzed. Nevertheless this analysis is similar for the second one.

The simultaneous graphical representation of the results and equation (1) reveals one problem with the correlations (see Figure 59). In fact, the correlation presents a slight deviation for high thicknesses.

As it can be seen, the correlations do not approach the 100 % limit of contrast ratio as should be expected. Remembering the analysis of equation (1), the limit for high thicknesses is given by the inverse of parameter *a*. In order for the correlation to approach 100 %, this parameter should be equal to 0.01; as it can be seen in Table 14, the results for parameter *a* for all the paints are slightly lower than 0.01, which means that the relation approaches an opacity slightly higher than 100 % (see Figure 59); for example, for Vinyl Matt:

$$a = 0.009651 \Rightarrow CR \rightarrow 103.6\,\%$$

This means that the fitting curve proposed is not indicated for all the range of thicknesses (from zero to infinite).

As mentioned, for the second correlation the analysis is similar: for high thicknesses there is also a deviation. In this case, the upper limit is given directly by parameter *c*. Consulting Table 15 one can see that this parameter is about 103 % for all the paints. It is somewhat lower than the upper limit of the first correlation, but it is still above 100%. This is another indication that, in fact, the second correlation proposed is slightly better than the first one.

One was told that usually the thicker applications performed are 200 micrometers. In fact, the correlation is extremely accurate for thicknesses up to 200 micrometers. This can be proved if the results of the 400 micrometers applications are removed. The next table presents the results for the linear correlations, discarding the 400 micrometers applications. In Figure 60, the simultaneous representation of the experimental data and the correlations is presented.

Table 16: results for correlation 1 and the respective coefficients (discarding the 400 micrometers applications).

Parameters	Vinyl Matt	Vinyl Silk	Vinyl Soft
a ($\mu m^{-1}\ \%^{-1}$)	0.009580	0.009632	0.009605
b ($\%^{-1}$)	0.07741	0.06220	0.07384
R^2	0.995	0.994	0.995

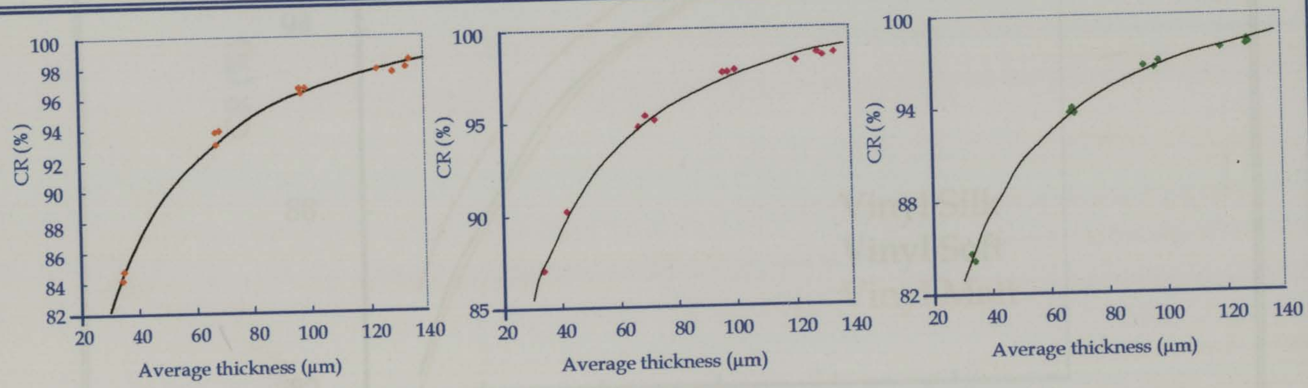


Figure 60: representation of the experimental data and correlation 1 (discarding the 400 micrometers applications).

As it can be seen by the results presented in Table 16, discarding the thicker applications enhances the correlation coefficients (comparison with results presented in Table 14). The results show that equation (1) is an excellent approach to fit the experimental data for the usual work range (applications up to 200 micrometers).

The same operation was performed for the second correlation. The results are presented in Table 17.

Table 17: results for the second correlation and the respective coefficients (discarding the 400 micrometers applications).

Parameters	Vinyl Matt	Vinyl Silk	Vinyl Soft
c (%)	103.65	103.35	103.38
d (μm)	7.0320	5.7933	6.6985
R^2	0.996	0.995	0.996

If both correlations are represented graphically one cannot distinguish the two correlations proposed graphically. Nevertheless, the exponential correlation provides a slightly better fit.

The comparison between the three paints is presented on Figure 61.

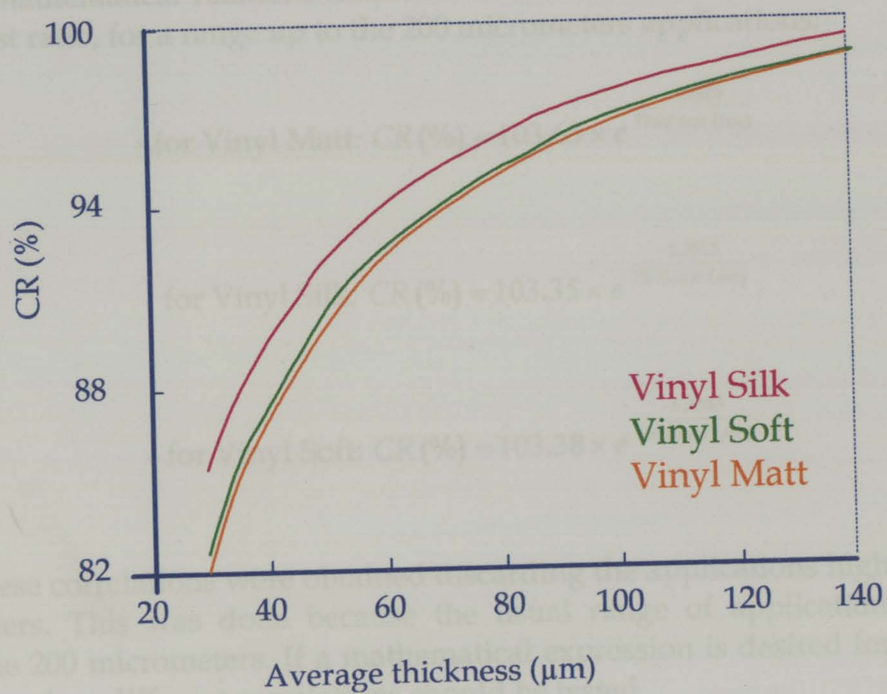


Figure 61: representation of contrast ratio versus opacity for the three paints.

As one can see, from the three paints analyzed it is Vinyl Silk that has the better opacity, this is, for the same thickness it has a higher contrast ratio. Vinyl Soft and Vinyl Matt have approximately the same contrast ratio, being Vinyl Matt the lesser opaque.

18. Conclusions

Concerning the *Development and testing of the thickness reading unit*, the goals were achieved: a system capable of reading the thickness of wet films of paint was developed. The tests proved that this system is highly accurate and with a very good repeatability. The results are independent of the colour of the paint. Additional tests should made concerning the transparency of the object, once that some problems were detected with this kind of substrate.

The first practical use of the system developed was the *Study of the relation between the opacity and the wet film thickness*. This study was performed for three different paints: Vinyl Matt, Vinyl Silk and Vinyl Soft.

The mathematical relations mathematical relation between the thickness and the contrast ratio, for a range up to the 200 micrometers applications:

- for Vinyl Matt: $CR(\%) = 103.65 \times e^{\frac{-7.0320}{Thickness\ (\mu m)}}$

- for Vinyl Silk: $CR(\%) = 103.35 \times e^{\frac{-5.7933}{Thickness\ (\mu m)}}$

- for Vinyl Soft: $CR(\%) = 103.38 \times e^{\frac{-6,6985}{Thickness\ (\mu m)}}$

These correlations were obtained discarding the applications higher than 200 micrometers. This was done because the usual range of applications does not exceed the 200 micrometers. If a mathematical expression is desired for the all the thicknesses then different correlations should be tested.

It was concluded for the three paints tested, Vinyl Silk is the most opaque (with the same thickness has higher contrast ratio); next is Vinyl Soft, that has a slightly higher opacity than Vinyl Matt, which is the less opaque.

19. Future developments

It is believed that the system developed has high potential. Its application range is not only for quality control of paints and its possible implications are not only the enhancement of the assessment of the opacity. It can be used for calibration of the draw down bars used, control of the quality of the cards where the paint is applied, study of the rheology of paints or statistical studies of the precision of the operators. It can be a useful tool to reach new formulations for paints.

Apart from its current possible applications, this system could suffer developments to increase its uses. These developments include a fully automatic system for spreading and reading the thickness of the paint. Another possibility is the implementation of a data base on the system, that with the introduction of the wet thickness of film and its opacity would automatically calculate the thickness for 100 µm for that specific paint.

20.1. Appendix A - Standard NP-2402

CDU 667.657.1

NORMA PORTUGUESA	TINTAS E VERNIZES Comparação da razão de contraste (poder de cobertura) de tintas do mesmo tipo e cor	NP-2402 1984

Peintures et vernis. Comparaison du rapport de contraste (pouvoir masquant, des peintures de même type et de même couleur

0 - PREÂMBULO

O método fixado nesta Norma é o método mais simples de comparação de razões de contraste de películas, aplicadas sobre um suporte negro e branco com uma espessura de película húmida uniforme; mostrou-se ainda que este método permite uma comparação reprodutível para tintas do mesmo tipo. No entanto, como operadores diferentes, utilizando o mesmo sistema de aplicação de películas podem obter películas de diferentes espessuras, devido provavelmente a variações de pressão sobre o aplicador, considera-se que o método não é satisfatório para uma determinação absoluta do poder de cobertura.

Com o fim de reproduzir as condições de uma aplicação prática, prefere-se fixar a espessura de uma película húmida (ou o rendimento superficial) em vez da espessura de uma película seca ou da sua massa. A espessura da película húmida escolhida é de aproximadamente 50 µm, o que corresponde a um rendimento superficial de aproximadamente 20m^2/l; para a maior parte das tintas, isto representa um meio de aplicação à trincha duma tinta não tixotrópica, sobre uma superfície lisa e não porosa.

1 - OBJECTIVO E CAMPO DE APLICAÇÃO

A presente Norma destina-se a fixar o método de referência a utilizar para comparar as razões de contraste apresentadas por películas de tintas brancas ou de cores claras, com um factor de reflectância de cerca de 40%, secas à temperatura ambiente e aplicadas com uma espessura de película húmida aproximadamente uniforme sobre suportes negros e brancos.

(Continua)

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CT 3

Edição Nov.1985

2 - REFERÊNCIAS

NP-1360- Tintas e vernizes.Exame e preparação das amostras para ensaio

NP-1734 - Tintas e vernizes. Amostragem.

3 - APARELHOS E UTENSÍLIOS

3.1 - Suportes

Escolhe-se um dos suportes seguintes:

3.1.1- Suportes de cartolina medindo cerca de 100 x 200mm de 0,20 a 0,30mm de espessura, impressos e envernizados de modo a formarem superfícies negras e brancas adjacentes, facilmente molháveis por tintas de solventes ou de água, mas impermeáveis a essas tintas. Cada uma das superfícies negras e brancas deve ter dimensões de cerca de 80 x 80mm. A reflectância da superfície branca da cartolina não deve ser inferior a 75%, nem superior a 85% e a da superfície negra não deve ser superior a 5%. Durante os ensaios comparativos, a reflectância da superfície branca da cartolina pode variar, no máximo, de ± 1% em relação ao valor médio.

NOTA:
Para análise dos ensaios comparativos, incluindo os ensaios laboratoriais, deve utilizar-se a cartolina impressa do mesmo modo.

3.1.2 - Folhas de poliéster transparente, claras, medindo cerca de 100 x 200mm e 50μm de espessura, a utilizar sobre placas de vidro negro ou branco. A reflectância da placa branca deve estar compreendida entre 84 e 86% e a da placa negra não deve ser superior a 5%.

3.2 - Aplicador

O aplicador é de forma rectangular tendo um entalhe com pelo menos 70mm de largura na face inferior de modo a formar uma abertura de 100 ± 2μm de profundidade quando é colocado sobre a superfície opticamente plana. A profundidade da parte plana do entalhe, desde a parte anterior até à parte posterior do

(Continua)

aplicador, não deve ser inferior a 50 µm. Por acordo, pode utilizar-se um aplicador de abertura diferente de 100µm.

3.3 - Aparelho de medida

O aparelho pode ser um reflectómetro do tipo visual ou fotoeléctrico que permita uma leitura proporcional à intensidade da luz reflectida sobre a superfície ensaiada, com uma precisão de 1% e que tenha uma resposta espectral próxima da função de eficácia luminosa foto-óptica CIE para o iluminante CIE C ou D65 (1).

4 - PREPARAÇÃO DA AMOSTRA

Devem colher-se amostras representativas dos produtos a comparar, de acordo com as especificações da NP-1734. Devem preparar-se as amostras para o ensaio, de acordo com as especificações da NP-1360.

5 - TÉCNICA

5.1 - PREPARAÇÃO DE SUPORTE

5.1.2 - Suporte de cartolina

Antes da aplicação, devem condicionar-se os suportes negros e brancos, nas condições de ensaio, a 23 ± 2 °C e humidade relativa 50 ± 5%, durante pelo menos 16h, e devem ser manuseados sempre pelos bordos para evitar contaminação das superfícies a revestir. Deve preparar-se o suporte para o revestimento:

- fixando uma extremidade, com uma pinça ou papel adesivo, a uma placa de vidro plana com pelo menos 6mm de espessura;
- ou, utilizando uma placa de sucção, que deve ser plana.

5.1.3 - Folha de poliéster

Deve preparar-se a folha de poliéster para o revestimento, estendendo-a sobre uma placa de vidro plana, com pelo menos 6mm

(1)Veja-se relatório CIE 1936 da Comissão Internacional de Iluminação (CIE).

(Continua)

de espessura, previamente molhada com algumas gotas de white spirit e de modo a conseguir manter-se a folha pela tensão superficial. Deve ter-se o cuidado de não molhar a superfície da folha com o líquido e de não introduzir bolhas de ar sob a folha.

5.2 - PREPARAÇÃO DOS PROVETES A ENSAIAR

Imediatamente antesda aplicação, mistura-se cuidadosamente a tinta, agitando-a vigorosamente para destruir qualquer estrutura tixotrópica e tendo o cuidado de não introduzir bolhas de ar. Aplica-se cerca de $2cm^3$ de tinta ao longo de uma das extremidades do suporte, de cartolina ou folha de poliéster,estendendo--a imediatamente com a ajuda do aplicador. Mantém-se uma forte pressão sobre o aplicador que deve ser deslocado suavemente a uma velocidade de cerca de 100mm/s.

Mantém-se a cartolina ou a folha revestida em posição horizontal, enquanto seca; prende-se de preferência os bordos sobre uma superfície plana. Preparam-se, pelo menos, 3 provetes para cada tinta a ensaiar.

5.3 - CONDICIONAMENTO DOS PROVETES

Devem conservar-se as películas a ensaiar a uma temperatura de 23 ± 2 °C e a uma humidade relativa de 50 ± 5% durante 16h no mínimo e 168h no máximo, antes de efectuar a medição do factor de reflectância.

5.4 - MEDIÇÃO DO FACTOR DE REFLECTÂNCIA

Depois de condicionados, os provetes estão prontos para a medição do factor de reflectância.

Fixam-se as folhas de poliéster revestidas sobre o verso das placasa negroe branco e introduzem-se algumas gotas de white spirit entre a superfície inferior e o vidro para eliminar o ar e assegurar um contacto óptimo.

Mede-se o factor de reflectância das películas a ensaiar, em pelo menos 4 posições,sobre as superfícies do suporte negro ou branco de cada cartolina ou folha revestida,e calcula-se a média dos factores de reflectância das superfícies negras do suporte,

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R_N, e a média dos factores de reflectância das superfícies brancas do suporte, R_B.

6 - RESULTADOS

6.1 - CÁLCULO

Sendo:

R_N, a média dos factores de reflectância obtidos sobre as superfícies negras do suporte;

R_B, a média dos factores de reflectância obtidos sobre as superfícies brancas do suporte,

a razão de contraste, R_C, para cada suporte, expressa em percentagem, é:

$$R_C = \frac{R_N}{R_B} \times 100$$

6.2 - APRESENTAÇÃO

A razão de contraste para cada tinta, expressa em percentagem, é dada pela média da razão de contraste de três suportes revestidos, arredondada às unidades.

7 - PRECISÃO

Os valores seguintes são válidos apenas para tintas brancas e cores claras:

7.1 - REPETIBILIDADE

A diferença entre as médias das razões de contraste de cada um dos 3 suportes preparados pelo mesmo operador, utilizando a mesma tinta, medidos com o mesmo aparelho na mesma altura, não deve ser superior a 1 unidade para um nível de confiança de 95%.

(Continua)

7.2 - REPRODUTIBILIDADE (de uma tinta)

A diferença entre as médias das razões de contraste da mesma tinta,obtidas por operadores diferentes em laboratórios diferentes, não deve ser superior a 8 unidades para um nível de confiança de 95%.

7.3 - REPRODUTIBILIDADE (de duas tintas do mesmo tipo e cor)

A diferença entre as diferenças das médias das razões de contraste de 2 tintas, determinadas por 2 operadores em 2 laboratórios diferentes, não deve ser superior a 3 unidades para um nível de confiança de 95%.

NOTA:
Se a diferença das razões de contraste de duas tintas num laboratório A é de 10 unidades,então a diferença das razões de contraste no laboratório B pode ser de 7 a 13 unidades.

8 - RELATÓRIO DO ENSAIO

O relatório do ensaio deve fazer referência à presente Norma e conter pelo menos as seguintes informações:

a) o tipo de suporte utilizado;
b) o tipo e a identificação das tintas ensaiadas;
c) a espessura da película húmida aplicada, expressa em micrometros;
d) a média das razões de contraste determinadas sobre cada tinta e o desvio dos resultados individuais;
e) referência a quaisquer modificações da presente Norma feitas por acordo ou não das partes;
f) data de realização do ensaio.

9 - REFERÊNCIA À NORMALIZAÇÃO INTERNACIONAL

A presente Norma baseia-se na Norma ISO 2814 - 1973 - **Peintures et vernis. Comparaison du rapport de contraste (pouvoir masquant) des peintures de même type et de même couleur,** com a qual se apresenta de acordo.

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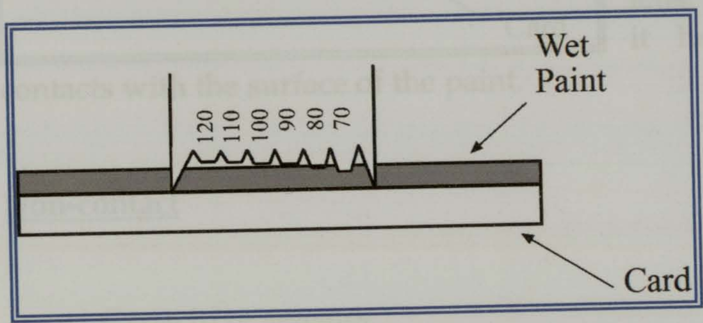
20.2. Appendix B – Additional information on sensors

Sensors

With contact:

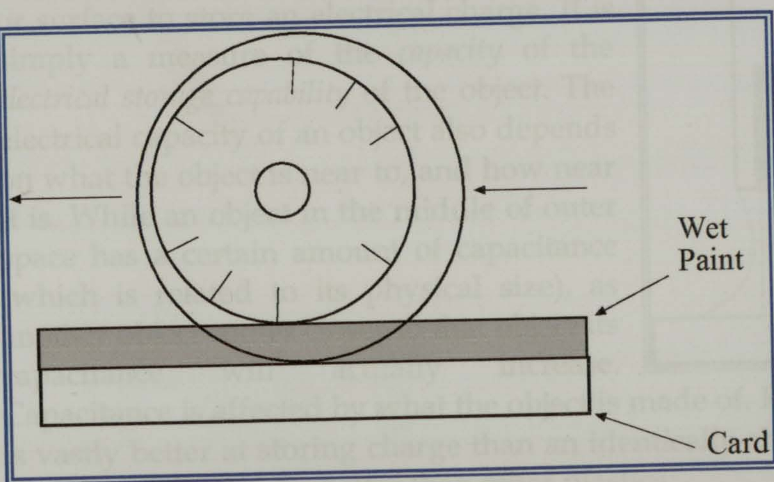
The methods used nowadays for determining the thickness of wet paint films involves contact with the paint itself, causing damages to the surface. These sensors are according to the standards, namely by the BS 3900 C5.

Wet Film Comb



This sort of measurers has a very simple functioning principle: one places it on the card with the wet paint film and sees where the paint reaches. The wet film comb has the advantage that it's very simple to use. Additionally to the fact that it damages the surface of the paint this method has the disadvantage that only determines specific thicknesses; it doesn't provide continuous values of reading.

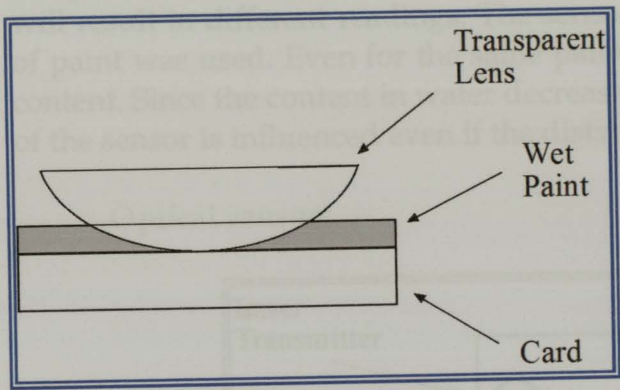
Wet Film Wheel



The wet film wheel represents an improvement in relation to the wet film comb. The thickness is determined by sliding the wheel on the card with the wet film paint. A scale of thicknesses is on the interior wheel, and the first value that is wet by the paint is the thickness of the film.

This system provides a continuous scale of thicknesses and is easy to use, but has the disadvantage that it damages the surface of the film.

Wet Film Gauge

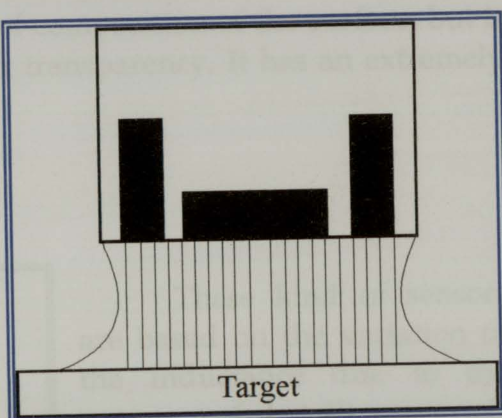


The method is based on geometric relations. Basically, a transparent lens is placed on top of the card. The diameter of the circle formed by the paint is related to the thickness of the film, which can be determined simple by reading the value on the scale presented on the lens. It is a method easy to use, but it has the disadvantage that it contacts with the surface of the paint.

Non-contact

Capacitive sensors

These sensors are capable of detecting any kind of solids or liquids, independently of its material. As the name indicates, the functioning is based on the changing of the induced capacitance of the surfaces that go close to the sensor (see Figure xx).

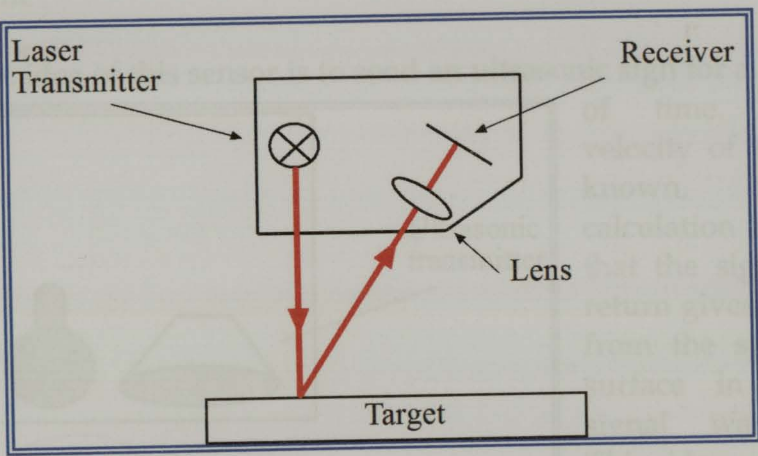


Capacitance is the ability of an object or surface to store an electrical charge. It is simply a measure of the *capacity* of the *electrical storage capability* of the object. The electrical capacity of an object also depends on what the object is near to, and how near it is. While an object in the middle of outer space has a certain amount of capacitance (which is related to its physical size), as another object comes closer to that object its capacitance will actually increase. Capacitance is affected by what the object is made of. For example, a metal object is vastly better at storing charge than an identically shaped one made of plastic. And some plastics are better than other plastics.

The typical resolution of this kind of sensors is about 1 μm, which is a good resolution considering that thicknesses.

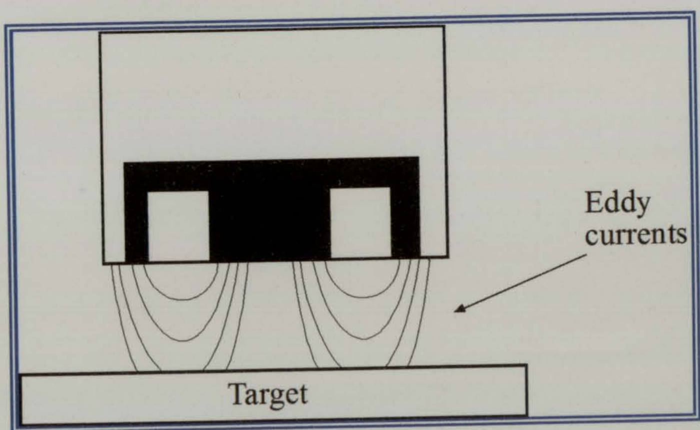
For this project in particular a capacitive sensor can't be employed. Its advantages are that it's capable of detecting any kind of material and has enough resolution, but its disadvantage is that the result depends on the composition of the paint, including the content in water. Same distances with different paints will result in different readings. The sensor could be calibrated if only one type of paint was used. Even for the same paint the result is dependent on the water content. Since the content in water decreases in time (the paint dries), the reading of the sensor is influenced even if the distance remains the same.

Optical sensors



The optical sensor determines distances by a triangulation method. Trigonometric relations enables the calculation of the sensor to the target's surface. This kind of sensors is independent of composition of the surface, but it can sometimes by influenced by its colour or transparency. It has an extremely high resolution (about 0.0001 mm)

Inductive Sensors



These kind of sensors are based on the variation of the inductance due to the presence of metallic materials and are amongst the most used in the industry.

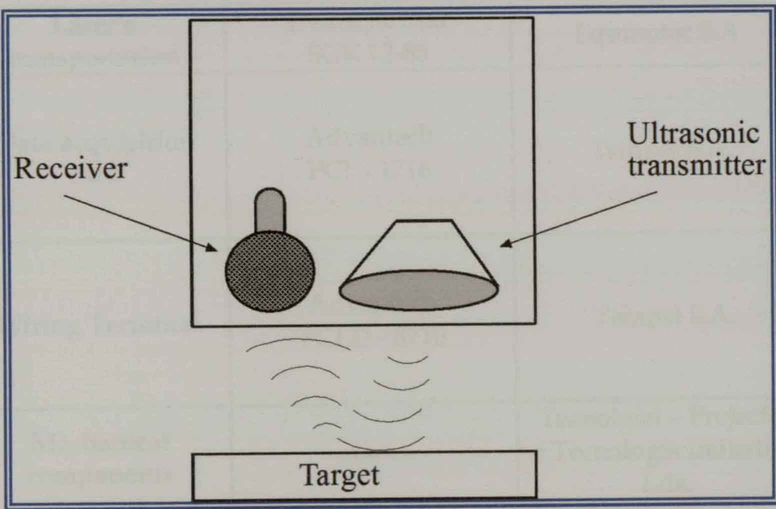
An inductive sensor consists of three main components: coil, oscillator and detection circuit. The oscillator creates a high frequency field that is emitted from the sensing face. When a metal target enters that field, eddy currents are induced in the metal target. Energy is required from the oscillator to maintain the eddy currents in the target. The resultant losses draw energy from the oscillating circuit and reduce the oscillations.

Typical resolution for this kind of sensors is better than 0.01 mm.

The inductive sensors are totally inappropriate for this application, since it only detects metallic materials and has a low resolution.

Ultrasonic

The basic idea of this sensor is to send an ultrasonic sign for a short period of time. Since the velocity of the signal is known, a simple calculation with the time that the signal takes to return gives the distance from the sensor to the surface in which the signal was reflected. This idea came up by observing the bats, which use a similar system for orientation.



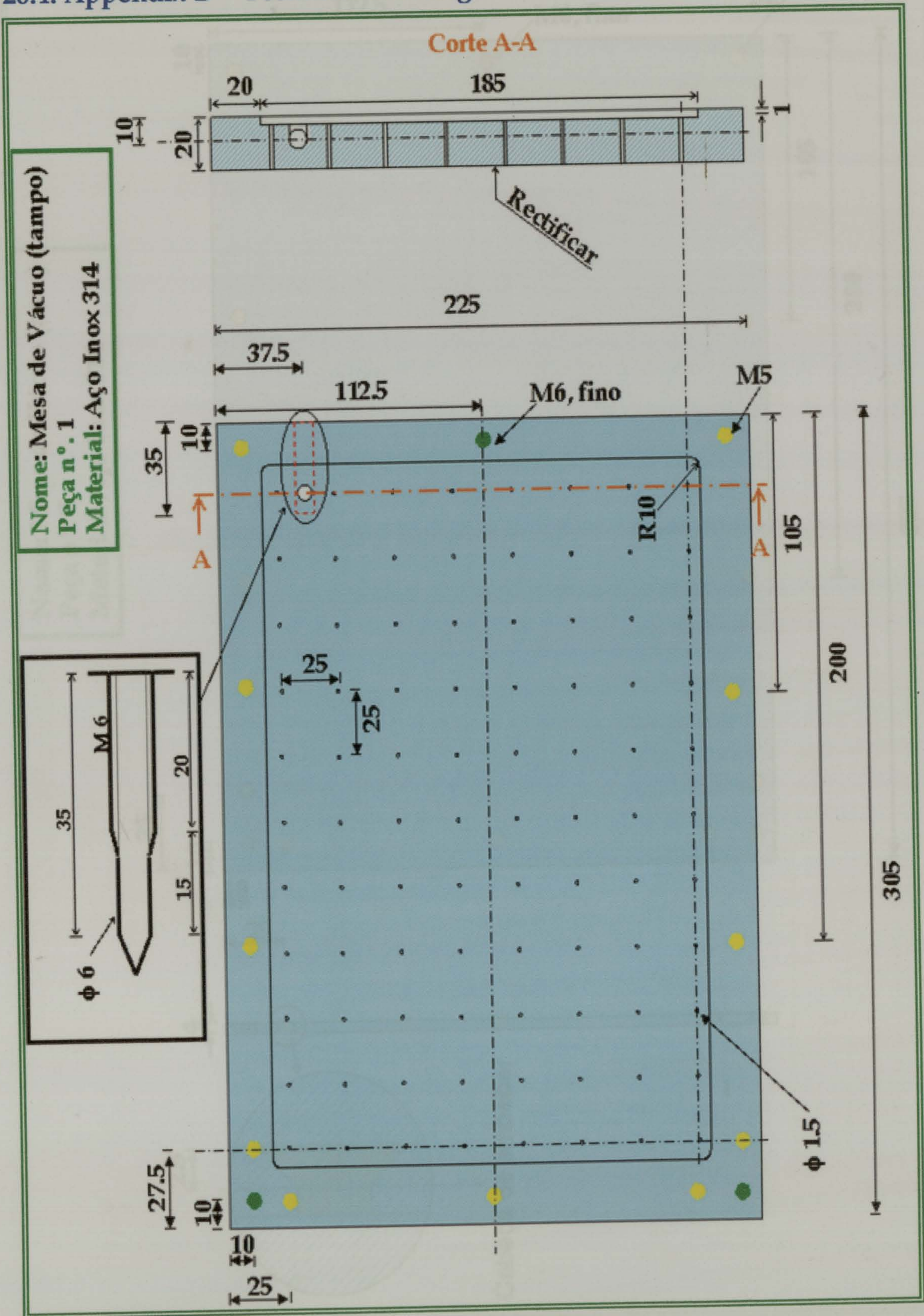
This sort of sensors have a resolution of about 0.1 mm.

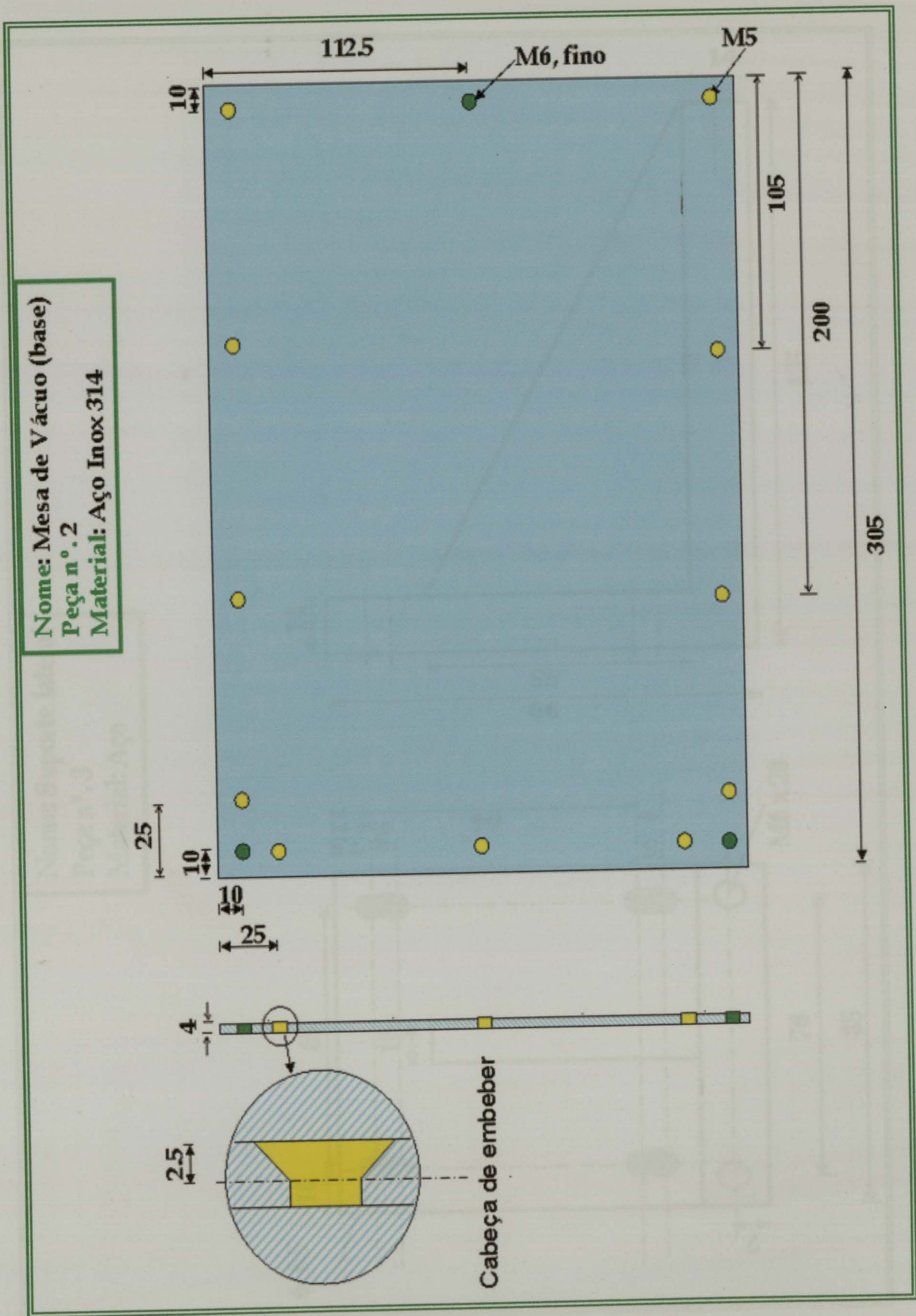
Although this kind of sensors has the advantage that can work with any sort of materials, it has the disadvantage of very low resolution, which makes the ultrasonic sensor inadequate for this application.

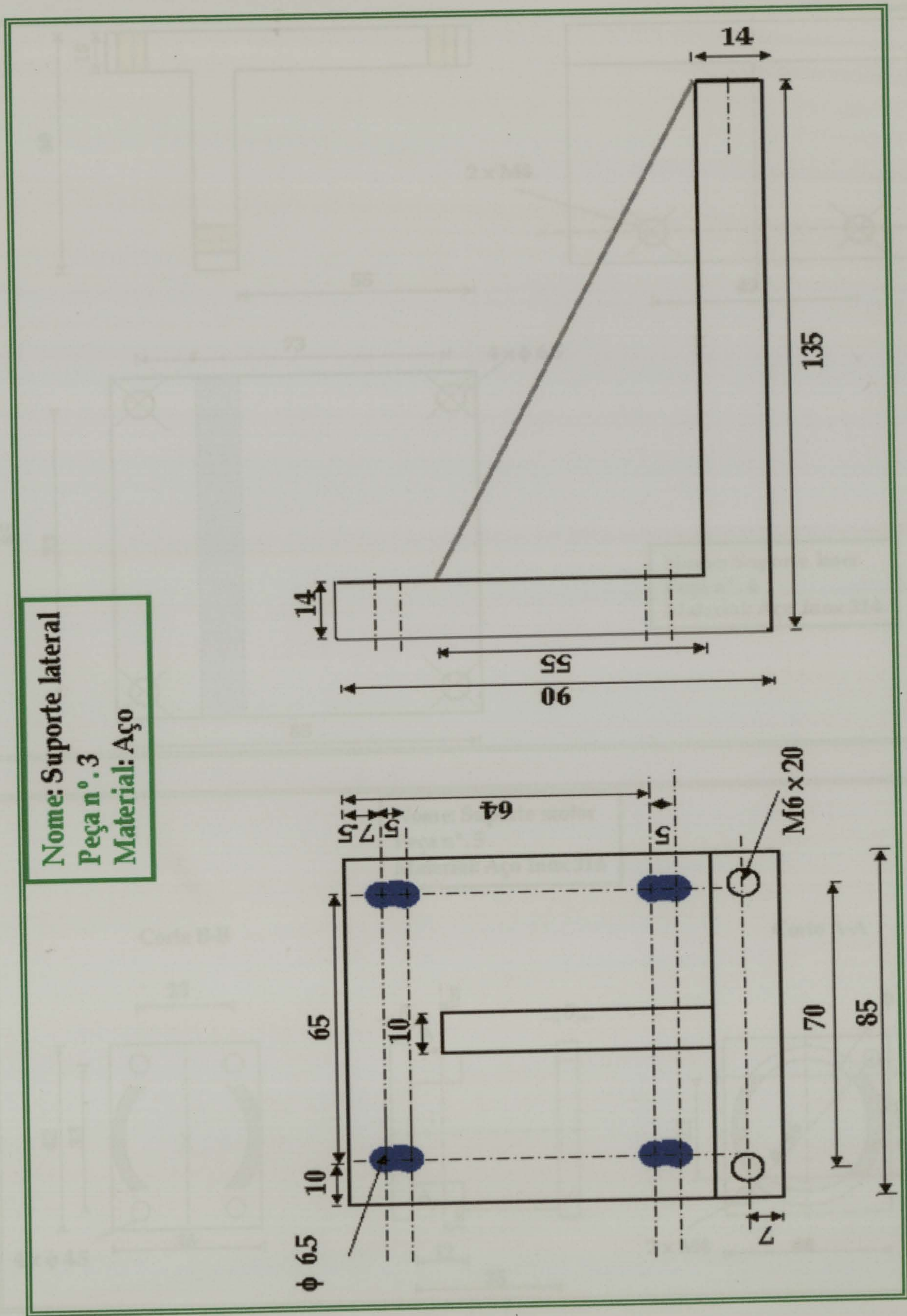
20.3. Appendix C - Components suppliers

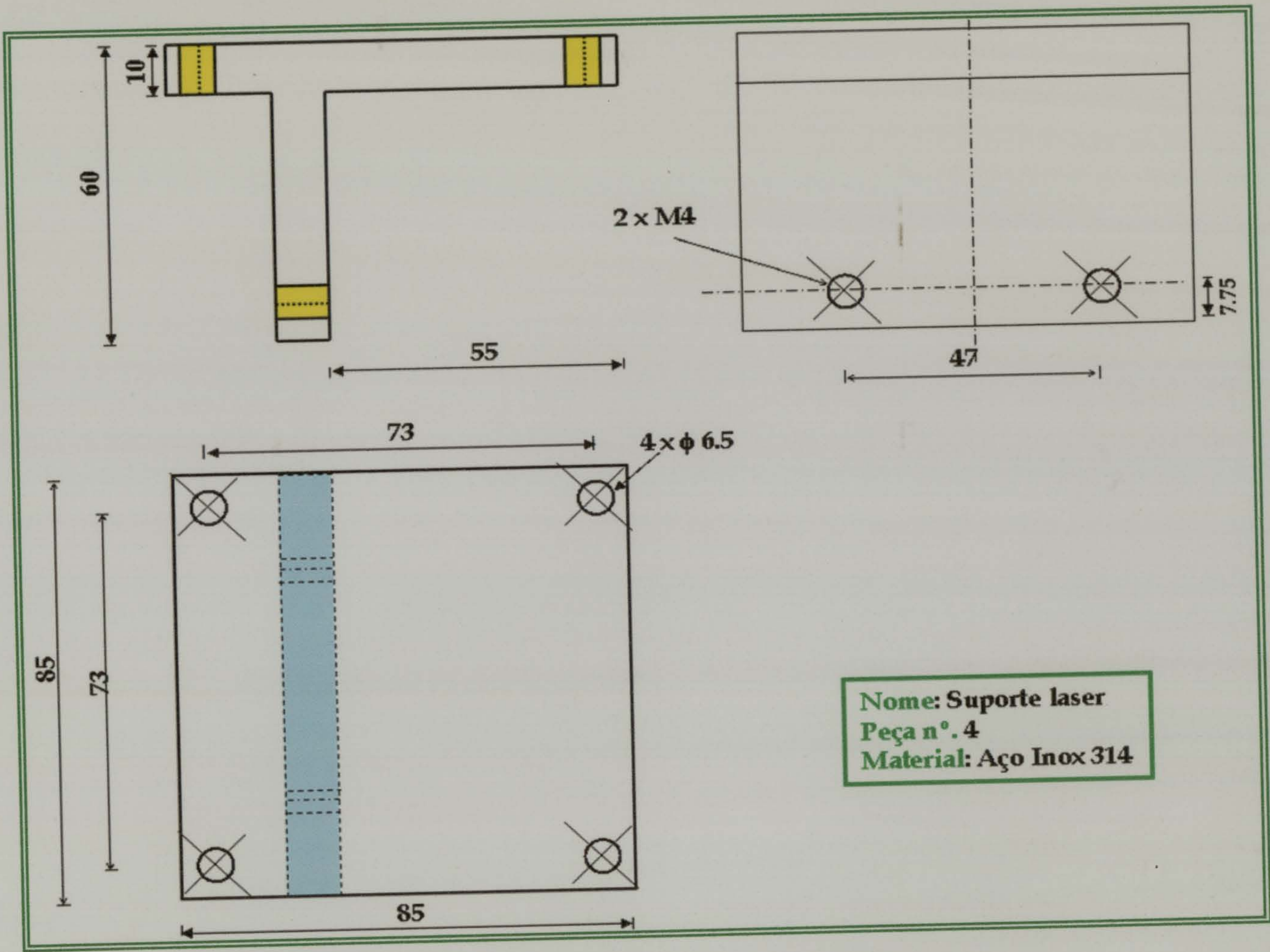
Component	Specification	Supplier	Contact
Laser	OMRON Z4M-N30V	OMRON Electronics Lda.	Edifício OMRON R. São Tomé, 131 2689-510 Prior Velho Tel. 219 429 400
Motor	OMRON Smartstep R7M-A05030-S1	OMRON Electronics Lda.	Edifício OMRON R. São Tomé, 131 2689-510 Prior Velho Tel. 219 429 400
Motor's Driver	OMRON Smartstep R7D-AP01L	OMRON Electronics Lda.	Edifício OMRON R. São Tomé, 131 2689-510 Prior Velho Tel. 219 429 400
Laser's transportation	Deutsche Star SGK 12-85	Equinotec S.A.	Email: hainke@equinotec.com
Data acquisition card	Advantech PCI – 1716	Tempel S.A.	Tecmaia – Parque de ciência e tecnologia da Maia R. Eng. Frederico Ulrich, 2650 4470-605 Nogueira da Maia Tel. 229 408 295/97
Wiring Terminal	Advantech PCLD - 8710	Tempel S.A.	Tecmaia – Parque de ciência e tecnologia da Maia R. Eng. Frederico Ulrich, 2650 4470-605 Nogueira da Maia Tel. 229 408 295/97
Mechanical components	---------	Tecnolgial – Projectos e Tecnologia Industrial Lda.	R. da Telheira, 59 Ap. 5096, 4455-562 Perafita – Matosinhos Tel. 229 955 880
Power Supply	HSB 24-1.2	RS Amidata S.A.	Av. De Córdoba, 21 28026 Madrid Tel. 800 102 037
Electrical Material	---------	Casa das Lâmpadas Lda.	R. da Arroteia, 894 4465-586 Leça do Balio Tel. 229 059 000
Electrical Material	---------	Tupael	R. Formosa, 138-142 4000-246 Porto Tel. 222 008 047
Electrical Material	---------	Aquário - Comércio de Electrónica Lda.	R. da Alegria, 93-A, B, 95 4000-042 Porto Tel. 223 394 780
Electrical Material	---------	Aquário - Comércio de Electrónica Lda.	R. Dr. Júlio de Matos, 65, 79 4300-356 Porto Tel. 225 072 810
Electrical Material	---------	Rexel – Distribuição de material eléctrico S.A.	R. Delfim Ferreira, 679 4100-201 Porto Tel. 226 167 090

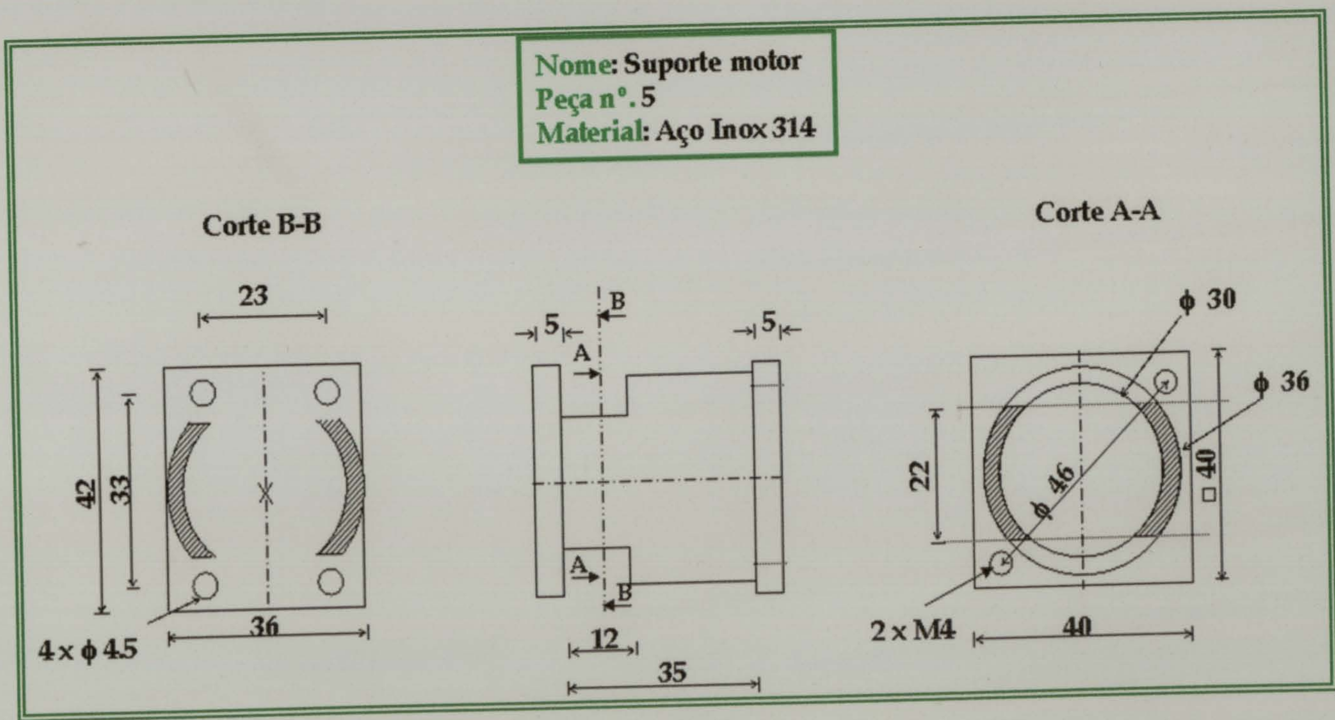
20.4. Appendix D – Technical drawings




Nome: Mesa de Vácuo (base)
Peça nº.2
Material: Aço Inox 314
112.5
M6, fino
M5
105
200
305
10
25
4
2.5
Cabeça de embeber


Nome: Suporte lateral
Peça n°.3
Material: Aço
14
135
14
55
90
64
5
7.5
5
5
65
10
10
70
85
7
ϕ 6.5
M6 x 20


10
60
55
2 x M4
7.75
47
73
4 x ϕ 6.5
85
73
85
Nome: Suporte laser
Peça n°. 4
Material: Aço Inox 314


Nome: Suporte motor
Peça n°. 5
Material: Aço Inox 314
Corte B-B
Corte A-A
23
42
33
36
4 x ϕ 4.5
5
5
B
A
A
B
12
35
ϕ 30
ϕ 36
ϕ 46
22
□ 40
2 x M4
40

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