Polishing process in naval industry: improvement of an existing electro-mechanical polishing machine

Treball Final de Grau

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Appretiations

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I would like to mention all the staff of Hispana de Maquinaria S.A. that have helped me and have given all the facilities during this process. Also, for the opportunity of taking part of the all the polishing projects that they have started more than 10 years ago.

Finally, for all the people who has been by my side every day, giving me energy to finish the project.

Resum

En aquest estudi pretenc estudiar tots aquells elements de llautó i bronze del món naval els quals requereixen d'excel·lents acabats superficials. Normalment, per aconseguir aquest acabat es requereix un procediment de polit, el qual es fa amb maquinaria especialitzada.

El projecte està dividit principalment en dues parts. En la primera enumeraré algunes de les solucions existents que s'utilitzen en les industries per l'acabat de les superfícies. Explicaré el procés, la màquina, els consumibles que s'utilitzen i donaré també algunes pautes pel desbastat i polit del llautó i bronze.

La segona part del projecte estarà enfocada en un dels processos en particular; el polit electro-mecànic. Descriuré la màquina, que actualment s'utilitza únicament en el món de la joieria. A més a més, enumeraré tots els seus punts dèbils; trencament d'alguna part degut a la fatiga, corrosió d'algunes parts degut al compost, esquitxades de compost degut el moviment del raspall, etc.

Finalment, donaré algunes propostes de millora en totes aquestes parts (a fi de millorar l'eficiència, el funcionament, el manteniment i la qualitat), per tal de que continuï sent una màquina competitiva en el mercat de les màquines de polit.

Abstract

This study aims to be an analysis of the different brass and bronze naval elements which require excellent surfaces. To get this finish, all those parts needs a polishing process made with a machine.

The project will be divided in two main parts. In the first one I will list some of the different existing processes used in industries for finishing pieces surfaces. I will explain the process, the machine, the consumables used and I will also give some parameters used for grinding and polishing brass and bronze.

The second part of the project will be focused in one particular process; electro-mechanical polishing. I will describe the machine, nowadays used only for jewellery, and all the failures existing; break of some parts of the machine due to fatigue, corrosion of some electrical parts due to the compound, splashes of compound due to the movement of the sliding brush, etc.

Afterwards, I will give some ideas in order to upgrade all these parts of the machine and improve it (the efficiency, operation, maintenance and quality), for continue being competitive in the market of polishing machines.

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Chapter 1. Introduction.

There are some industries where great quality finishing surfaces are demanded. This causes that during years new machines have been developed in order to have best results possible for grinding and polishing pieces. In the following text, I will talk about the different industrial polishing methods used for finishing pieces; starting from manual polishing, through rotatory machines with abrasive inside and electro-polishing, until new methods developed during this last decade for a Spanish company seated in Barcelona; Hispana de Maquinaria S.A.

For almost three years ago I started working with this company which developed an innovative system for grinding and polishing jewellery, called electro-mechanical polishing. Due to most jewellery pieces needs perfect surfaces, a new system with better performances is necessary for this industry.

EN-34, machine developed for electro-mechanical polishing, can process different alloys depending on the compound used. All the compounds are formed by liquid (oils and chemicals) and resins, which allows the pass of current.

Inside the working tank, where the compound is poured, there are an anode and a pair of cathodes. The anode (+) is connected to the rack where the pieces are hanged. The cathode (-) is a metallic plate where the metal is adhered during the process. Thanks to the pass of current between the anode and the cathode, starts the electro-polishing of the pieces hanged on the rack.

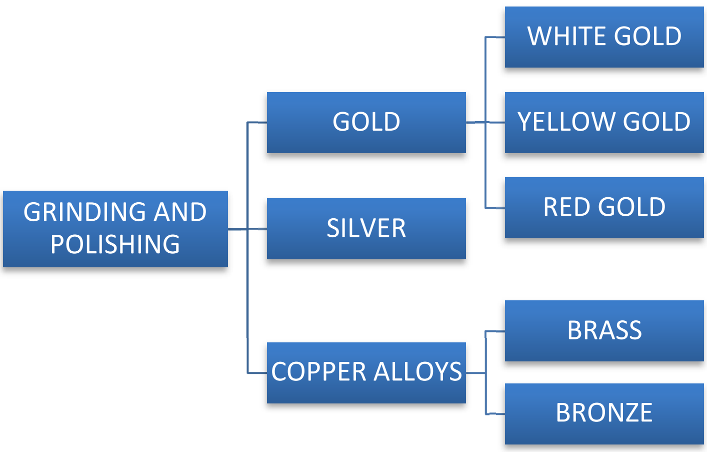
The metal adhered at the cathode can be recovered, for example, by burning the cathode. This is very important for the jewellery industry, where precious metals are used. Silver, but especially gold, are very expensive materials, so by recovering them the customer can recover money.

Inside the working tank there are also a pair of brushes, one of them moved by a motor. The purpose of these brushes is touching the surface of the pieces hanged in the rack with their hair, allowing the pass of current. They are also used to push the resins of the compound inside all the interior parts. Thanks to this continuous mechanical movement of the brushes it is possible to process the pieces.

This machine, which has to be placed on top of a table, has a total dimensions of 450 x 390 x 370 mm. Its weight is approximately of 32 Kg, and with the compound reaches 40 Kg. The consumption of the machine is 400W.

Figure 1. EN-34 machine. *Source: Own*

In the following lines I will describe the main metal alloys that can be grinded and polished with the EN-34 machine. The compound is made specifically for each metal, so good results are achieved in more pure alloys, in those ones which there is less content of other metals.



Graphic 1. Metals polished with the EN-34. *Source: Own*

a) Gold

It is the most popular metal used in jewellery. The electro-mechanical polishing machine EN-34, can polish all kind of gold alloys with the same compound (only by changing the parameter). It is possible to classify this metal depending on:

- Karats

Gold is a soft chemical element when it is pure (24K), so it is usually alloyed with other metals, typically used for jewellery. Those additions increase its hardness, ductility, melting point and colour, as well as many other properties.

The addition of those other metals reduces the gold percentage, which means that the gold has less karats. Most typical combinations are 24K, 22K, 18K, 14K or 10K.

- Colour

As told before, with the addition of other metals it is possible to change the properties of the gold. One of the properties is the colour, so depending on the metal alloyed with the gold, it is possible to classify it by colours:

- Yellow gold

  It is an alloy of gold, and usually similar percentages of copper and silver (10-15% of each one). Due to the high content of gold, the yellow colour is maintained.

- White gold

  It is an alloy of gold and nickel, manganese or palladium. Those three metals give the white colour to the alloy.

- Red gold

  It is an alloy of gold and high content of copper. Thanks to the high content of copper, the alloy gets reddish.

In the following table I will describe the main properties of 24K gold:

GOLD	Density (g/cm3)	Melting point (ºC)	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)	Thermal conductivity (W/m·ºK)	Electrical conductivity (S/m)	Hardness (Rockwell B)
	19.32	1064.43	120	205	30	318	$4.1 \cdot 10^{7}$	25

Table 1. Gold properties. *Source: www.matweb.com*

b) Silver

Silver is also one of the most popular metals in jewellery. Fine silver (or also called pure silver, which is 99,9% silver) is very soft. To increase the hardness and strength is necessary to add some other metals. The most popular silver is Sterling silver, which has 92,5% of silver and the rest 7,5% by weight is composed by other alloys (usually copper).

Even though there are other silver compositions, with the EN-34 machine it is only possible to get good polishing results with Sterling silver.

In the following table I will describe the main properties of silver:

SILVER	Density (g/cm3)	Melting point (ºC)	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)	Thermal conductivity (W/m·ºK)	Electrical conductivity (S/m)	Hardness (Rockwell B)
	10.491	961.93	140	54	25	419	$6.3 \cdot 10^7$	30

Table 2. Silver properties. *Source: www.matweb.com*

c) Copper alloys

In jewellery, and mainly in costume jewellery, are used cheaper metals based in copper. After all the proceeding, a plating is made in the piece surface (normally with gold). Those alloys are:

- Brass. Obtained basically by mixing copper and zinc.
- Bronze. Obtained basically by mixing copper and tin.

Both metals can be polished with the EN-34, obtaining good results in surface finishing and shinning of the piece.

Of all those metals described before, brass and bronze are not only used for jewellery, they are also used in naval industry. Propellers and decorative parts of the ship are made of these alloys, as good as plumbing accessories. Those metals are recommended due to their good strength properties and high corrosion resistance, in comparison with other metals with approximately the same price.

In conclusion, it is possible to process those metal pieces for naval purposes with the EN-34, moving away from the traditional machines.

This machine has entered in the market before being tested carefully. This not enough checking of the machine, causes a lot of problems in customers factory. This factor added to the sharp competition with other companies of the sector, which have copied the electro-mechanical polishing process, force us to improve the machine in order to get the best machine of the market.

As I am working in the technical department, I am directly in touch with the customers so I know which are the main problems that they face during production. Knowing these problems of the EN-34, the main goal of this project is do all the possible changes in order to get a more efficient and without so many fails.

All those changes have to be done under the following premises:

- Improve the performance of the machine after hours of working.
- Do not change some working parameters stablished in order to not change the quality of the surface.
- Maintain the producing cost of the EN-34, in order to do not increase the sale price.
- In order to improve the maintenance of the machine, it is important to make an easier removal of the working tank.

Chapter 2. Brass and bronze.

2.1 Brass

Brass is the most used copper alloy and it is obtained basically by mixing copper and zinc. Depending on the proportions of each material and the mixing temperature, the final metal has different properties.

The mechanical and physical chemistry properties of the brass will change depending on the metals range used, and also on the metals added to the alloy.

Figure 2. Brass profiles. *Source: www.copper.org*

2.1.1 Brief history of brass

After the "Copper Age" comes the "Bronze Age", followed later by the "Iron Age". The reason is very simple; there was not "Brass age" because of the difficulty of getting zinc before the 18th century.

Despite this fact, people get brass from using ground smithsonite ore (calamine, $ZnCO_3$) and mixing it in high temperatures with copper. We know that this metal was used:

- Roman people used a brass called "Aurichalum" in order to have sesterces coins and golden coloured helmets. The contain of zinc was about 11 – 28% and it is only added for decorative and ornamental purposes. For ornament pieces, which needs a more ductile metal, they usually use 18% of zinc.
- In Medieval ages, brass was mainly used in churches and monuments. The content of zinc was between 23-29%, and they give small additions of lead and tin to the alloy.

With the Industrial Revolution the brass became more important, so an easiest way to get the zinc was needed. In 1738, William Champion take out the patent of zinc production by distillation from calamine and charcoal.

Thanks to the invention of Muntz 60/40 brass, was possible to reduce the prices of hot workable brass plates. For example, this allows the use of brass instead of copper for the sheathing of wooden ships (preventing biofouling and worm attack).

In 1894, Alexander Dick revolutionize the production of good quality and low-cost rods, by inventing a new extrusion press. Subsequent developments in the production have improved the final product, as good as reduced the price of brass.

2.1.2 Brass description

Brass is a very common material for equipment's in all industries. Due to the combination of its properties, it is a very valuable material for wide uses. For example:

- Its machinability is better than in many other materials.
- It can be easily casted to get de desired shape. It is also good to fabricate pieces by extrusion, rolling, hot stamping and cold forming.
- It can usually be used without any protection layer.
- Brass is usually chosen for producing low cost machined products.

Brass is mainly done by mixing cooper and zinc. The percentage of zinc and the temperature can change the atomic crystal structure, so it is possible to divide it in different categories depending on their crystal structure. Basically, three types of brass structures can be differentiated depending on the content ratio of materials and the temperature of mixing.

a) Alpha brasses (>65% of Copper)

   They crystalize in the cubic system centered on the faces. Those type of metals are also called cold working brasses due to they are the only kind of brasses malleable and worked at cold.

   Basically, their main characteristics are their high ductility at room temperature, so they can be deformed by rolling, drawing, shearing, bending of the plate, stretching the metal, spinning and thread rolling.

b) Beta brasses (50-55% of Copper)

   This metal crystallizes at the cubic system centered in the body (BCC). Above the critical temperatures (approximately 500ºC) the zinc atoms start moving randomly. When the temperature decrease, each atom moves to their preferential position. In conclusion, in phase beta and under the critical temperature, the zinc atoms stay in its preferential position, causing very large organized grids.

c) Alpha – beta brasses (55-65% of Copper).

   It is a combination of both brasses above. That type of metal does not allow the deformation at room temperature due to the content of beta phase, in other words this brass works better with higher temperatures. This allows to the brass to be extruded into bars or tubes, and hot forged in matrices.

By decreasing the Beta phase and increasing Alpha (by being more an alpha structure), it is possible to obtain very good properties in machinability and easy to deform in lower temperatures.

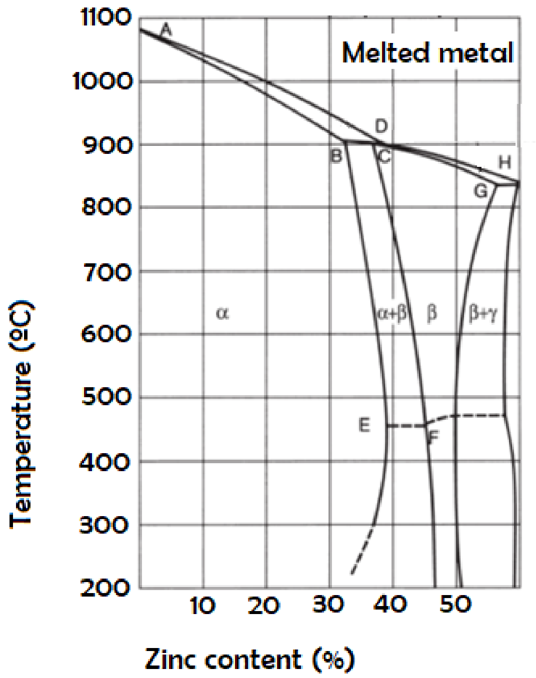


Figure 3. Crystal structure of brass depending on Temperature (ºC) – Zinc content (%). *Source: www.cimsaww.com*

As told before, the addition of different metals to the alloy can also change the properties. The following alloys are the most common used:

Alloy name	Proportion by weight (%)				Other metals	Characteristics
	Copper	Zinc	Tin	Lead		
Abyssinan gold	90	10	-	-	-	
Admiralty brass	69	30	1	-	-	Tin doesn't allow the loss of zinc in many environments.
Aich's alloy	60.60	36.58	1.08	-	1.74% Iron	Used in marine service due its hardness and toughness, also as for its good performance against corrosion.
Aluminium brass	77.5	20.5	-	-	2% Aluminum	Aluminium improves corrosion resistance.
Cartridge brass	70	30	-	< 0,07	-	Good cold working properties.

Common brass or Rivet brass	63	37	-	-	-	Standard for cold working and it is also very cheap.
Delta metal	55	41-43	-	-	1-3% Iron	The addition of iron makes a harder material.
Free machining brass	61.5	35.15	-	3	0.35 Iron	Good machinability.
Gilding metal	95	5	-	-	-	Softest brass available.
High brass	65	35	-	-	-	High tensile strength.
Low brass	80	20	-	-	-	Very ductile..
Manganese brass	70	28.7	-	-	1.3% Manganese	
Muntz metal	60	40	-	-	Traces of Iron	
Naval brass	59	40	1	-	-	Similar to admiralty brass.
Nickel brass	70	24.5	-	-	5.5% Nickel	
Nordic gold	89	5	1	-	5% Aluminium	
Prince's metal	75	25	-	-	-	
Red brass	85	5	5	5	-	
Silicon tombac	80	16	-	-	4% Silicon	
Tombac	95-80	5-20	-	-	-	Cheap and hand malleable alloy
Yellow brass	67	33	-	-	-	

Table 3. Main brass alloys. *Source: www.thoughtco.com*

In conclusion, as it is possible to see in the table before, there are many kinds of brasses depending on the alloy added. Each alloy will change some main properties of the brass.

- Colour

  Depending on the zinc addition, the colour of the brass can change from red to yellow. Thanks to this property, brasses are used for decorative applications.

- Ductility

  If copper content is higher than 63%, the brass is very malleable at room temperature. When copper content is lower than 63%, and there are no other kind of metals alloyed, the ductility decreases, so these metals have to been worked with heat.

- Machining

  All brasses have good machining properties, but the addition of lead improves this property (makes softer brasses).

- Corrosion resistance

  Brasses has good properties against corrosion, but for marine environments is recommended to add some tin to the alloy.

- Dezincification resistance

  Brasses with more than 15% of zinc need little additions of arsenic to improve the dezincification.

- Wear resistance

  Normally, adding silicon or tin to the alloy improves the wear resistance of the brass.

In the next table it is possible to see the differences in properties between most used brasses in industry.

Brass alloy	Density (g/cm3)	Melting point (ºC)	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)	Thermal conductivity (W/m·ºK)	Electrical conductivity (S/m)	Hardness (Rockwell B)
Red Brass	8.75	988	393	338	12	159.2	$2.2 \cdot 10^7$	56
Cartridge brass	8.53	916	427	359	25	121.2	$1.6 \cdot 10^7$	54
Muntz Metal	8.39	899	483	345	10	122.9	$1.6 \cdot 10^7$	85
Naval Brass	8.41	888	483	400	17	116.0	$1.5 \cdot 10^7$	25

Table 4. Main properties of most used brasses. *Source: www.copper.org*

Brass is usually used in naval industry due to its great mechanical properties, and also due to the high corrosion resistance. It is mainly used for propeller shafts, marine hardware, decorative fittings and turn buckles. In conclusion, most used brasses for naval industry are:

- Aich's alloy
- Admiralty brass
- Naval brass

Figure 4. Pieces made with naval brass. *Source: www.henssgenhardware.com*

In chapter 2.4 I will give more information about the use of brass in naval industry, giving some examples of pieces made of this metal.

2.2 Bronze

Common bronze is an alloy obtained basically from mixing copper and tin, and depending on the proportions of each material, the final metal has different properties. Tin is usually alloyed in proportions from 0.5% to 11% of the total weight, depending on the properties desired of the final metal.

It is also possible to add some other metals for upgrading the alloy. For example, phosphor, aluminium, manganese and silicon are usually added to bronze in order to increase its properties.

Figure 5. Bronze profiles. *Source: www.bronmetal.com*

2.2.1 Brief history of bronze

The first apparition of copper alloyed with tin is in Pločnik, Serbia. There is an ace head which is dated approximately in 4500 BC, before the "Bronze Age". This new material allows to replace the stone, getting more possibilities in terms of shapes (thanks to the casting). The apparition of this metal improves the manufacture of weapons and tools.

The use of bronze mainly starts with the "Bronze Age". It is difficult to date it because depending the region started in different centuries. It is possible to divide the "Bronze Age" in the following periods:

- Around 3000 BC, brass is commonly used to manufacture weapons, ornaments and fitting for chariots. One of the firsts dated brass objects dated, is a knife found in China, which has been casted in a mould. Most of the bronzes are alloyed also with arsenic, which led to poisoning. Due to this, bronze was used during several years (although tin was more difficult to obtain).
- By 2500 BC, tin is the most favourite metal alloyed with bronze. Casting techniques have been improved, so it is possible to create human sized statues.
- During 2000 BC, the use of bronze started being more common in Egypt and China. Firsts years, these two civilizations used sand for bronze casting, basically to create objects like bells. Eventually, they improve the technique and start using moulds made from clay and stone.

Figure 6. First weapons made of bronze. *Source: www.monaghan.ie*

After this age, in 800 BC, the bronze was very used in ship constructions due to its properties against oxidation in comparison with iron alloys. Bronze creates a superficial oxidation layer of copper oxide, which forms a protective barrier.

Despite the gunpowder was discovered in China around 800AD (used to create the first firearms), this technology arrives at Europe in the 13th century. Brass was mainly used due to the small metal friction for firing iron cannon bullets.

Nowadays, bronze has a lot of applications in our life. For example:

- Aluminium bronze is quite hard and is usually used for springs, bearings and car gearbox bearings.
- As bronze does not make sparks when it hits against other surfaces, is an ideal material for hammers, mallets or any other tool used in flammable environment.
- Phosphor bronze is usually used for ships propellers thanks to the good properties of this material against rusting.
- Most of the musical instruments are made of bronze. Most cymbals and bells are made of this material.

2.2.2 Bronze description

As told before, common bronze is composed basically from copper and tin (from 0.5 to 11%). Depending on the proportions of each material, the final metal has different properties. It is possible to divide bronze in different categories, depending on the addition of other metals to the main alloy.

Figure 7. Naval propeller made of brass. *Source: www.heliceskelly.com*

The following alloys are the most common used:

Alloy name	Proportion by weight (%)		Other metals	Characteristics
	Copper	Tin		
Phosphor bronze	89 – 99	0.5 - 11	0.01 – 0.35% phosphor	High strength and durability. High fatigue resistance and low friction coefficient. Good properties against corrosion.
Aluminium bronze	89 - 95	-	5 – 11 % aluminium Other alloys in small quantities	Higher tensile strength and resistance than other bronze alloys. Good performance against wear and heavy loads. The apparition of the alumina prevents the metal of being corroded. This makes the material resistant to sea water, also preventing the accumulation of sea life and marine organisms.
Manganese bronze	66 - 75	1	2.5 – 5 % manganese 22 – 28 % zinc	Ideal for high loads due to its high strength properties and hardness.
Silicon bronze	95 – 97.5	-	2.5 – 5 % silicon Zinc, manganese or tin in small quantities	Hard material with high strength in different temperatures. Good properties against corrosion.

Table 5. Main bronze alloys. *Source: www.zoresrecycling.com*

In the next table it is possible to see the differences in properties between most used brasses in industry.

Bronze alloy	Density (g/cm3)	Melting point (ºC)	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)	Thermal conductivity (W/m·ºK)	Electrical conductivity (S/m)	Hardness (Rockwell B)
Aluminium bronze	7.45	1040	586	221	12	58.6	$0.7 \cdot 10^7$	92
Silicon bronze	8.53	971	676	363	8	36.3	$0.41 \cdot 10^7$	40
Phosphor bronze	8.86	954	517	448	25	69.2	$0.9 \cdot 10^7$	26

Table 6. Main properties of most used bronzes. *Source: www.matweb.com*

Bronze is usually used in naval industry due to its great mechanical properties and also due to the high corrosion resistance. It is mainly used for propeller shafts, marine hardware, decorative fittings and turn buckles. In conclusion, most used brasses for naval industry are:

- Phosphor bronze
- Aluminium bronze
- Silicon bronze

In chapter 2.4 I will give more information about the use of bronze in naval industry, giving some examples of pieces made of this metal.

2.3 Main differences between using brass and bronze

The main metal from booth alloys, as explained before, is copper, but depending on the other metals added, the properties of the material would change. In conclusion, depending on the use, different brasses or bonzes can be chosen. In the following table are resumed the main differences between booth metals.

	Brass	**Bronze**
History	Due to the difficulty of getting zinc, the production has been delayed until 18th century.	Use of bronze dates approximately about 3000BC.
Composition	Mainly copper and zinc, but other metals can be added to the alloy.	The alloy consists primarily of copper and tin as the main additive. To this base, sometimes other elements can be added.
Main properties	1. Higher malleability than zinc or copper. 2. Low melting point (900ºC). 3.The combinations of iron, aluminium, silicon and manganese improves the anti-corrosive properties of the alloy. 4. Not hard as steel.	1. Hard but brittle material. 2. Low melting point (950ºC). It depends basically on the tin percentage of the alloy. 3. Resists especially seawater corrosion. 4. Better conductor of electricity and heat than most of steels.
Colour	Most of the alloys have different shades of yellow.	Reddish brown.
Uses	1. Decorative 2. Low-friction applications 3. Musical instruments 4. Anti-spark tools for flammable environments 5. Fittings for boats and ships	1. Fittings for boats and ships 2. Boats and ships propellers 3. Sea-water submerged bearings 4. For casted sculptures 5. Electrical connectors 6. Bells and cymbals

Table 7. Main differences between using brass and bronze. *Source: Own*

2.4 Uses of brass and bronze in naval industry

Brass and bronze are usually used in marine environments mainly due to the great performance of these metals against corrosion, as good as for their great mechanical performance. It is also used due to its golden colour and because it is very easy to get shine again after some time of use. Thanks to these properties, brass and bronze are very used for furniture and decorative objects. Some examples of this can be:

a) Hinges

Hinges are usually fitted in doors and all other kind of furniture that have to be opened. In most cases, that hinges are made of phosphorus bronze due to their good low friction coefficient, ideal for reducing the material wear. This material is also used do to its rusting resistance against marine environment.

Figure 8. Bronze hinge. *Source: www.morehandles.co.uk*

b) Locks and levers for doors

As in the previous case, it is necessary to avoid the wearing of the piece do to its use. Due to this main premise, added to the corrosion resistance, it is possible to use phosphorus bronze.

Figure 9. Bronze lock. *Source: www.force4.co.uk*

c) Door handle

Door handles are only used for decorative purposes, so it is only necessary resistance against sea environment. Brass and bronze are good for this purpose, so depending on the colour desired (yellow or reddish), one or the other will be chosen.

Figure 10. Brass handle. *Source: www.premierdoorhandles.co.uk*

d) Wall lamps

As in door handles, it is only used for decorative purposes. It is very important that the material has good resistance against sea water in case it is placed at outdoor (it is permanently in contact with water). Any kind of brass or bronze can be used for this purpose, depending on the colour desired (yellow or reddish).

Figure 11. Bronze wall lamp. *Source: www.lightiningandceilingfans.com*

e) Metal parts of clocks (or any other decorative furniture)

As in wall lamps, those objects are only used for decorative purposes; in conclusion, it only necessary that the material used resists the marine environment, avoiding rusting. Any kind of brass or bronze can be used, choosing one or another only depending on the colour desired (yellow or reddish).

Figure 12. Bronze antique clock. *Source: www.johnlewis.scene7.com*

Due to the good performance against marine environment, and good strength properties, those metals are also used for plumbing accessories in nautical industry. Some examples are:

a) Through-hull

For all the pieces in contact with seawater it is necessary a good performance against corrosion. In conclusion, for the through-hull the most used material is the phosphor bronze.

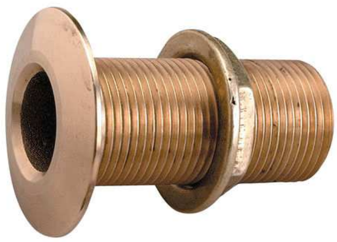


Figure 13. Bronze through-hull. *Source: www.nauticexpo.es*

b) Valves

All the valves installed in a ship will be in contact with the seawater that goes through them. For this reason, it is very important that the valve material has a good performance against corrosion. Most used material for valves is phosphor bronze.

Figure 14. Bronze valve. *Source: www.nauticaglobal.es*

c) Trunk connection

For all the pieces in contact with seawater it is necessary a good performance against corrosion. In conclusion, for the trunk connection the most used materials are phosphor bronze and naval brass.

Figure 15. Bronze trunk connection. *Source: www.barcos.online*

Those are not the only uses in the maritime world of copper alloys; it is also used for the construction of ship propellers. For small, as good as for big propellers, the most used alloy for manufacturing the screw is the aluminium bronze.

Figure 16. Small bronze propeller. *Source: www.sodel.com*

As commented before (see chapter 2.2.2), this alloy is composed by 5-11% of aluminium and 89-95% of copper. Normally some nickel can be added to the alloy in order to ensure better properties of the material.

The main reasons of using aluminium bronze use for propellers are:

- It is very resistance to the sea water corrosion.
- It is also useful for reducing the accumulation of marine organisms
- The phenomenon of cavitation is reduced thanks to this alloy. In conclusion, even after several time of using the propeller, the surface keeps very smooth. This allows us having always a great performance, increasing the fuel efficiency.
- As there is aluminium in the alloy, the weight of the screw is reduced. This is important to reduce the bending in the propellers shaft.
- It has excellent resistance to bending, breaking and wearing.
- It needs less maintenance because of its good mechanical properties.

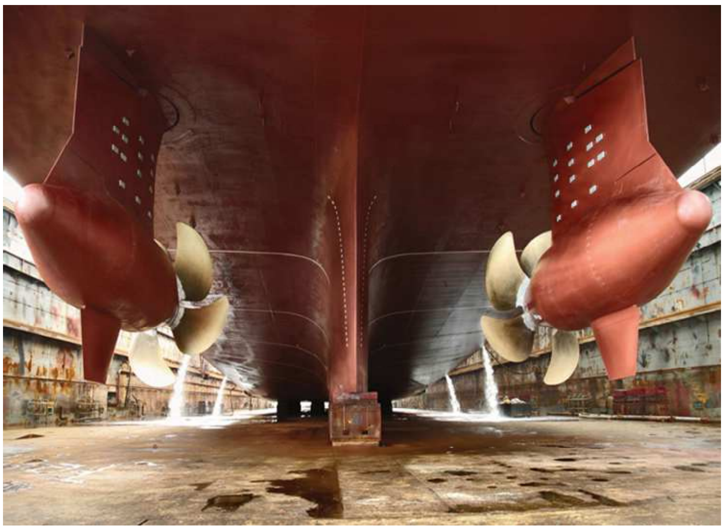


Figure 17. Bronze propellers. *Source: www.yachting-pages.com*

Chapter 3. Polishing methods.

3.1 Polishing

For most industries a good final surface of the pieces is needed. To obtain this quality after manufacture the piece, it is necessary another process: the polishing. Over the years the polishing systems have improved and evolved.

The objective of all polishing systems is to transform a rough surface into a smooth one. Depending on the initial surface condition, will be needed different procedures. Thinking about the surface magnified thousand times, it is possible to see mountains and valleys of material, so the purpose of the polishing procedure is to wear down all those mountains, leaving a flat surface. In conclusion, for our eyes, before doing any treatment the surface will dissipate the light, but after the polishing process, light will not be dissipated, will be reflected, allowing the piece to shine.

In the following Figure 18. Reflection differences in a polished / not polished surface. *Source: www.cdn.britannica.com* it is represented the difference between a polished surface, and a rough surface. As it is possible to see, the light will not have the same performance in both cases.

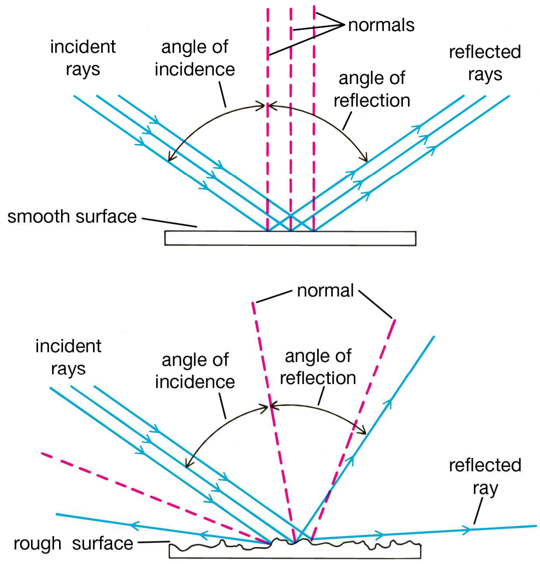


Figure 18. Reflection differences in a polished / not polished surface. *Source: www.cdn.britannica.com*

In most cases, to complete the whole polishing process and have this final surface, are needed different steps:

1. Rough down the surface

   It is the first step of the process and in those systems are used very abrasive materials. Thanks to it, we will able to remove biggest imperfections of the piece before starting the polishing process.

Rough down has also a negative part, it produces new scratches at the piece because of the abrasiveness of the material used.

This process is only necessary when there are very big imperfections (like welding strips, burs, etc.), and you want to remove them efficiently. In conclusion, it is not an obligatory step in all cases.

2. Grinding

It is used to smooth the surface and decrease the rugosity in the whole piece. In this step is necessary to attack the metal with less abrasive materials, in order to decrease the scratches that has appeared due to the manufacturing of the piece or during the first step above described.

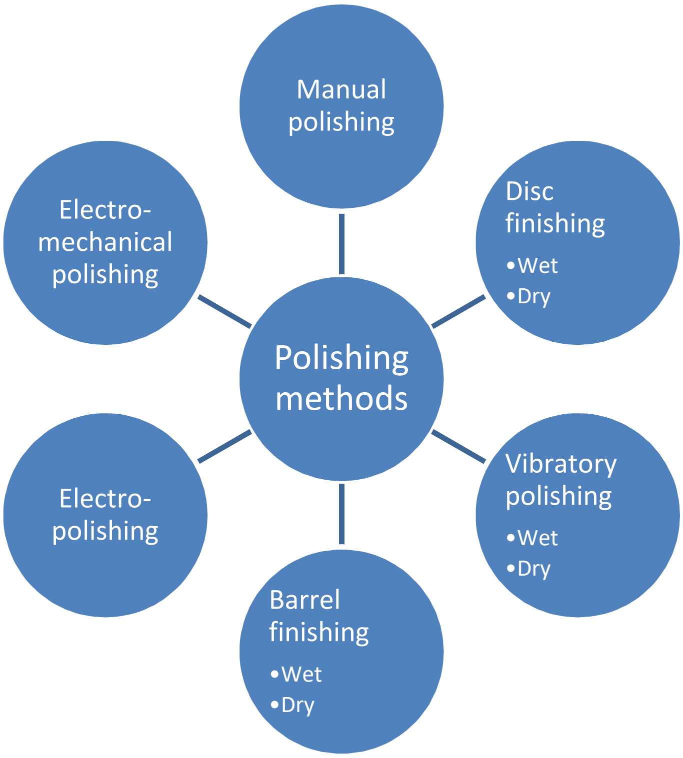
3. Polishing

It is the final step required. It is necessary the use of the lowest abrasive options. Depending on the polishing material, we can obtain different type of final surfaces:

- Mirror finish
- Matt finish
- Satin finish
- Gloss finish
- Etching finish

Normally in one process is not possible to cover all the steps described before. Each step can be complemented with another process on the same machine, or also with another system, to improve the final result.

I will focus the study on the following polishing methods showed in the next graphic.



Graphic 2. Main polishing solutions. *Source: Own*

Of all those systems listed before, I will describe:

- Theory of the polishing system
- Description of the machine
- Materials needed for polishing
- Recommendations for polishing brass and bronze
- Advantages and disadvantages of the method

Of all the processes described in Graphic 2, in Chapter 3 I will analyse manual polishing, disc finishing, vibratory polishing, barrel finishing and electro-polishing. Electro-mechanical polishing will be described in a separate chapter (chapter number 4) because it is the process used in the EN-34, the machine which has to be improved.

3.2 Manual polishing

3.2.1. Theory of the system

This is the simplest way for polishing but is also the most laborious of all. Basically, we have a motor connected to an abrasive wheel. Thanks to the velocity that the motor reaches and the abrasiveness of the material of the wheel, the operator can wear away manually the metal piece placing it in contact with the wheel.

In these machines the operator needs good knowledge about how to polish (pressure between the wheel and the piece, angle attack between the wheel and the piece, etc.) and all the steps needed to obtain a good final result. Obviously, depending on their skills they will have better results. The most important thing is the material of the wheel and the polishing compound used. This will affect directly to the final result obtained.

In conclusion, thanks to the rotation of the spindle motor connected to the wheel, and the movement of the piece in different directions by the operator, there is an erosion of the piece surface.

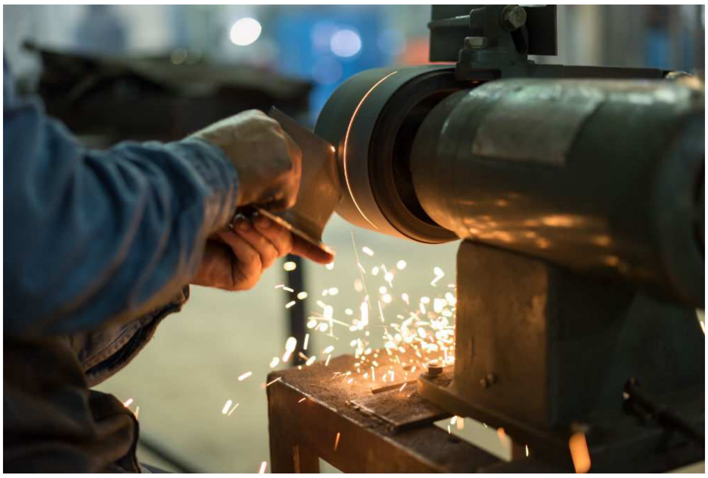


Figure 19. Use of a manual polishing motor. *Source: www.theprecisiontools.com*

3.2.2. Description of the machine

The machine is set up by an electrical motor, which normally has two outputs, two spindles, where is possible to fit the different wheels.

When the machine is switched on, the motor starts running so the wheel starts the rotation. The operator can starts polishing, first placing the piece in contact with the wheel and then moving it in different orientations to polish all the parts. We can differentiate three types of machines, depending where can be placed.

Bench grinder

It needs to be fitted in a bench with its own subjection system. It is used for smaller pieces because of its size and speed rotation (less than other kind of grinders).

Figure 20. Bench grinder. *Source: www.ffx.co.uk*

Pedestal grinder

This model is bigger than the other because has a body that allows to the machine to be fitted directly at the floor. It is possible to use it for bigger pieces.

Figure 21. Pedestal grinder. *Source: www.bigcommerce.com*

Grinder fitted in a cabin.

In this case the motor is fitted inside a cabin that can be put on top of a table. It is usually used for jewellery, and this design is thought to work while the operator is seated on a chair. Thanks to an extractor system, it is possible to recover all the metal removed from the pieces (very important for precious metals).

Figure 22. Grinder used mainly in jewellery. *Source: www.cdn.shopify.com*

In each machine we can basically differentiate the following parts:

1) Motor.

Gives the rotational movement to the polishing wheel. The power and the rotational velocity are the main characteristics of the machine.

2) Spindle.

It is a shaft where is possible to fit the polishing wheel. Normally these machines have two spindles, so we will be able to have two kinds of wheels at the same time fitted in the machine.

3) Switch.

Allows the machine to start running.

4) Eye protector.

It is a security part, which has to be covering the wheel while the machine is running, in order to avoid that some metal removal goes to the operator.

5) Hand support.

Depending on the machine, there is a support where the operator can rest the hand while he is doing the polishing process over the piece.

6) Abrasive wheel.

It is the part used to make the polishing. There are different types, depending on the final surface desired.

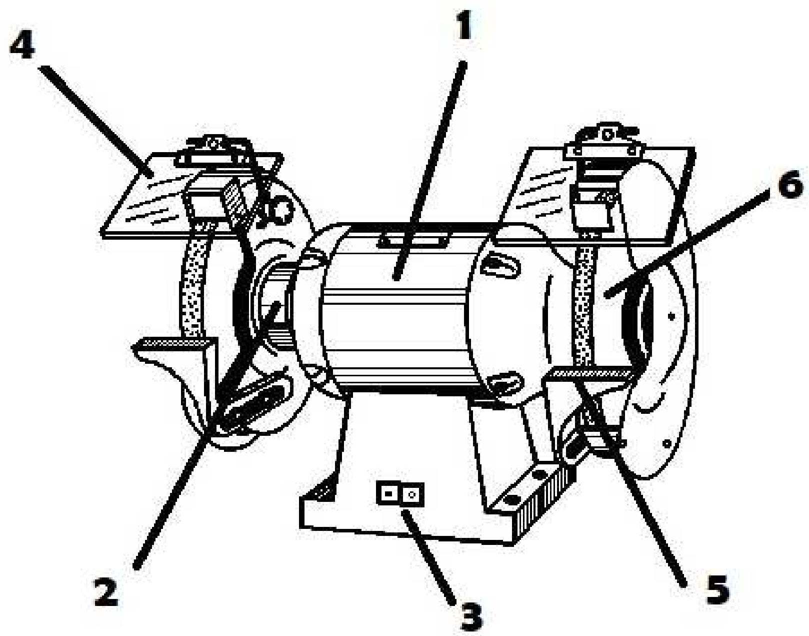


Figure 23. Differentiate parts of a bench grinder. *Source: www.metalartspress.com*

3.2.3. Materials used for polishing

For manual polishing it is necessary two kind of materials: abrasive wheels and polishing pastes.

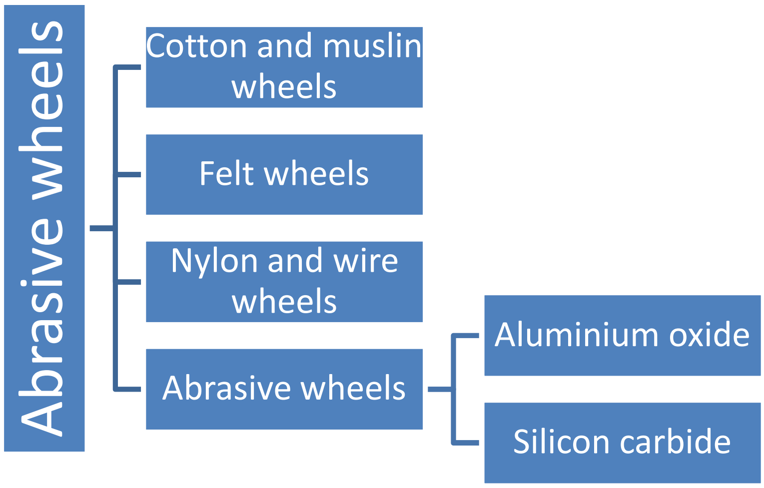
Abrasive wheels

They are placed in the spindle of the machine and they are used for removing the metal from the surface of the piece. Many different kinds of abrasive can be used, depending on the desired final surface.

The size of the wheel basically depends on the machine used (total diameter allowed to install in the machine) and the part needed to be polished (the piece will determine the width of the wheel).

Figure 24. Different examples of abrasive wheels. *Source: www.taberindustries.com*

Depending on the desired final surface, we normally use different wheel materials. In other words, all these abrasive wheels (described in the following lines) can be used for all kind of metals, but the result on the surface will be different (depending on the hardness of the material to polish, the results will be different).



Graphic 3. Abrasives wheels used for manual polishing. *Source: Own*

In the following lines I will describe the most common materials used for polishing wheels.

a) Cotton and muslin wheels

This soft material is generally used for the final part of polishing process. It is possible to classify those wheels in:

- *Combed*

It is a soft material wheel, very used for finishing the piece after all the rough process.

- *Uncombed.*

Thanks to their structure, those wheels have a harder surface than the typical combed ones. Thanks to this property, they can be great for rough finishing and for removing scratches.

- *Stitched*

It is usually used to give a final high polished surface. More row stitches will give more stiffness to the whole wheel, allowing to the operator applying more pressure against the piece.

- *Unstitched*

It is a very soft and flexible wheel, very common for final finishing. As it is a very soft material, is perfect for contoured edges and curves.

- *Treated*

This kind of wheels usually live longer and have a better compound retention (in comparison with the other types described). It comes in a wide type of varieties, from aggressive abrasion as good as for giving a final polished surface.

Figure 25. Different cotton polishing wheels. *Source: www.panadent.co.uk*

b) Felt wheels

These wheels are made of dense and tightly compressed wool felt. They are considered of medium hardness, so are suitable for all polishing purposes. Depending on their density they can be extra hard.

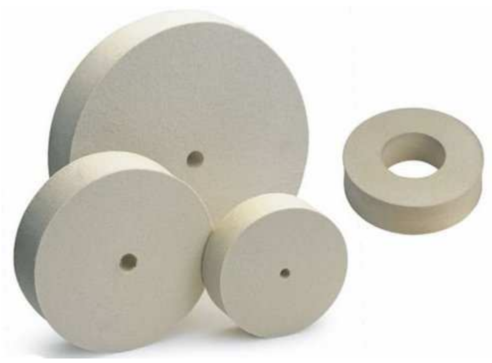


Figure 26. Different sizes of felt wheels. *Source: www.victoryhardware.com.sg*

c) Nylon and wire wheels or brushes

The nylon and wire assembled brushes to the wheel are usually used for cleaning, deburring and smoothing rough surfaces. Those brushes can be made also from other materials like bass or steel bristles. Depending on the material, the wheel will be good for different tasks.

Figure 27. Steel wire wheel. *Source. www.amazon.com*

Figure 28. Nylon wheel. *Source: www.public.snapon.com*

d) Abrasive wheel

Those types of wheels are made of abrasive grains joined thanks to a binder material. This wheel is also reinforced with a metallic mesh, which is useful to have pores between the grains. It is possible to have different kind of wheels, depending on some parameters:

1. Type of abrasive grain

It is possible to have two different abrasive grains; the aluminium oxide and the silicon carbide.

- *Aluminium oxide flap wheels*

This wheel incorporates an abrasive granule of aluminium oxide. Depending on the hardness of the material needed to be processed, it can be used for deburring, polishing or to create a satin finish.

Figure 29. Aluminium oxide wheel. *Source: www.amleo.com*

- *Silicon carbide wheels*

These types of wheels are very strong so they are normally used for grinding (instead of polishing).

Figure 30. Silicon carbide wheel. *Source: www.exportersindia.com*

2. Grain size

It is the grain dimensions and it is possible to divide the grain sizes in:

- *Thin grains.*

These grains are used to obtain different smooth surfaces in hard and breakable materials.

- *Heavy grains*

These grains are used in soft and fibrous materials for removing quickly material from the surface.

3. Hardness grade

It is the capacity of the binder material to maintain the abrasive grains together with the wheel. We can divide the hardness between:

- *Soft*

If it is soft, the binder is not able to maintain together all the grains, so those grains will detach. This can be good because the wheel will sharpen automatically.

- *Hard*

If it is very hard, the grains are joined very tightly so these wheels will have a longer live.

4. Structure

The structure represents the distance between the grains in a wheel. Depending on the material of the piece needed to be polished, the material speed elimination, the precision and the final surface required, we will choose between different kind of structures.

5. Binder material

It is the material used to join the abrasive grains. The type of binder material depends on the working speed of the wheel and the required final surface. Some binder materials are:

- Synthetic resins /Bakelite
- Oxychloride
- Rubber
- Reinforced rubber
- Silicate
- Ceramic

Polishing pastes

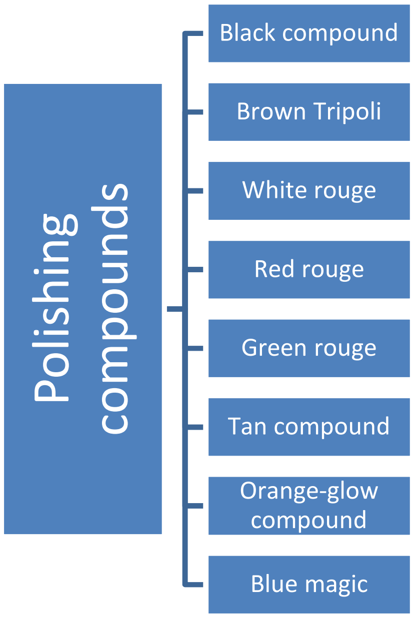
In these machines is not enough with the correct type of polishing wheel, it is also necessary the use of a polishing paste to have the desired final surface. There are different kinds of polishing pastes, depending on the material needed to be polished. The paste is added to the abrasive wheels in order to facilitate the metal removing.

Figure 31. Different examples of polishing pastes. *Source: www.divinebrothers.com*

These pastes are made by a mixture of polish, wax and metallic rust. The buffing compounds are mainly used with the polishing or buffing wheels (described before), and depending on the material needed to be polished we will choose one or another kind of compound.

Those materials help the operator doing the polishing process faster. Some of them are rougher, so are useful to remove the material faster (to remove all the scratches and imperfections), and others are softer, so are designed to obtain a beautiful finished surface.

Depending on the material and the desired finishing (mirror, satin, gloss, etc.), it is necessary a different type of paste. Normally, the colour of the paste determines the properties, so it is possible to classify those consumables as shown in the graphic below.



Graphic 4. Compounds used for manual polishing. *Source: Own*

Now, once the different kind of polishing pastes are named, I will describe the different compounds used, depending on its colour.

1. Black compound.

This compound is made of emery minerals. It allows the removing of scratches, small pitting, rough surfaces, etc. It is very useful when there are a lot of imperfections, because you can save time of the polishing process.

Figure 32. Black compound for manual polishing. *Source: www.picclick.co.uk*

2. Brown Tripoli

This compound is useful for two purposes: grinding and polishing. The compound can easily remove scratches while is leaving a smooth finish. For example, it is a good solution for soft materials as brass, copper or aluminium.

Figure 33. Brown compound for manual polishing. *Source: www.goshineon.com*

3. White rouge

It is great for hard metals like chrome or nickel-plated things. It gives good shine to the surface of those kind of alloys.

Figure 34. White rouge compound for manual polishing. *Source: www.jewelquestmarketing.com*

4. Red rouge (or jeweller's rouge)

It is ideal for high quality finishing in gold, silver and other precious metals. This consumable gives to the metal a true colour, at the same time that they will shine as like new.

Figure 35. Red rouge compound for manual polishing. *Source: www.silversupplies.com*

5. Green rouge

It is designed to provide a high shinny finish on all type of materials (soft and hard). Despite is good for all materials, has better performance with chrome, stainless steel and platinum.

Figure 36. Green rouge compound for manual polishing. *Source: www.goshineon.com*

6. Tan compound

It is known for its fast grinding characteristics, so is an ideal pre-polishing compound for removing light scratches. It can give a good performance in gold and silver if it is used together with buffing wheels.

Figure 37. Tan compound for manual polishing. *Source: www.riogrande.com*

7. Orange-glow compound

This is normally used for platinum, white/yellow gold and stainless steel to give a very shiny surface.

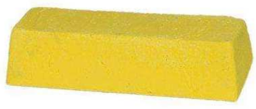


Figure 38. Orange-glow compound for manual polishing. *Source: www.es-dental.keystoneindustries.com*

8. Blue magic

It is designed to give a high-quality shine to the platinum jewellery, as well as for other type of precious metals.

Figure 39. Blue magic compound for manual polishing. *Source: www.goshineon.com*

3.2.4. Parameters recommended for polishing brass and bronze

In next paragraphs I will give some recommendations for polishing brass or bronze from casting. In this polishing system are needed different steps to get the final desired surface, so I will give the best parameters to get shiny results. It is advisable to do all those steps with a motor at 3000 rpm.

- <u>Rough down the surface</u>

  It is advisable to use a silicon carbide wheel in order to remove all big imperfections that the piece have after casting. Depending on the initial surface, we will use one grain size or another.

- <u>Grinding</u>

  Previous step produces new scratches in the surface that must be removed, so before giving the final polishing surface to the piece, it is advisable to use the combination of an uncombed wheel and brown tripoli compound.

- <u>Polishing</u>

  For brass and bronze, to get the desired shine and polished final surface, it is recommended to use an unstitched wheel with green rouge compound.

3.2.5. Advantages and disadvantages of the system

After seeing all this information about this polishing system, I can conclude that there are some advantages and disadvantages.

AVANTAGES

- Simple polishing machines.
- Machines are not expensive, so it is affordable for most companies.
- Useful for easy pieces. If they have a lot of flat surfaces it is a good solution.

DISADVANTAGES

- Polishing needs three different steps in order to have a good final surface.
- Many different types of abrasive wheels and polishing pastes are needed, depending on the material and the final finish required.
- The final result depends exclusively on the polishing experience of the operator.
- For large productions you need a lot of operators, which means a lot of salaries.
- Depending on the shape of the piece, will be necessary more or less polishing time. For difficult pieces it will be necessary to use more time in order to have a good finishing.
- As it is a manual polishing, it is difficult to respect the geometry of the piece. In other words; for critical shapes, it is not a very good system.
- As there is mainly man interaction, it is provable that some pieces do not have the final desired result, so they will be rejected.

After seeing all the advantages and disadvantages from manual polishing, I can conclude that manual polishing is interesting for those small brass and bronze pieces which have opened and flat surfaces, also as where respecting the initial geometry of the piece is not very important. Some pieces examples are:

- Hinges
- Door handle
- Clock's and decorative parts
- Small ship's screws

Big ship propellers cannot be done with any machine described before due its dimensions, so the most common option is doing all the polishing process with an angular grinding machine. As this machine is easily transportable, it gives freedom to the operator, allowing him to move without any dimension restriction. This method is also very useful because can also be used when the propeller is inside the water (for maintenance tasks).

Figure 40. Polishing a bronze propeller inside the water with an angular grinding machine. *Source: www.dynamicdivers.gr*

For each polishing method I will give a punctuation depending on its effectiveness and limitations in different parameters. After all methods are described, it will be possible to compare all of them in order to see the better one for naval industry.

The punctuation system will be as follows:

+ + Very convenient

+ Convenient

- Not convenient

- - Nothing at all convenient

For manual polishing, the punctuation is described in the below table:

Polishing method	Cost of machine	Consumables cost	Polishing time	Polishing quality	Automatic process	Number of pieces / process	Use in big pieces	Use in small pieces	Noise
Manual polishing	+ +	+	-	-	- -	- -	+ +	-	-

Table 8. Punctuation for manual polishing. *Source: Own*

3.3 Disc finishing machine

3.3.1. Theory of the system

Disc polishing machine works using a drum with a (rotary) disc placed at the bottom. The rotation of the disc creates a centrifugal force, allowing the pieces and media to move upward while there is also a rotating movement. The pieces and the media have different weight, so the centrifugal force is different for both.

This movement creates a rolling action between pieces and media, causing erosion of these two components, but not of the drum, because it is covered with a polyurethane liner that can stand up a repeated friction.

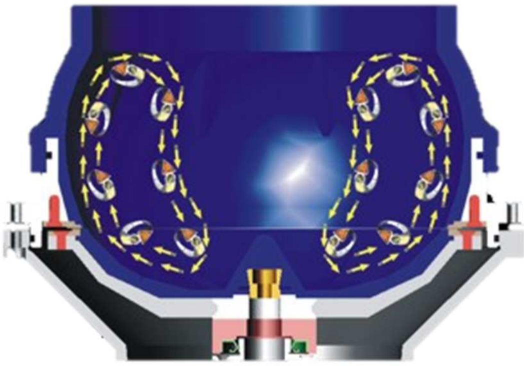


Figure 41. Movement of the pieces inside the disc finishing machine. *Source: www.makromakine.com.tr*

For a good final surface of the pieces, the final result can depend on many different parameters:

- Quality, shape and size of the abrasive media
- Type, capacity and design of the machine
- Material, dimensions and weight of the piece to process.

Figure 42. Disc finishing machine with two drums: for dry and wet polishing. *Source: www.otec.de*

3.3.2. Description of the machine

These machines are set up by one static part (the drum) and one moving part (the disc). This last one moves thanks to a motor connected to the disc (normally by belt). When the machine is switched on, the motor runs in the programmed velocity, allowing the rotation of the disc. We can divide the machine in the following parts:

1) Mantle

It is the upper part of the drum and gives some height to the compartment in order to allow that the media and the pieces stays inside of the drum.

2) Stopper

The stopper is made of polyurethane in order to avoid its wearing down. It allows the movement of pieces and media inside the drum (as described in Figure 41. **Movement of the pieces inside the disc finishing machine. *Source: www.makromakine.com.tr***). It is also used to cover the pressure sleeve.

3) Pressure sleeve

This mechanical part joins the spindle with the rotor disc. In other words, it is the transmission part which allows the rotational movement of the disc.

4) Rotor disc

This part is the moving disc of the drum. It allows the movement of the pieces and media thanks to its rotation.

5) Pot

It is the below static part of the machine. There are all the mechanical parts inside (the ones which allows the movement to the disc).

6) Spindle

It gives the power of the motor to the drum. It is the transmission part between the motor assembled at the frame and the rotational disc.

7) Drum

The size of the pieces determines the diameter of the drum. Normally, the diameter has to be 4 times the maximum length of the piece (to have enough space to move).

There are basically two models of drums. Depending on media used (which determines the final surface desired) it is advisable to use:

- Dry drum

  It works directly with the pieces and the media inside the drum.

- Wet drum

This drum works with pieces, media and water inside the drum. For pouring the water, the machines have a dosing pump which puts water with compound inside the drum. The drum has also an evacuation for this liquid, allowing to throw it inside another compartment. This kind of system is usually used to sweep along dirty from inside the drum. It can only be used for some kind of media.

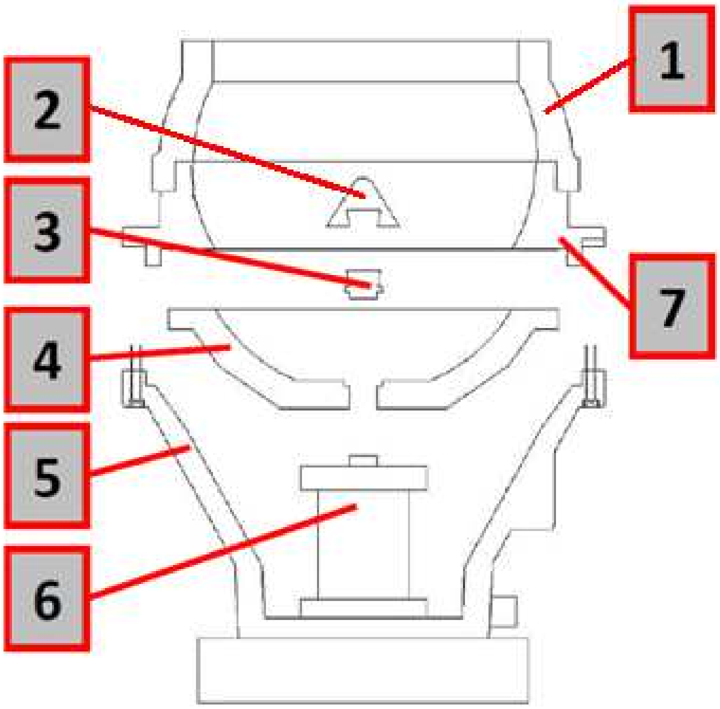


Figure 43. Parts of the disc finishing machine. *Source: Instructions of Avalon disc finishing machine, model EC10*

The motor is hold on the rear part of drum, and transmits the power by belt to the spindle. The motor power can change depending on the compartment size, so if there are more pieces and media inside the drum, more power will be needed to move them with the rotor.

Another part not represented in the drawing is the control panel. In this part, the operator can program the necessary parameters for working. The main controls are:

8) Main switch.

It is used to switch on/down the machine.

9) Time controller.

Depending on the material, initial surface, desired finishing and media used, it will be necessary to program more or less time. It is a screen where it is possible to set a total time of process.

10) Rotating velocity controller.

It is possible to change the revolutions of the disc, so depending on the material to polish, size and media it can be necessary to apply more or less velocity.

11) Flow regulator for the dosing pump

The pump is only used in wet drums for mixing the soap and the water, taking it from a compartment and settling it inside the working drum. We can modify the liquid flow depending on which material we are processing. Pumps with more capacity will be needed in order to pour sufficient liquid inside the drum for the polishing process.

Figure 44. Control panel of a disc finishing machine. Source: www.en.avalon-machines.pl

With disc finishing system is necessary the subsequent separation of the pieces from the polishing media. Some automatic systems have been developed, but all of them have in common a sieve put on top of a deposit. Depending on the pieces processed and media used, the diameter of the holes of the sieve must be different.

When a process has finished, pieces are thrown into the deposit. The polished pieces stay at the top of the sieve and the media goes across it, staying to the bottom of the deposit (see picture below).

Figure 45. Sieve used to separate media from pieces. *Source: www.riogrande.com*

3.3.3. Materials used for polishing

The right media and the ideal compound must be selected for each kind of piece. Depending on the material, the final surface desired and the shape of the piece, different media and compound have to be used in the machine. As explained before, we can differentiate the media and the compound depending on the drum used (wet or dry polishing).

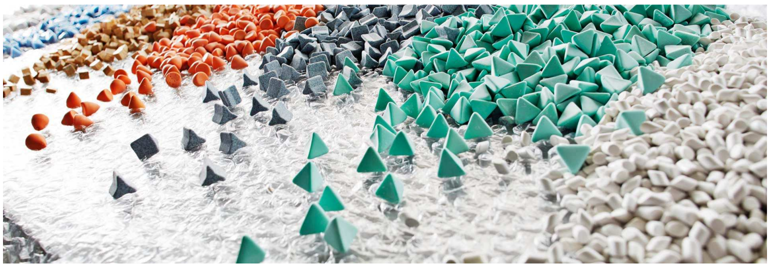
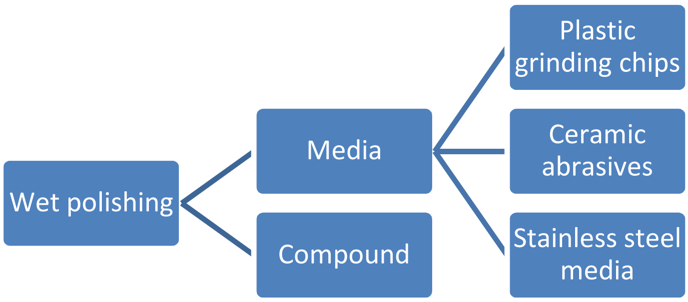


Figure 46. Different media types. *Source: www.otec.de*

Wet finishing

For wet disc finishing it is necessary to use media and compound. Depending on the piece, different media will be used.



Graphic 5. Material used for wet polishing in disc finishing machines. *Source: Own*

a) Media

The media can be classified depending on the material used to manufacture it.

- <u>Plastic grinding chips</u>

  Plastic grinding chips offers a good removal and a fine finishing thanks to their low density and soft surface. They are mainly used for grinding and fine grinding of precious or non-ferrous metals.

  We can differentiate these chips depending on their grinding effect (from fine to very intense grinding) and depending their geometry and size. The main geometries are:

CONICAL

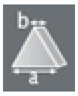
PYRAMID

Figure 47. Plastic grinding chips for wet disc finishing. *Source: www.otec.de*

- <u>Ceramic abrasives</u>

Ceramic chips with a high density and hard surface are mainly used for grinding all kind of steel alloys. In this case we can differentiate the ceramics depending their grinding effect (from light polishing to a very strong abrasive), their geometry and the size. The main geometries are:

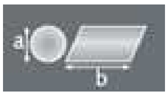
TRIANGLE



TRIANGLE (straight cut)

ELLIPSE

CYLINDER



TRISTAR

Figure 48. Ceramic abrasive media for wet disc finishing. *Source: www.otec.de*

- <u>Stainless steel media</u>

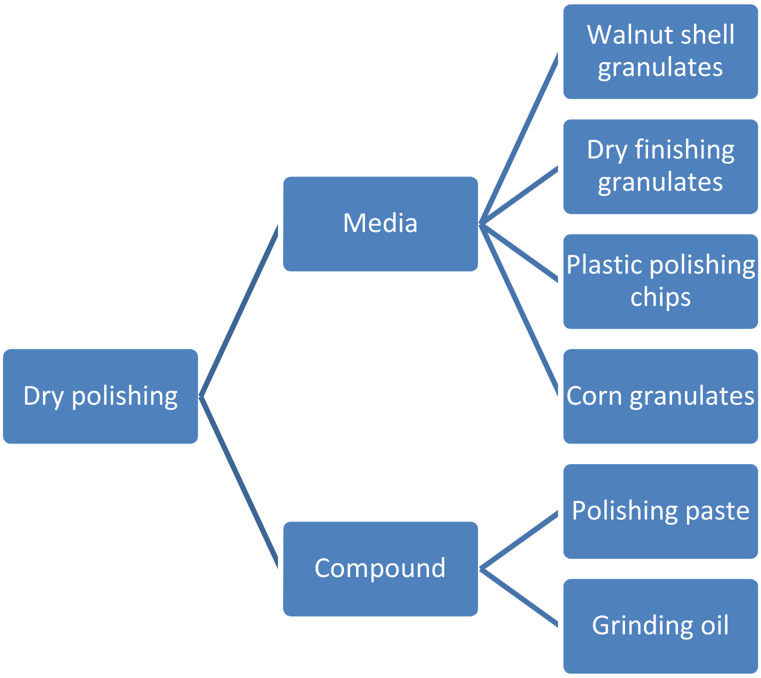
  In contradistinction with the medias before, there is no material removed during the process when stainless steel media is used, but it is very useful to get a good polished surface. There are different diameters for those stainless-steel balls and are used to compact and smooth the surface.

b) Compound

A mix of compound and water are used for wet polishing. Thanks to this mixture, the pieces are rinsed away from all the dirty and the abrasive media, guaranteeing the maximum efficiency of the process. There are different kinds of polishing compounds; each one has to be applied depending on the material that needs to be polished. In other words, there are different compounds and each one is used for different materials.

Dry polishing

For dry disc finishing it is necessary to use media and compound:



Graphic 6. Material used for dry polishing in disc finishing machines. *Source: Own*

a) Media

- Walnut shell granulates

  This granulates must be impregnated with a polishing paste and it is usually used for the final stage: for polishing. There are different hardness (depending on the material to polish) and size type of walnut shell (depending on the shape of the piece).

Figure 49. Walnut shell media for dry disc polishing. *Source: www.otec.de*

- Dry grinding granulates

  We can classify them depending on their material:

  - Cylindrical granules which are made of polyethylene with silicon carbide. Their advantages are that they do not break and are self-sharpening (they retain their shape).
  - Media made from white corundum. It is useful to get a low roughness surface.

Figure 50. Dry grinding granulates for dry disc polishing. *Source: www.otec.de*

- Plastic polishing chips

  This media is normally used for polishing in jewellery. Their consistent geometry prevents producing dust while it is working. This media gives also a lot of shine to the metal.

Figure 51. Plastic polishing chips for dry disc polishing. *Source: www.otec.de*

- Corn granulates

  This granulate has to be impregnated with polishing paste and it is advisable for getting a mirror polishing surface.

Figure 52. Corn granulates for dry disc polishing. *Source: www.otec.de*

b) Compound

Polishing pastes or grinding oils are only used in dry polishing. They adhere to the polishing media and give a high-quality surface. Thanks to their oil content, they also give good protection against corrosion. Depending on the metal needed to be polished, there are different polishing pastes or grinding oils for dry polishing.

Figure 53. Polishing paste and grinding oil for dry disc polishing. *Source: www.otec.de*

3.3.4. Parameters recommended for polishing brass and bronze

In next paragraphs I will give some recommendations for polishing brass or bronze from casting. In this polishing system are needed different steps to get the final desired surface, so I will give the best parameters to get a shiny surface.

- Rough down and grind the surface

  Both steps can be made in only one process, if more time is taken and the correct media is used. The use of plastic grinding chips (in a wet drum) combined with a universal compound for wet grinding (which is advisable for all kind of metals) would be useful for the surface of the piece.

- Polishing

To get the desired shine and final surface the dry drum will be used. It is recommended for example the use of walnut shell with some special polishing paste especial for non-ferrous metals, in order to get a mirror surface at the piece.

3.3.5. Advantages and disadvantages of the system

After seeing all this information about this polishing system, I can conclude that there are some advantages and disadvantages.

ADVANTAGES

- It is easy to work with the machine. The operators do not need knowledge about polishing; they only have to follow some steps in order to obtain great results.
- It is a semi-automated process, and thanks to some improvements is possible to automate it at all.
- Big capacity machines.
- There is practically no dimensions limit of the pieces that needs to be polished. There is only the restriction that the diameter of the drum has to be 4 times the maximum size of the piece.
- With the experience, it is easy to draw up a maintenance program of the machine and the consumables.
- Easy to load and unload the machine, only by knock over the drum.

Figure 54. Unloading the media and the pieces from the machine. *Source: www.en.avalon-machines.pl*

DISADVANTAGES

- In wet polishing, due to the rotation and depending on the compound and media, a lot of foam is produced.
- If different metals are polished, a lot of different consumables are needed.
- Consumables have big wear, so there is a high economic cost.
- It is a very noisy system.

- You need more than one step to do all the polishing process with the disc finishing machine. In other words, more than one kind of media is needed for the whole process.
- It is a slow process, so the whole polishing process takes long times.
- Due to the continuous grinding of the pieces, it is possible that some edges became rounded. It is a critical factor for example in jewellery, because it is needed to respect the original design of the piece.
- It is needed some system to separate the media from the pieces.

After seeing all the advantages and disadvantages from disc finishing, I can conclude that those machines are interesting for all kind of brass and bronze pieces. As there are many sizes options for the drum, and many different media and compounds, it is possible to process different models and pieces, obtaining great results with all them. From small hinges and door locks, to parts of wall lamps and decorative accessories, different pieces dimensions are allowed to be polished if the correct media and compound are used.

Disc finishing is also a great solution in all factories that have a serially high production of pieces. Due to the possibility of semi-automate the process, a lot of pieces can be practically done without the interaction between the operator and the machine.

Definitely, disc polishing machine is not good for grind and polish ship propellers. Due to its weight, there would not be movement of the screw inside the drum (the disc does not have enough power to move it), so the media will not interact uniformly in all the parts, and in conclusion the results will not be good.

As told before, for each polishing method I will give a punctuation depending on its effectiveness and limitations in different parameters. After all methods are described, it will be possible to compare all of them in order to see the better one for naval industry.

The punctuation system will be as follows:

+ + Very convenient

+ Convenient

- Not convenient

- - Nothing at all convenient

For disc finishing, the punctuation is described in the below table:

Polishing method	Cost of machine	Consumables cost	Polishing time	Polishing quality	Automatic process	Number of pieces / process	Use in big pieces	Use in small pieces	Noise
Disc finishing	+	-	-	+	+	+ +	-	+ +	- -

Table 9. Punctuation for disc finishing. *Source: Own*

3.4 Vibratory polishing machine

3.4.1. Theory of the system

This system consists in a spring-mounted open drum containing media inside, where a vibration generator is attached. This movement of the bowl causes some frictional forces between the pieces and the media, which after some processing time they reach the desired result.

As a result of this vibration and thanks to the design of the working bowl, the media become fluidized and develop complex flow field inside the drum (see Figure 55. **Movement of the pieces inside the vibratory machine. *Source: www.vacaero.com***). The pieces (needed to be polished) are entrained by the flowing media so experience a slower relative velocity. The interaction between the media and the pieces produce mainly erosion, allowing to the pieces become grinded and polished. The drum is not affected of this erosion because it has a polyurethane liner that can stand up a repeated friction from the media.

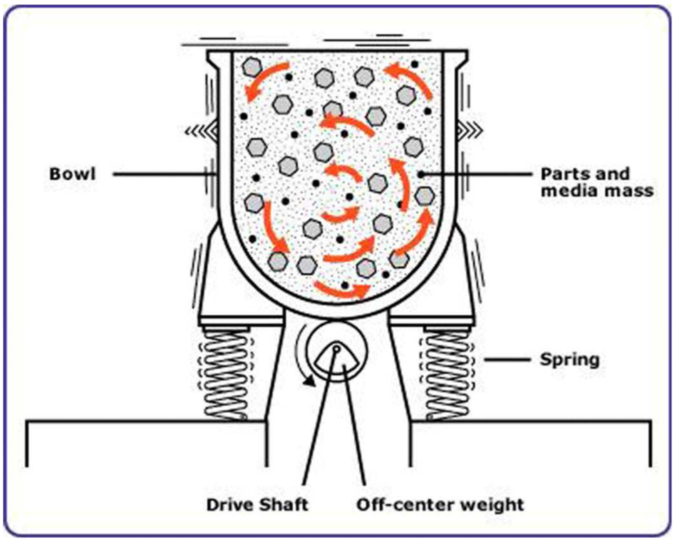


Figure 55. Movement of the pieces inside the vibratory machine. *Source: www.vacaero.com*

Depending on the parameters of the process, a wide range of contact conditions (different results) can be reached. Most important parameters for working and get the desired results are:

- Material and dimensions of the processing piece.
- Size, shape and material of the media used.
- Frequency and amplitude of the working vibration.

Depending on the piece we will first choose the media and then we will be able to fix the parameters (frequency and amplitude) of the machine. All those parameters will affect to the final surface of the pieces. Basically, vibratory tumbling machine is used for deburr, clean and polish unfinished or dirty pieces.

Frequencies can vary from 900 to 3600 cycles per minute (CPM) and the amplitude goes approximately from 0 to 5 mm. Modifying these two parameters is possible to obtain different type of results on the surfaces.

Figure 56. Example of a vibratory machine of high capacity. *Source: www.rotomex.com.mx*

3.4.2. Description of the machine

The machine has a bowl which thanks to a vibration movement can polish the pieces. This vibratory generator normally is an eccentric weight joined to a motor, and some springs mounted in the bowl. While the motor is rotating, the eccentric shakes de entire load producing the vibration.

Figure 57. Mix of pieces and media inside a vibratory machine. *Source: www.interempresas.net*

When the machine is switched on, the motor starts running and all the bowl begins to shake. Depending on the amplitude and frequency parameter programmed, the movement of the media will be different, so the action over the pieces will change. Basically, we can divide the machine in the following parts:

1) Control panel

In this part we are able to control the operating of the machine. It is equipped with:

- Main switch.

  Used to switch on/down the machine.

- Start-stop buttons.

  They are used to start or stop a programmed process.

- Rotation regulator.

  This control changes the rotational speed of the motor, so it is used to change the vibration frequency of the machine.

- Programmer time.

  It is used to program the desired polishing time.

2) Water drain system

Most times dry processes have not good enough result. In order to get better surfaces, this system usually works with some water and compound (wet polishing). It is necessary a pump for mixing those two parts and settle it inside the bowl. We can modify the liquid flow depending on which material is processed.

3) Bowl

The bowl is the container of the media and pieces while the machine is running. This container is normally of metal recovered of polyurethane in its inside. The size depends on its utilization industry, so there are many different diameters available depending on the pieces.

Normally, the bowl is circular with a structure in the centre which helps to the media movement. Thanks to this centre body, the media moves describing circles inside the bowl.

4) Motor and eccentric weight

Attached to the motor there is the eccentric weight, which is the reason of the movement of the whole system. Depending on the bowl size is necessary a more powerful motor.

5) Springs

Springs are necessary to make the vibration movement. They allow to the bowl returning to its initial position (thanks to stress-strain deformation). Depending on the diameter of the bowl, the spring's diameter and the number of springs around all the diameter must be different.

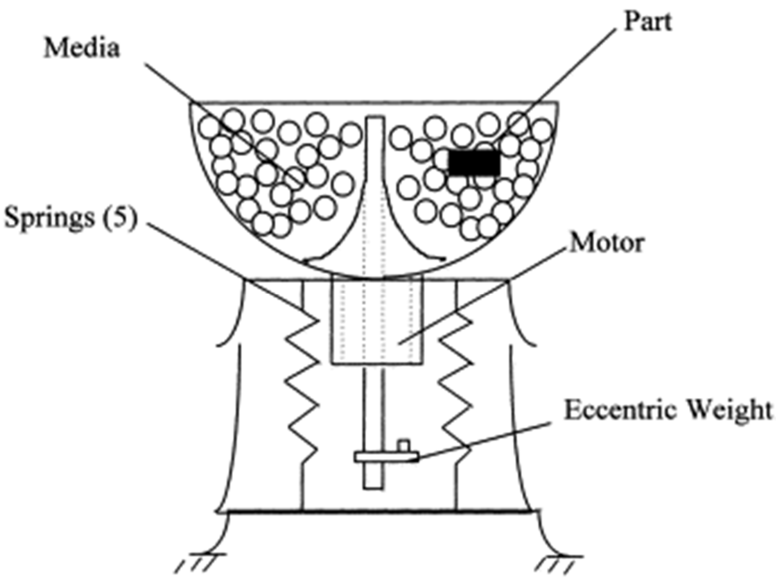


Figure 58. Main parts of the vibratory machine. *Source: paper "Experimental investigation of vibratory finishing of aluminium"*

With vibratory system is also necessary the subsequent separation of the pieces from the polishing media. There are different systems developed (as good as some automatic systems), but all of them have in common a sieve put on top of another deposit. Depending on the media used the diameter of the holes of the sieve must be different.

When the polishing process has finished, pieces are thrown into the new deposit. The polished pieces stay at the top of the sieve and the media goes across it, staying at the bottom of the deposit.

For vibratory machines there are some easy solutions in order to automate the separation process. The most common way is called flow-through system. Only by changing the velocity and the spinning direction of the motor, all the media and the pieces starts climbing the sieve on top of the bowl. Media will fall down, but the pieces will continue advancing until the end of the sieve (see picture below), falling into another container.

Figure 59. Vibratory machine with the system flow-through, which automatically separates media and pieces.
Source: www.rotomex.com.mx

3.4.3. Materials used for polishing

The right media must be selected for each kind of piece. Basically, depending on the dimensions and material of the workpiece, we will choose between different medias.

The main characteristics of the media are:

- <u>Material.</u>

  Depending on the desired final surface it is advisable to use different media materials. The material will determine the final polishing quality.

- <u>Shape</u>

  Depending on the media shape, it would be more aggressive order to polish better some parts of the pieces.

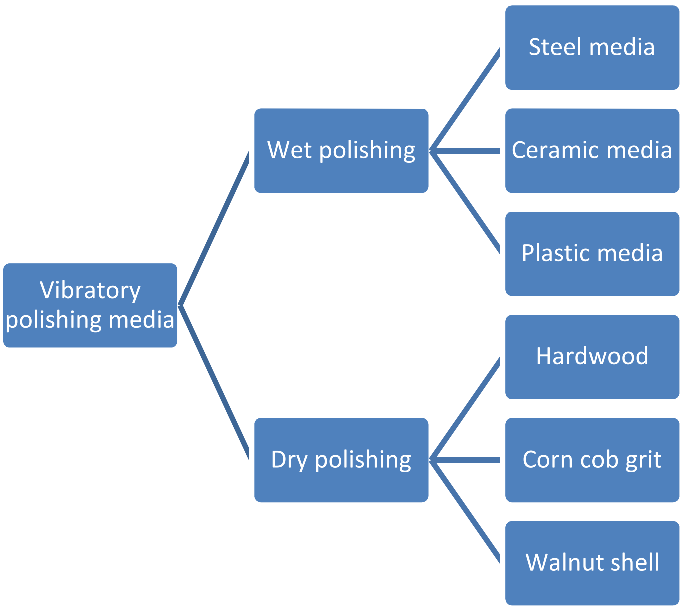
- <u>Size</u>

Particles size depends basically on the surface of the piece. For large opened surfaces without very internal parts is better to use bigger media; for close surfaces angles and very internal parts it is advisable to use smaller media.

As commented before, vibratory machines are normally used in wet, but there are some kind of media which can be used in dry conditions. Depending on the material needed to be polished and the final surface desired, we have to choose between different media possibilities.

All these types of media (for dry and wet polishing) will wear down slowly because of their constant impacts while the machine is working. This erosion depends on how aggressive the media is and also on the vibration of the bowl. After some processes it is needed to change the media.

In the following graphic, we will see which are the most used media for wet and for dry polishing, and in next lines I will describe all these materials.



Graphic 7. Media used in wet and dry polishing for vibratory machines. *Source: Own*

Wet polishing

Water is usually needed for vibratory tumbling. Minimum water has to be added to have a harder grinding and as more water is added, more shine will be reached.

The different media available at the market are:

- Steel media

  It is normally used for polishing (gives a bright shine) and burnishing. Thanks to their substantial weight (more than three times the density of ceramic media) a big pressure is applied to the working piece reducing working time.

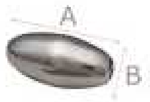
  It is a very interesting media due to there is no wear down of the pieces. The steel makes compressive stress to the surfaces, so there is no erosion; the balls smothers the pieces by compressing their surface (they compact the material). This is very useful to reduce the porosity on plated pieces.

This media can be purchased normally in different sizes and shapes. Most common shapes are:

ROUND BALLS

CONES

OVAL-BALLS



DIAGONALS

BALL-CONES

PINS

ECLIPSE BALLS

Figure 60. Different shapes for steel media. *Source: www.kramerindustriesonline.com*

- <u>Ceramic media</u>

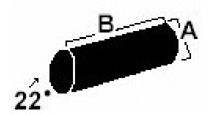
  Depending on their abrasiveness, ceramic media is recommended for polishing and for light and heavy deburring. It is a very good option for hard and heavy metals (like steel).

  Ceramic media is made of silica, other minerals and also abrasives combined at high temperatures, producing a very hard material. It is the most common media used for vibratory machines thanks to their long-live, reduced price and very versatile properties.

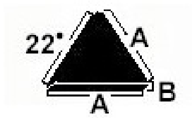
  The density determines the abrasiveness of the media, so as denser more aggressive it will be. It is not very recommended to work with most aggressive ceramics, because there will be a lot of consumption of media (they will wear down easily so it will be necessary to change the consumables very often). It is important to find the best relation between time process and cost of consumable.

This media can be purchased normally in different sizes and shapes. Most common shapes are:

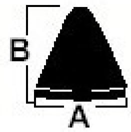
ANGLE CUT CYLINDERS



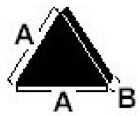
ANGLE CUT TRIANGLES



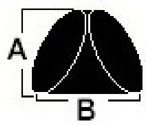
CONES



STRAIGHT CUT TRIANGLES



CYLINDRICAL WEDGES



ANGLE CUT TRISTARS

ANGLE CUT ELLIPSES

Figure 61. Different shapes for ceramic media. *Source: www.kramerindustriesonline.com*

- <u>Plastic media</u>

Plastic media is usually used for general metal removal, polishing and fast and heavy cutting of soft metals (as aluminium or brass). These particles are not aggressive as ceramics but can get a better final surface. They are considerably lighter in weight than ceramic media, in other words, they can process parts that provably ceramic media might damage.

This media can be purchased normally in different sizes and shapes. Most common shapes are:

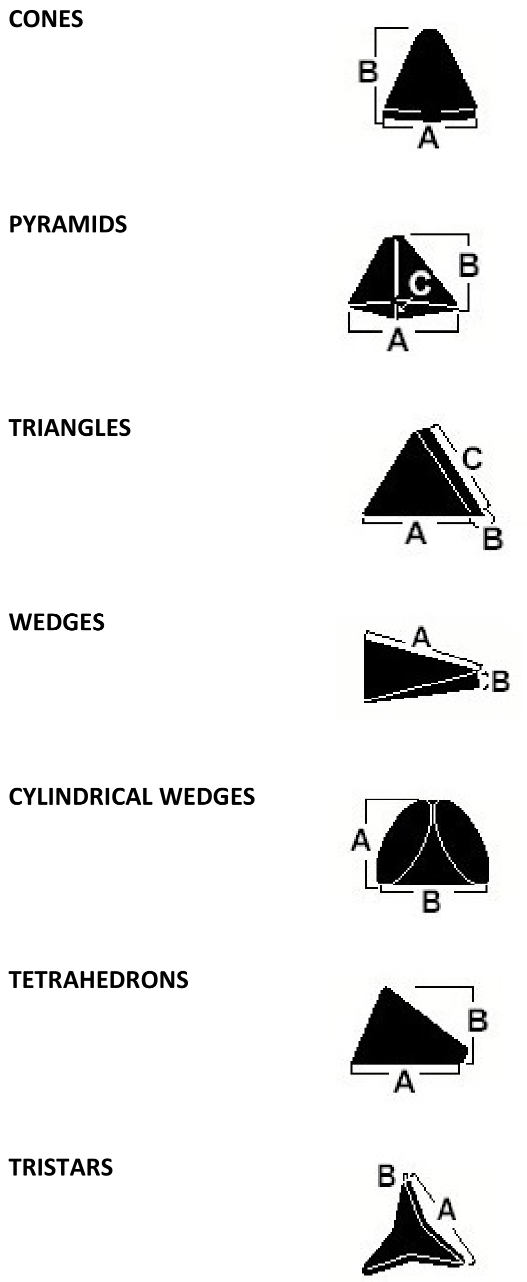


Figure 62. Different shapes for plastic media. *Source: www.kramerindustriesonline.com*

Dry polishing

For dry polishing it is not necessary the use of the recirculation pump. Media with just some polishing compound can be used in order to get good results. In this case the media is organic, and the most common used are:

- Hardwood

  It is one of the materials used in dry polishing mixed with abrasive or polishing compound. It is normally used for smoothing and finishing plastic, also as for light deburring and finishing metal. Hardwood media is effective and durable for plastic, ceramics, wood, metals and other materials.

  This media can be purchased normally in different sizes and shapes.

Figure 63. Examples of different shapes and sizes of hardwood media. *Source: www.riogrande.com*

- Corn cob grit

  Corn cob grit is specially used for delicate parts, and it is useful to remove surface contamination, debris and coatings without affecting the piece.

  There are different sizes and roughness of the corn cob grit and depending on their size will be more or less aggressive. This media is biodegradable, organic and it is resistant to break down (can be re-used multiple times).

Figure 64. Corn cob grit media. *Source: www.ntruddock.com*

- Walnut shell

  In this case it is possible to work with or without polishing compound. Walnut shell is great for cleaning dirty or tarnish. The use of this consumable offers less working time in preparation due to the walnut shell not only does the cleaning of the pieces, it also polishes the metal in the same step.

  New fresh walnut shell cleans very fast, but as we use it, it becomes rounded and dirty increasing the time of processing the pieces. When the processing time of a batch increases to about twice of normal time, it is recommendable to replace the walnut shell for fresh one.

This media can be purchased in different specified particles size, so depending on the size will be more or less abrasive. This product is biodegradable, organic and can be re-used multiple times.

Figure 65. Walnut shell media. *Source: www.black-walnuts.com*

3.4.4. Parameters recommended for polishing brass and bronze

In next paragraphs I will give some recommendations for polishing brass or bronze from casting. In this polishing system are needed different steps to get the final desired surface, so I will give the best parameters to get a shiny surface.

- <u>Rough down and grind the surface</u>

  Those two steps can be made in only one process if more time is taken. As those materials are soft, in order to not deform the piece, it is advisable to use a softer material; the plastic media. Ceramic media can also be used but we will have to take care about the parameters programmed in order to not deform the original shape of the piece.

- <u>Polishing</u>

  As in the previous step, it is possible to use for example metal media to get more shinny and reduce the porosity, but as brass is a soft material it is possible to deform the shape of the pieces if the correct parameters are not selected.

  In conclusion, to get the desired final surface in brass or bronze pieces, it is more recommended the use of corn cob grit, which will give a very good smooth and shiny surface.

3.4.5. Advantages and disadvantages of the system

After seeing all this information about this polishing system, I can conclude that there are some advantages and disadvantages.

ADVANTAGES

- It is easy to work with the machine. The operators do not need knowledge about polishing, they only have to follow steps to obtain great results.
- In comparison with rotary tumbler, this system is better for processing internal parts of the pieces.
- There are big machines, which are a good solution for large pieces or for large productions.
- It is easy to automate all the process thanks to a flow-through system.
- It is good for smothering surfaces and finish delicate or large parts that could be damaged in other systems.
- Easy to load and unload all the media.

DISADVANTAGES

- It is a very noisy system.
- Consumables have big wear, so there is a high economic cost.
- If different metals are polished, a lot of different consumables are needed.
- With disc vibratory machine, you need more than one step to do all the polishing process (more than one kind of media is needed).
- It is a slower process than disc finishing machines.
- Due to the continuous grinding of the pieces, it is possible that some edges became rounded. It is a critical factor for example in jewellery, because it is needed to respect the original design of the piece.
- After the process, it is needed to separate the media from the pieces

After seeing all the advantages and disadvantages from vibratory machines, I can conclude that as in disc finishing machines, those machines are interesting for all kind of brass and bronze pieces. As there are many sizes options for the drum (even bigger than disc finishing drums) and many different medias, it is possible to process different models and pieces, obtaining great results with all them.

From small hinges and door locks, to parts of wall lamps and big decorative accessories, different pieces dimensions are allowed to be polished if the correct media is used.

In my opinion, vibratory system is a better solution than disc finishing in case of have serially high production, basically due to:

- Most automated system thanks to the flow-through system. This means less operators working with the machine.
- Bigger drums, which means that those machines are able to process more pieces at the same time (higher productions are allowed).

Like in disc finishing, vibratory system is not a good solution for bronze propellers due to the weight of the piece. In this system is needed that the piece flows inside the media, so if we put the screw inside the bowl, it will rest at the bottom and the media will not interact uniformly in all the parts.

As told before, for each polishing method I will give a punctuation depending on its effectiveness and limitations in different parameters. After all methods are described, it will be possible to compare all of them in order to see the better one for naval industry.

The punctuation system will be as follows:

+ +	Very convenient
+	Convenient
-	Not convenient
- -	Nothing at all convenient

For vibratory finishing, the punctuation is described in the below table:

Polishing method	Cost of machine	Consumables cost	Polishing time	Polishing quality	Automatic process	Number of pieces / process	Use in big pieces	Use in small pieces	Noise
Vibratory finishing	-	-	- -	+	+ +	+ +	-	+ +	- -

Table 10. Punctuation for vibratory finishing. *Source: Own*

3.5 Barrel finishing machine

3.5.1. Theory of the system

Barrel, or rotatory finishing system, consists in a horizontal barrel full of media and pieces, which slowly rotates (constant speed of 10-30 rpm). This rotational movement causes that the superficial media and pieces slide, from the upper section to the bottom of the barrel. It is a cyclic process, so every time a layer goes down, starts the sliding of the next layer.

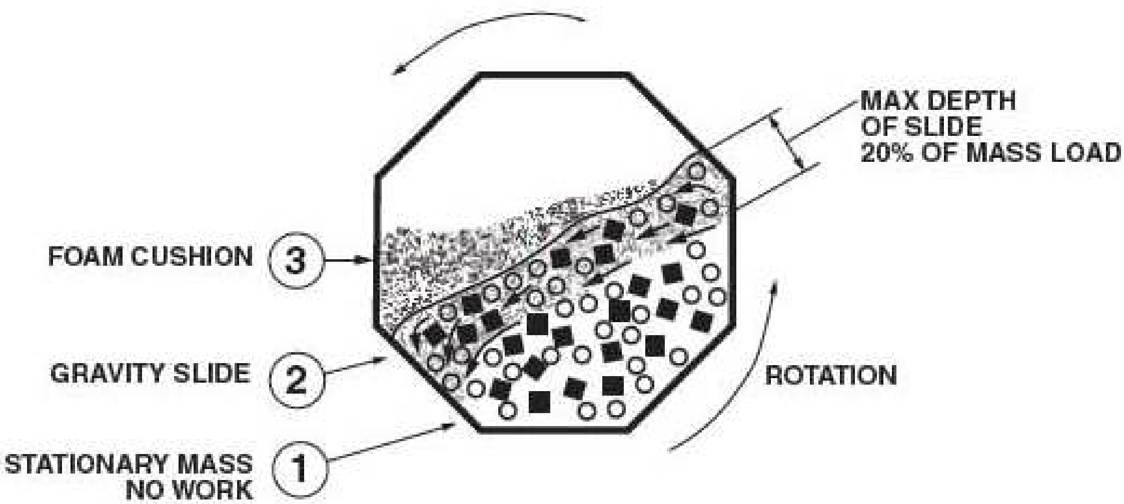


Figure 66. Mix of water, media and pieces inside a barrel. *Source: www.raytechmetalfinishing.com*

This tumbling inside the rotating barrel, creates friction between the media and the parts, producing the grinding of the surface. The total force applied depends on the gravity, so the weight of the pieces and polishing media is very important.

To get the final desired result, the following parameters are very important:

Rotational speed of the barrel

The rotational velocity of the barrel is a very important parameter (rpm), so it is important to adjust it accurately.

- If the speed is too low, there will not be enough friction between pieces and media. In other words, more processing time will be needed.
- Faster velocities will do the job before, but with give a poorer finish.

Ratio of media, pieces to polish and water with compound.

We can achieve different results by changing the proportions of media, water with compound and pieces. Normally the total barrel load for excellent results is between 50-60%. We can change the proportions of:

a) Pieces

- Good surfaces will not be obtained if too many pieces are inside the barrel.
- With few pieces inside the barrel better finished surface will be reached.

b) Media

- As more media is added (so the total load height increase) the polishing action to the surface is lower.
- Less media added to the barrel increases the speed of polishing, but the smoothness of the surface will not be as good as possible

c) Water with compound

- As less water is added to the barrel, faster is the process
- When there is more proportional part of water, the finished surface is smoother.

Type of media used

Depending on the media used, the results will be different. Choose the correct media for each purpose is very important in order to get the best result possible.

3.5.2. Description of the machine

Depending on the production desired, machines can be quite different. For higher productions it is possible to have:

- Larger barrels
- More barrels in the same machine

Figure 67. Example of a barrel finishing machine. *Source: www.massfin.com*

In this chapter I will focus the explanation on a single barrel machine. Those machines have one hexagonal or octagonal barrel, which is connected to a motor reducer. Thanks to a transmission system, the barrel rotates at the same time than the motor.

When the machine is switched on, the motor starts to run, so the barrel begins to move. Depending on the velocity programmed, the barrel will rotate faster or slower. As told before, the speed is important to get the desired result. The main parts of the machine are:

1) Frame

The frame is the main structure of the machine, where all the other parts are fitted.

2) Control panel

In this part we are able to control the operating of the machine. It is equipped with:

- Main switch.

  Used to switch on/down the machine.

- Start-stop buttons.

  They are used to start or stop a programmed process.

- Rotation regulation.

  Depending on the material needed to be polished, it is necessary to change the rotational speed. Normally barrel speed goes from 10 to 30 rpm.

- Programmer time.

  It is used to program the desired polishing time. In many of those machines there is the option to program directly 12h or 24h processes.

- Reversing switch.

  Sometimes is useful to change the spin direction meanwhile the machine is working. This switch activates the automatic changing direction.

3) Motor-reducer

When the rotational speed is changed at the control panel, the motor gives the movement to the reducer, which decreases the final speed. In conclusion, the barrel will rotate at the speed given by the reducer.

4) Transmission system

It is necessary some way to transmit the movement from the motor-reducer to the barrel. Most industrial machines have a shaft that joints the barrel with the motor-reducer, allowing the movement of the container.

5) Barrel

Barrels are the compartments were the pieces and media are added. Those barrels are normally made of steel with some kind of liner, which allows the barrel to not wear away due to the impact of the media. We can differentiate two kinds of barrels:

- Barrel for wet tumbling.

  In those barrels we mix the media with water and some polishing compound. Normally the barrel is filled up about 50% of its capacity with pieces and media. After this, water with compound is added within 10 centimetres below the total load.

  The barrels can have two different shapes: hexagonal or octagonal. They can be used in horizontal or oblique position. Speeds for wet tumbling are normally kept between 20-38 rpm. It is very important that those barrels are perfectly watertight to prevent leaking while are working.

- Barrel for dry tumbling

  In dry tumbling, only pieces and media are poured inside the container. It is only possible to use the horizontal octagonal barrel (in comparison with wet tumbling). Speeds for dry tumbling are normally kept between 28 to 32 rpm.

Figure 68. Hexagonal barrel. *Source: www.navalwiki.info*

With this rotatory system is also necessary the subsequent separation of the pieces from the polishing media. There are different systems for separate the pieces from the media, but all of them have in common a sieve put on top of a deposit. Depending on the media used, the diameter of the holes of the sieve must be different.

When a process has finished, pieces are thrown into the deposit. The polished pieces stay at the top of the sieve and the media goes across it, staying at the bottom of the deposit.

3.5.3. Materials used for polishing

a) Media

The right media must be selected for each kind of piece. Basically, depending on the dimensions and material of the workpiece, we will choose between different medias. The main characteristics of the media are:

- Material.

  Depending on the desired final surface it is advisable to use different media materials. The material will determine the final polishing quality.

- Shape

  Depending on the media shape, it would be more aggressive in order to polish better some parts of the pieces.

- Size

  Particles size depends basically on the surface of the piece. For large opened surfaces, without very internal parts, is better to use bigger media; for close surfaces angles, and very internal parts, it is advisable to use smaller media.

For rotatory tumblers the media used is the same as in vibratory machines (see chapter 3.4.3).

Figure 69. Different shapes for plastic media. *Source: www.bvproducts.com.au*

b) Compound

For wet polishing it is needed to add some compound to the water and mix it. This abrasive compound is the additive which will determine the type of operation that will be done, so depending on the compound used different results can be reached.

It is possible to differentiate two different compounds for all the metals:

- Cutting compound

  This compound is mainly used when it is needed a lot of grinding action to the pieces. In other words, it is usually used for the first stage of the polishing process, when it is important to remove more material.

- Polishing compound

  This compound is mainly used when it is needed to get shine in the pieces. In other words, it is usually used for the final stage of the polishing process, just when the pieces are finishing polishing phase.

3.5.4. Parameters recommended for polishing brass and bronze

As described in last chapter (3.5.3), the media used for barrel finishing is the same as for vibratory finishing. In conclusion, the media for processing brass and bronze in this method are the same as in the chapter 3.4.4. The

For polishing brass or bronze from casting, two different steps are needed to get the final desired surface. In this chapter I will give the best solutions in order to get a shiny surface.

- Rough down and grind the surface

  Those two steps can be made in only one process if more time is taken. As those materials are soft, in order to not deform the piece, it is advisable to use the softer material, the plastic media. Ceramic media can also be used but we will have to take care about the parameters programmed in order to not deform the original shape of the piece.

- Polishing

  As in the previous step, it is possible to use for example metal media to get more shinny and reduce the porosity, but as brass is a soft material it is possible to deform the shape of the pieces if the correct parameters are not selected.

  In conclusion, to get the desired final surface in brass or bronze pieces, it is more recommended the use of corn cob grit, which will give a very good smooth and shiny surface.

3.5.5. Advantages and disadvantages of the system

After seeing all this information about this polishing system, I can conclude that there are some advantages and disadvantages.

ADVANTAGES

- Economical finishing process because large batches can be run (big machines, for big productions).
- It is easy to work with the machine. The operators do not need knowledge about polishing, they only have to follow steps to obtain great results.
- It is cheaper than polish by hand.
- Simple machine and process.
- For deburring and burnishing is a good solution.

- For long processes this machine can run over-night

DISADVANTAGES

- It is not very easy to unload the media and pieces.
- It is not a good solution for big pieces.
- Long processes to finish the pieces (12-24h)
- It is a very noisy system.
- Due to the continuous grinding of the pieces, it is possible that some edges became rounded. It is a critical factor for example in jewellery, because it is needed to respect the original design of the piece.
- Consumables have big wear, so there is a high economic cost.
- It is needed to separate the media from the pieces
- With the rotatory finishing machine is needed more than one step to do all the polishing process (more than one kind of media is needed if very good results are expected).

After seeing all the advantages and disadvantages from barrel finishing machines, I can conclude that those machines are interesting for small brass or bronze pieces. Even it is possible to have many different barrel sizes, the diameter of the barrel determines the maximum size of the pieces.

Having this in mind, due to the barrel dimensions and quantity of barrels for machine it is possible to have large productions. In conclusion, barrel finishing can be interesting for small pieces produced serially, like hinges, small knobs and other furniture parts.

As told before, for each polishing method I will give a punctuation depending on its effectiveness and limitations in different parameters. After all methods are described, it will be possible to compare all of them in order to see the better one for naval industry.

The punctuation system will be as follows:

+ + Very convenient

+ Convenient

- Not convenient

- - Nothing at all convenient

For barrel finishing, the punctuation is described in the below table:

Polishing method	Cost of machine	Consumables cost	Polishing time	Polishing quality	Automatic process	Number of pieces / process	Use in big pieces	Use in small pieces	Noise
Barrel finishing	-	-	- -	+	-	+ +	- -	+ +	- -

Table 11. Punctuation for barrel finishing. *Source: Own*

3.6 Electro-polishing machine

3.6.1. Theory of the system

Electro-polishing system is a chemical process used for finishing metal surfaces of pieces. With this system, metal is removed ion by ion from the surface of the object so the piece roughness is minimized. Even the plating machine does the opposite process (metal is added ion by ion to the surface of the piece), the process and the machine are very similar.

Electro-polishing machine uses the electrolysis principle for working. The piece (hanged in the anode, and fitted inside the working tank) loss metal thanks to the pass of electric current from the anode to the cathode. The piece is submerged in a specific liquid electrolyte (mostly acids) and the electrolyte act as a conductor, allowing to the metallic ions removed from the piece (positive) go to the cathode (negative).

Figure 70. Electro-polishing machine with a rinsing tank. *Source: www.tst.tw*

With the apparition of the mentioned current, a polarized layer (with high electrical resistance) is created all around the anode. This phenomenon is called anodic passivation layer. This layer thickness is not constant all around the piece; in the micro-hollows has more thickness than in the higher points, so the current will attack more all the protruding parts of the surface, that will not have so high electrical resistance as the hollows. This phenomenon produces smooth, levelled and deburred surfaces. It can also give brightness to the entire piece.

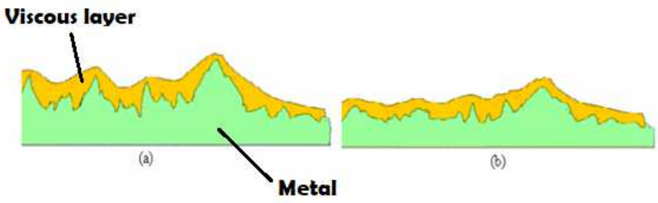


Figure 71. Apparition of the viscous layer over the metal. *Source: www.inoxidable.com*

Most part of the dissolved metals remains in the solution. The other part, which are some ions, will be deposited, in sludge form, on the cathodes (a regular cleaning is necessary). The quantity of metal removed and final results from the pieces depends on many different parameters:

- <u>The voltage applied to the piece</u>

  With the controls of the machine is possible to change the voltage that goes through the piece, so depending on the surface of the piece and the conductivity of the material, more or less voltage is needed. The voltage is directly related to the current density; increasing the voltage will augment the density current in the electrolyte.

  If the relation between voltage and current density is not good, the final surface of the piece can have some defects.

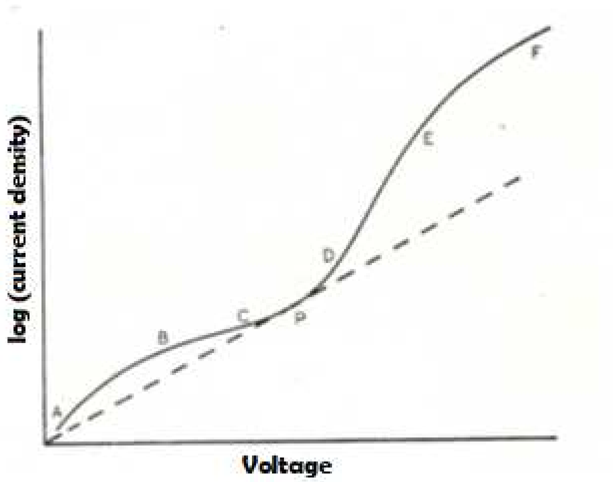


Figure 72. Relation between the voltage and the current density. *Source: "Polissage électrolytique et chimique des métaux"*

The previous picture (Figure 72. Relation between the voltage and the current density. *Source: "Polissage électrolytique et chimique des métaux"* relates the voltage with the current density, showing the best relation for polishing. Depending on booth parameters, the piece will react different to the polishing. The dashed line relates the better parameters of voltage and current density, and point P is the optimum parameter for polishing. It is possible to divide this relation between both parameters in different in ranges:

- A – B. Attack

- B – C. Instability
- C – D. Polish
- D – E. Slow gaseous release with pitting on the surface
- E – F. Polishing with fast gas release

- Efficiency of the electrolyte

  For a good polishing results, this electrolyte needs very frequently revisions in order to maintain the correct chemical parameters. If the concentrations are not correct, the electro-polishing speed will decrease and the results will not be as good as expected.

- Exposure time of the piece in the chemical bath

  Depending on the material, the initial surface (roughness) and the solution used, more or less treatment will be needed. Most treatments are usually between 2 and 20 minutes.

  Due to it is an aggressive polishing system, a difference of some minutes of process, can change a lot the final result. In other words, if the piece is inside the electrolyte too much time, the design of the piece will not be respected.

- Temperature of the electrolyte

  The resistance of the electrolyte decreases with higher temperatures, so there is more current density with the same voltage. Despite this, if the liquid is too hot, the viscosity of the polarized layer decrease. This effect makes difficult to maintain the layer around the anode.

  In conclusion, the optimized temperature has to be found in order to get the desired current density, without affecting negatively the final surface.

- Initial cleaning of the piece

  Normally, before the electro-polishing process an exhausting cleaning is needed to remove all contaminants dirties that can affect to the result. This metal preparation includes two different steps:

  - Cleaning / degreasing

    This step is made with alkaline or solvent cleaners and is useful to remove oils, grease or similar dirty films on the piece surface.

  - Pickling

    Pickling or acid descaling removes light oxidation appeared in previous processes.

3.6.2. Description of the machine

A power source converts AC current to DC current. Inside a tank, made of plastic or lead-lined tank, there are cathode plates in contact with the chemical liquid. Those cathodes are connected to the negative side of the power source (-). The pieces are fixed to a rack which is connected to the positive side of the power source (+).

When both terminals (positive and negative) are submerged in the electrolyte, a complete electrical circuit is formed so when the DC current is applied over the pieces the electro-polishing process starts.

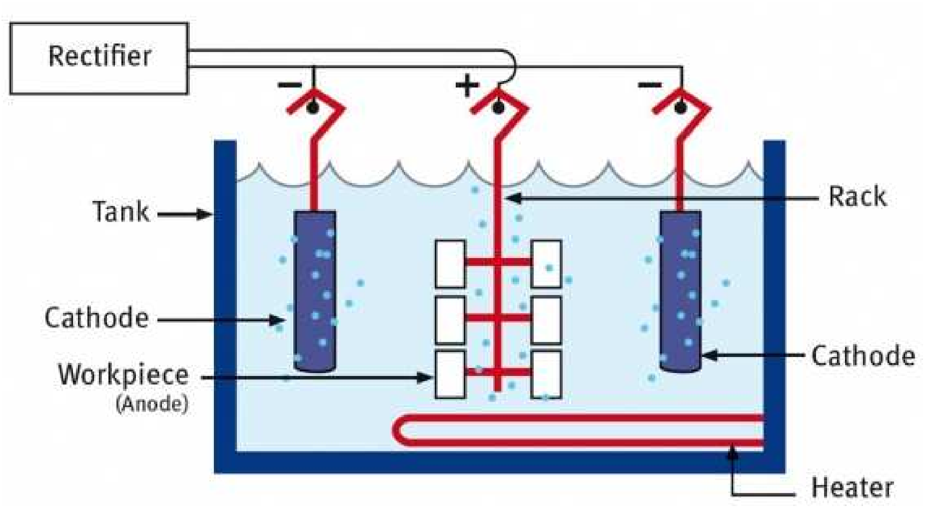


Figure 73. Mains parts of the electro-polishing machine. *Source: www.chimiderouil.com*

There are different models of those machines, but normally all of them have in common:

1) Power source

For the process is needed to apply a continuous current (depending on the electrolyte and pieces the applied current is different). The power source gives this voltage to the rectifier, which transforms it into CC. Then, this current is transmitted to the rack with the pieces.

2) Control panel

To program the desired parameters, a controlling panel is needed. Normally, this panel has:

- Main switch.

  Used to switch on/down the machine.

- Start-stop buttons.

  They are used to start or stop a programmed process.

- Temporizer

  It is used to control the processing time of the pieces. After the programmed time, the machine will turn off.

- Voltage selector

  As told before, depending on the material and the surface, more/less current will be needed. Changing the voltage, we will be able to modify the current that the pieces receive.

- Amperemeter

  It shows the total density current that goes through the rack, allowing the operator to modify the voltage in order to be in the correct parameter.

- Temperature controller

As told before, some electrolytes need a specific temperature for working. This control is used to program the temperature inside the tank.

3) Tank

Its main function is keeping the electrolyte inside him and prevents its contamination. Materials used for the tank have to be chemically resistant to avoid the attack from the electrolyte, although it is possible to coat the tank surface with some material. Most common used materials to manufacture the tanks are:

- Fibber glass
- Acrylic resin
- Polyethylene
- Polypropylene
- Steel (always with some coating)

The size and shape construction depends on the kind of pieces needed to be polished. It is very important the distance between the cathodes and the rack with pieces (anode), also as the distance between the anode and the tank walls in order to get the desired results. The conditions of the electropolishing will change depending on the size of the system.

Figure 74. Electro-polishing tank with cathodes placed inside the bath. *Source: www.indiamart.com*

4) Cathodes

The negative wire from the power source is connected to a metallic plate, called cathode. In this part is where the negative polarity is applied. Thanks to the electrolyte, the positive ions (cations) will move towards the cathode when the current is applied.

Basically, cathode material depends on the electrolyte and material needed to be polished. Most common materials are:

- Stainless steel
- Cooper
- Titanium
- Nickel
- Aluminium

5) Heating system

For a good performance of the electrolyte is necessary to keep a temperature at the tank, so usually a controlled heating system is installed inside the tank. A heating coil is the most used system.

6) Anodic rack

The rack is connected to the positive wire of the power source and its main function is to transmit the electrical current to the hanged pieces. This accessory is not only used for hang the pieces, it can also be used to maintain the pieces in the best possible position to get best results possible. Normally, the larger parts of the pieces have to be focused to the cathodes in order to have more density current in those parts.

Figure 75. Anodic rack inside the tank. *Source: www.techinc.com*

7) Exhausting system

In order to avoid health problems to the operators, an exhausting system is needed for taking all the gases produced by the electro-polishing process.

3.6.3. Materials used for polishing

Basically, the element used for polishing is the bath. There is the possibility to use different chemical products to create the bath, but all of them needs to:

- Separate in positive and negative ions when they are mixed with water.
- React chemically with the metal needed to be polished.
- Needs to be viscous in order to create the anodic layer.
- It has to be a good solvent of the metal polished.
- It doesn't have to react with the metal (has to be neutral) while there is no pass of current through the system.

The reaction between the metal and the chemicals depends basically in the composition of the electrolyte and the metal needed to be polished. Booth variables will determine the voltage needed to polish the pieces. The most common acids and solutions used for the electro-polishing are:

- Orthophosphoric acid (H_3PO_4)
- Hydrochloric acid (HCl)
- Nitric acid (HNO_3).
- Perchloric acid ($HClO_4$)
- Sulphuric acid (H_2SO_4)
- Acetic acid (CH_3COOH)

3.6.4. Parameters recommended for polishing brass and bronze

In next paragraphs I will give some recommendations for polishing brass or bronze from casting. In this polishing system are needed different steps to get the final desired surface, so I will give the best parameters to get a shiny surface.

- <u>Rough down and grind the surface</u>

  In booth metals it is recommended to make some polishing process before putting the pieces inside the electrolytic bath. It can be made for example with a manual polishing, for removing big imperfections that can appear during casting and also to level all the surface to the same roughness.

  This is highly recommended because of electropolishing mainly removes layers from the pieces, which means that big imperfections will remain if they are not removed before.

- <u>Polishing</u>

  There are different possibilities to polish brass and bronze. Because of each company has a secret formula, it is very difficult to get the composition of the baths. All electrolytes described below, are only approximations of the real baths used in industries. In the following tables, I will give two examples of useful parameters for polishing brass and bronze.

OPTION A	
Chemical products for bath	- 950 cm3 of orthophosphoric acid (H_3PO_4) - 50 cm3 of sulphuric acid (H_2SO_4)
Cathodes material	Copper plate or tube, preferably coated with tin-lead or lead alloy
Voltage	5 – 10 V
Current density	22 - 65 A/dm2
Processing time	From 10 to 15 minutes
Temperature	60 to 65ºC

Table 12. Parameters to polish brass and bronze in electro-polishing machine (1). *Source: "Polissage électrolytique et chimique des métaux"*

OPTION B	
Chemical products for bath	- 100 – 300 cm3 orthophosphoric acid (H_3PO_4) - 700 – 900 cm3 of water - 420 g/l of sodium chromate

	- 80 – 85 g/l of sulphuric acid - 180 g/l of chromic oxide - 3 – 6 g/l of hydrofluoric acid - 80 – 150 g/l propionic acid
Cathodes material	Copper
Voltage	14 V
Current density	15 - 38 A/dm2
Processing time	From 5 to 10 minutes
Temperature	15 to 49ºC

Table 13. Parameters to polish brass and bronze in electro-polishing machine (2). *Source: "Polissage électrolytique et chimique des métaux"*

3.6.5. Advantages and disadvantages of the system

After seeing all the information about this polishing system, I can conclude that there are some advantages and disadvantages.

ADVANTAGES

- High quality surfaces can be achieved with this system.
- It is easy to reproduce the same results following a very easy procedure.
- For electro-polishing there is no need of mechanical, thermal or chemical impact. This means that this procedure can be applied for fragile parts and in any kind of shape or size pieces.
- Low processing time in comparison with the other systems.
- As larger is the tank, more pieces of the same metal can be polished at the same time.
- There are no problems to process big pieces, it is only needed a bigger tank.

DISADVANTAGES

- The electrolyte is made of dangerous chemicals.
- Due to those dangerous chemicals, it is very important to take attention in the recovery and disposal waste.
- Due to acids used, in many countries this polishing has been restricted.
- Expensive machine and consumables.
- Due to the layer removing of the electro-polishing, it is possible that after the process the surfaces are not flat at all.
- For the numerous maintenances, a chemist is needed.
- Those machines work with high voltages.
- The space between anode, cathode and wall tanks is very important, so depending on the piece dimension, those distances have to be redesigned.

After seeing all the advantages and disadvantages from electro-polishing machines, I can conclude that those machines are not a good solution for naval brass and bronze pieces. It is an expensive technology which is recommendable to use in parts where the final polishing result is very important (pipping, alimentary industry, medical applications, etc.).

Even thought is not the best solution for naval industry, electro-polishing can be applied for example in small brass or bronze parts used for furniture (hinges, bells, handle door, etc.), which can be easily hanged in the racks.

As told before, for each polishing method I will give a punctuation depending on its effectiveness and limitations in different parameters. After all methods are described, it will be possible to compare all of them in order to see the better one for naval industry.

The punctuation system will be as follows:

+ + Very convenient

+ Convenient

- Not convenient

- - Nothing at all convenient

For electro-polishing finishing, the punctuation is described in the below table:

Polishing method	Cost of machine	Consumables cost	Polishing time	Polishing quality	Automatic process	Number of pieces / process	Use in big pieces	Use in small pieces	Noise
Electro-polishing finishing	- -	- -	+ +	+	+	-	- -	+	+ +

Table 14. Punctuation for electro-polishing finishing. *Source: Own*

Chapter 4. Electro-mechanical polishing.

4.1. Theory of the system

In jewellery industry, the most part of the pieces have a lot of insides surfaces and closed angles (due to the difficult designs). The quality surface demand is very important so it is needed a machine able to gives excellent results in those difficult parts. Due to all these necessities, a new polishing and grinding machine has been developed this last decade. This system is developed in Spain and has very good performances with all types of gold alloys (all different colour and karats), silver, brass and bronze.

Figure 76. Gold ring before/after being polished with the electro-mechanical polishing machine. *Source: Own*

The working basis is very similar to the electro-polishing system. There is an anode (where pieces are hanged) and a cathode in contact with the electrolyte, so when there is pass of current the electrolysis process starts. The ions of the anode surface come off and move to the cathode thanks to the specific electrolyte. In this case, the electrolyte is not made up from acids; it is basically composed by oils and small particles (resins).

As in electro-polishing, with the apparition of current, a polarized layer (with high electrical resistance) is created all around the anode. In comparison with the traditional electropolishing system, the electrolyte produces an organized and thicker layer in all parts (in micro-hollows as well as in the highest points of the surface). This new disposition of the polarized layer produces a smoother finish in all parts of the piece, without affecting the geometry.

The particles mixed with the compound, are used to break this isolating layer generated when the current goes through the rack, so at the point where there is a contact between the piece and the particle, appears an ionic transfer.

Figure 77. The action of the small particles over all the piece surface. *Source: www.hispanaspain.com*

To make possible these contacts, it is necessary to move all the media inside the working tank, so this machine has a sliding brush which mixes the compound while there is pass of current. This allows a lot of random contact points per second between the particles and the piece hanged in the anode. The advantage of the particles size (they have a diameter between 0.1-0.3 mm) is that they can go to all the inside parts of the pieces (breaking the passivation layer) and polish it.

But mixing the compound is not the only purpose of the brushes; their hair is also used to break this polarized layer generated by the current. In conclusion, while the isolation layer is generated, the particles and the brush hair break it, allowing the pass of current where those parts touch.

Figure 78. General view of the EN-34. *Source: Own*

In that system the most part of the metal removed from the piece goes to the cathode, where you can recover the metal. The quantity of metal removed and the final results on pieces basically depends on:

- <u>Compound.</u>

  As I will explain in next chapters, depending on the metal of the piece it is needed a different compound.

- <u>Voltage through the rack.</u>

  Depending on the material, different voltage will be needed to get the desired result. If the voltage is not correct the surface after the process will not be shinny.

- <u>Processing time</u>

  It will change depending on the initial surface of the piece and the desired final results.

To guarantee the shorter processing time and the best results possible it is recommended to do a selective grinding in order to rough down the surface. This procedure will remove all the imperfections of the piece and homogenise the surface.

Most pieces in jewellery are small so actually the machine is not thought for very large polishing surfaces. Otherwise, some changes on the machine can allow us to grow in capacity and size of the pieces, permitting enter in other industries.

4.2. Description of the machine

Before starting a process with the machine is necessary to hang all the pieces at the hooks. Then we can put the rack in the anodic contacts of the working tank and program the parameters of the process desired.

Figure 79. Anodic rack with hooks, where the pieces are hanged. *Source: Own*

The main part of the machine is basically the working tank where the electro-polishing is done. Inside the tank there are the pieces hanged in the hooks and also a pair of cathodes. The anode (with the pieces) is placed between a pair of brushes, a fixed one and also a sliding brush. This last one moves the compound allowing to the particles going to all the surface of the piece.

Figure 80. General view of inside the working tank. *Source: Own*

This is not the only purpose of the brushes. The hooks are between the brushes so when the sliding brush moves the hair it hit the pieces, pushing them to the fixed brush. This constant contact of the pieces and the hair of both brushes breaks the polarized layer of the pieces, causing more electro-polishing points.

After pressing the ON button, a process starts, so the motor runs and the sliding brush begins the mixing of the compound. After 30 seconds, and depending on the power programmed, a voltage will go through the rack to the pieces, starting the electro-mechanical polishing process.

The main parts of the machine are:

1) Machine frame

This is the metallic structure of the machine where all the components are fitted. The total machine dimensions are 450 x 390 x 370. Considering the rinsing tank, the machine increases its dimensions until 660 x 390 x 370.

It is possible to divide the structure in:

- Electrical cabinet

  In the rear part of the structure there are all the electrical components which set up the machine. Inside this part there is also the motor which allows the movement of the sliding brush.

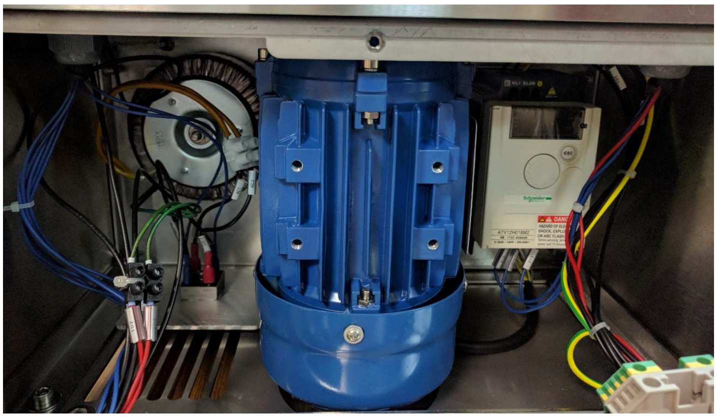


Figure 81. Interior of the electrical cabinet (1). *Source: Own*

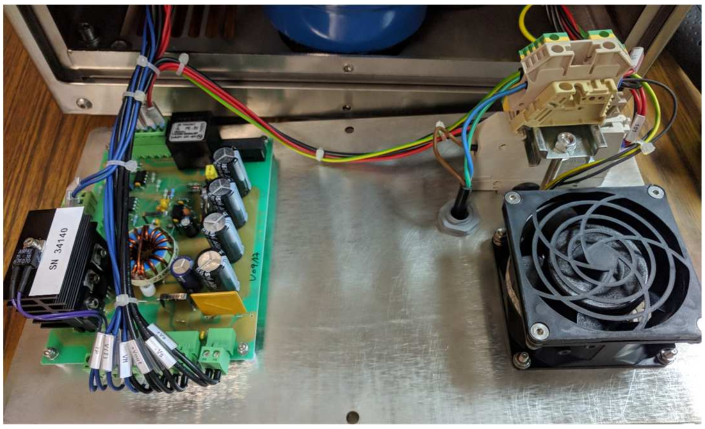


Figure 82. Interior of the electrical cabinet (2). *Source: Own*

- Electrical cabinet plate separator

There is an aluminium plate which divide the machine, separating the electrical cabinet from the working tank. This plate is also used to hold the motor, and to fix the driving head and the working tank to the structure.

Figure 83. Electrical cabinet plate separator. *Source: Own*

- Metallic cover

It is the upper plate of the machine, the visible part for the operator. It is divided in two different plates, which together forms the whole metallic cover. Plate number 1 where there are all the controls. Plate number 2 which covers the working tank and it is also where the plastic cover is resting while the machine is working.

Figure 84. Parts 1 and 2 are the metallic cover of the EN-34. *Source: Own*

2) General switch, START and PAUSE buttons

There are three controllers in the machine.

- General switch

  It is placed in the rear part of the machine, and it is used to turn on the machine.

- Start button

  The green button is fixed on the upper part of the metallic cover, and it is used to begin a process.

- Stop button

  The red button is fixed on the upper part of the metallic cover, and it is used to interrupt a process while the machine is working.

3) Programming panel

We can divide the programming panel in two parts:

- Programming screen

  In this part we are able to change the processing parameters, and it is localized in the right part. The value of those parameters depends on the metal and the alloy. We can program:

  - Power
    This value is related directly to a voltage and depends on the metal and the alloy used. If the power is not correct, the result will not be the as good as desired (bad polishing and shine of the surface).
  - Pulses
    In some alloys (mainly in gold), to get better results is useful to program pulses of current while the process is running. Pulses means that the current will not be continuous. With EN-34 machines is possible to change:

- T. ON
  Also called time of current ON. The value determines how much time there is pass of current through the rack (units in milliseconds).
- T. OFF
  Also called time of current OFF. The value determines how much time the current is interrupted (units in milliseconds).

- Time process
  Depending on the initial surface of the pieces it will be necessary more or less time. Time also depends on the metal and the alloy. Having the same initial surface, from casting, the processing time (from less to more time) is:
  - Silver
  - Gold
  - Brass
  - Bronze

- Lecture screen

While the machine is working, in the left screen we can see:

- Voltage
  Thanks to this screen it is possible to look at the voltage. As explained before the voltage is related to the power programmed.
- Current
  The current that goes through the rack depends on the metal and number of pieces, which are the resistance of the system.
- Remaining process time
  The screen shows the minutes remaining before finishing the process.

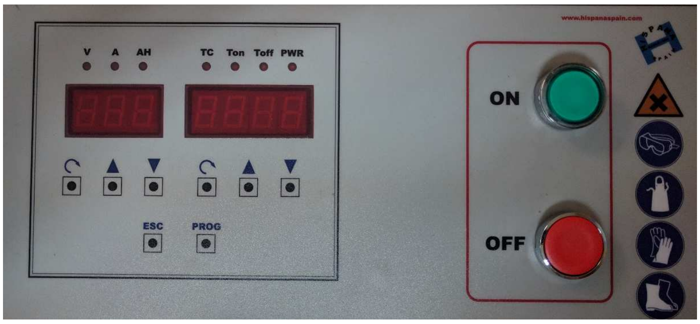


Figure 85. Programming panel of the machine. *Source: Own*

4) Working tank

The working tank is a PVC compartment where the process runs. The compound is poured into it, and thanks to the current between anode and cathode, the polishing process can start.

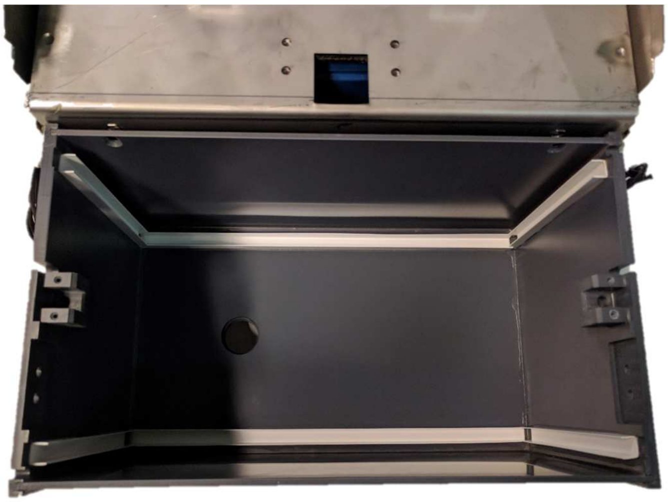


Figure 86. View of an empty working tank. *Source: Own*

There are different components inside the working tank, so it is possible to classify them into the following ones:

- Anodic connection to the rack

  The rack is composed by a stainless-steel bar with titanium hooks fixed on it. The rack has to be fitted at the anodic contact inside the working tank so when there is current, all the workpieces hanged in the hooks will have electrical contact.

  To get this current, it is necessary to have a electrical connection. The anodic connection to the rack is composed of:

  - Plastic piece used to hold the bar rack.
  - Metallic pressuring rack piece. It is the receptor of the current and it is used to maintain the rack inside the anodic connection.
  - The pressure spring of the rack, which is only used to guarantee good electrical contact between the rack and the metallic pressuring rack piece.

Figure 87. Anodic connection to the rack, fitted inside the working tank. *Source: Own*

- <u>Cathodes</u>

There are a pair of cathodes inside the working tank. The recovering of the metal adhered will be made after several hours of use. Those cathodes can be made of different materials.

- Stainless-steel cathode.
  Those cathodes are made of folded stainless-steel plate. Those folds are used to have more cathodic surface (better ion transmission during the process).
  It is the most standard cathode because can be used for all materials. To recover the metal there are two options; scrap the surface of the stainless-steel plate or put it inside a stripper chemical solution.

Figure 88. Stainless steel cathode. *Source: Own*

- Organic cathode.
  They are called organic cathodes because are made of thin filaments of organic material covered with a thin layer of nickel. As it is composed by filaments, it has a lot of cathodic surface, allowing a better transmission than the stainless-steel cathodes.
  It can only be used for gold, and to do the recovering process normally they are burnt. This means that can only be used one time.

Figure 89. Organic cathode. *Source: Own*

- <u>Brushes</u>

There are two different brushes inside the working tank; the sliding brush and the fix brush. Those parts make possible the contacts between the pieces and the particles that are mixed with the compound (in order to break the polarized layer). Their hair it is also used to break the isolation layer which appears with the pass of current.

Rack with pieces is fitted between booth brushes so when the sliding brush push the pieces, they also touch to the fixed brush. In other words, we can say that the rack is fitted in the middle of a hair wall.

- Sliding brush
  The sliding brush is fitted inside of the driving head, which thanks to a motor allows its movement. The brush has different kind of movements in the working tank thanks to the driving head design.

Figure 90. Sliding brush for EN-34. *Source: Own*

- Fix brush
  It is fitted on the working tank, in the opposite wall from the sliding brush. When the sliding brush pushes the pieces, they touch with the fix brush hair.

Figure 91. Fix brush for EN-34. *Source: Own*

- <u>Emptying cap</u>

  It is placed in the bottom of the PVC part so when it is necessary to remove the compound from working tank inside's, by loosen the cap (with a gasket) all the liquid comes out from the compartment.

5) Motor

A motor is needed in order to make possible the movement of the sliding brush. The rotational movement of the motor has to be transformed and transmitted to the sliding brush. The used tool is the driving head. The velocity of the motor is very important in order to get a good polishing result in a reasonable time.

6) Driving head

It is necessary an element which transmits the movement from the motor to the brush. This function is made by the driving head, which is composed by different stainless-steel machined parts and bearings.

Figure 92. Driving head fitted on the electrical cabinet plate separator, with the brush at its end. *Source: Own*

This part, fixed on the electrical cabinet plate separator, changes the rotational movement of the motor to a:

- Translation movement.
- Rotational movement.

Those are not all the movements that the sliding brush has. Thanks to a bearing that connects the brush with the driving head, another rotational grade is added to the brush. This allow to the brush to spin on its own axis.

Thanks to all those movements, the sliding brush attacks the pieces in many different angles, causing an optimum polishing of all piece's parts.

7) Rinsing tank

When the process has finished, it is very important to clean the pieces. In order to make this cleaning, the machine has a rinsing tank with a pair of compartments.

- First compartment has deionized water and a special compound for rinsing the pieces.

- Second compartment only has deionized water.

By rinsing the pieces in this tank is not enough for cleaning them. In order to remove liquid layers that can remain in the pieces, it is necessary to put them also inside of an ultrasonic cleaner.

Figure 93. Rinsing tank fitted in front of the EN-34. *Source: Own*

4.3. Materials used for polishing

The machine can grind and polish different kind of metals, only by changing the compound. If the compound used is not correct, we will not achieve good results. This compound is basically made of:

- Water
- Surfactants (like oils)
- Chemical additives
- Small ion exchange resins

Figure 94. Mixed compound ENSI010 inside the can, before pouring it to the machine. *Source: Own*

The mix of oils and small particles is made by the manufacturer, so the operator only needs to put the compound inside the working tank. This system is developed by only one company, Hispana de Maquinaria S.A., so the names used below are their commercial names.

- EN0010 compound.

  This compound is used for gold alloys from 9KT to 18KT.

- EN0024 compound.

  This compound is used for gold alloys from 20KT to 24KT.

- ENSI010 compound.

  This compound can be used for:

  - Silver
  - Brass
  - Bronze

As told before, when the process is finished it is necessary to clean the pieces inside the rinsing tank. The first rinsing tank has a special compound mixed with deionized water. Depending on the processing compound used, the rinsing compound can be:

- For EN0010 compound, rinsing compound ENJ010 is needed.
- For EN0024 compound, rinsing compound ENJ024 is needed.
- For ENSI010 compound, rinsing compound ENSI010 is needed.

4.4. Parameters recommended for polishing brass and bronze

In next paragraphs I will give some recommendations for polishing brass or bronze from casting. In this polishing system there is no need to do different steps to get the final polishing results, even thought if the initial surface is very bad, it is advisable to do a previous grinding in order to remove all the big imperfections. This step can be done with a manual polishing machine.

For making the polishing, compound ENSI010 will be used (useful for silver, brass and bronze alloys). To get the desired results we need to change the voltage that pass through the rack. To modify the voltage, we have to adjust the power setting.

Figure 95. Silver ring before/after being polished with the electro-mechanical polishing machine. *Source: Own*

Normally, for brass and bronze, most used parameters are:

- Brass

  We usually work with powers between 45 and 50 (depending if they have some special alloy) which is equivalent approximately to 7.5 - 8V. Time depends on the initial surface.

- Bronze

  We usually work with a power of 50 (depending if they have some special alloy) which is equivalent approximately to 8V. Time depends on the initial surface.

4.5. Advantages and disadvantages of the system

After seeing all this information about this polishing system, I can conclude that there are some advantages and disadvantages.

AVANTAGES

- The electrolyte doesn't have any dangerous or hazardous chemical.
- It is possible to do all the grinding and polishing in one process.
- Perfect system to respect the shape design of the pieces, also as for very close edges and difficult parts.
- In comparison with all the other systems, polishing time per piece is lower.
- The cost of compound per piece is very low (around 0,02€).
- In comparison with all the other systems, it is not noisy.
- All the metal removed remains inside of the working tank, so it is easy to recover it (very important in jewellery industry, where precious metals are used)

DISADVANTAGES

- The operator needs knowledge about the process, to adjust the correct parameter depending on the alloy.

- Still not a system thought for large pieces and productions.
- There is a lot of splashing compound to outside of the working tank, which fouls the machine.
- To buy the machine a strong investment is needed. Nowadays, the price of the machine without any accessory and compound is 8.000€.
- A pre-polishing process is needed to remove all the big imperfections (rough down the surface).

After seeing all the advantages and disadvantages from electro-mechanical polishing, I can conclude that nowadays this system is not optimized for this kind of production. To assume the production of brass or bronze naval pieces it is necessary to increase the dimensions of the machine. Because of the working dimensions of the brushes are 300 x 80 mm, it can only be used to process small pieces like hinges or small brass or bronze furniture parts.

By resizing the machine, it is possible to do a new machine with the same characteristics, but which is able to do bigger pieces and needs a very good polishing surface.

In the future, electro-mechanical polishing can be interesting for finishing the propellers surface because this technology respects all the original shapes, it doesn't modify the edges and the angles. This allows to the operator to maintain as best as possible the designed shape, and made a more efficient propeller.

As told before, for each polishing method I will give a punctuation depending on its effectiveness and limitations in different parameters. After all methods are described, it will be possible to compare all of them in order to see the better one for naval industry.

The punctuation system will be as follows:

+ + Very convenient

\+ Convenient

\- Not convenient

\- - Nothing at all convenient

For electro-mechanical finishing, the punctuation is described in the below table:

Polishing method	**Cost of machine**	**Consumables cost**	**Polishing time**	**Polishing quality**	**Automatic process**	**Number of pieces / process**	**Use in big pieces**	**Use in small pieces**	**Noise**
Electro-mechanical finishing	- -	+	+	+ +	+	-	- -	+	+

Table 15. Punctuation for electro-mechanical finishing. *Source: Own*

Chapter 5. Problems in the EN-34.

As I told in the introduction, the EN-34 has been commercialized before a good testing, causing a lot of problems to customers. In this chapter I will analyse and describe all the problems of the actual machine, and in next chapter I will give some solutions for improving all these weak points described.

5.1. Electrical isolation of the connections

Due to the movement of the sliding brush, there is a lot of compound splashing inside the working tank, causing corrosion problems in all the electrical connections.

5.1.1 Anode connections

The anodic plastic supports of the rack are inside the working tank (one on each side). It is necessary to take the current from the power supply to the rack, so there are electrical connections in these supports which transmit the current from the machine to the rack (with pieces hanged).

There is a hole on the working tank which allows the wire to going inside and, as it is shown in the picture, there is a connection done between the wire and the plastic support with a screw, some washers and nuts. A metallic pressuring rack piece fitted in the same screw makes the electrical contact with the rack.

Figure 96. View of the anodic connection inside the working tank. *Source: Own*

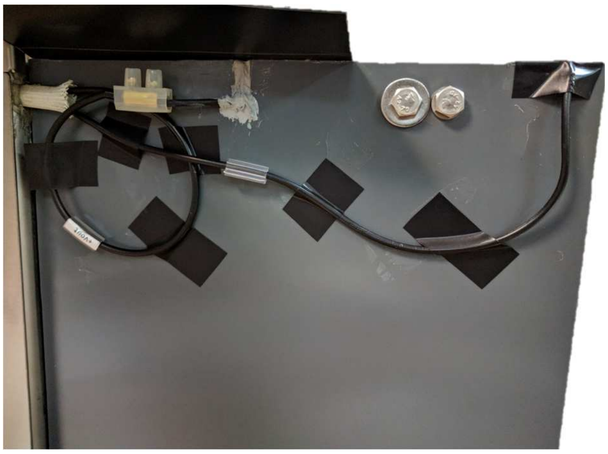


Figure 97. Wires placed outside the working tank for the anodic and cathodic connections. *Source: Own*

Even though the wire is protected with insulating plastic, the splashing of the brush movement wets all these parts with compound, causing corrosion problems. Consequently, after some time it is necessary to change all the connections in order to guarantee good electrical transmission.

A bad current transmission will increase the electrical resistance, so the current that arrives to the pieces hanged at the rack, will not be correct. The objective is to change the electrical connection of the anode in order to move it away from the compound, avoiding the corrosion of the copper.

5.1.2 Cathode connection

Actually, there are a pair of terminal strips (a mechanized stainless-steel terminal) inside the working tank, which connects the cathodes with the corresponding cathodic wire that comes from the power supply (there are two cathodes, one in each side of the working tank).

As the terminal is inside the working tank, the wire that makes the connection has to go also to inside's the tank. Sometimes, due to the movement of the sliding brush, the wire breaks.

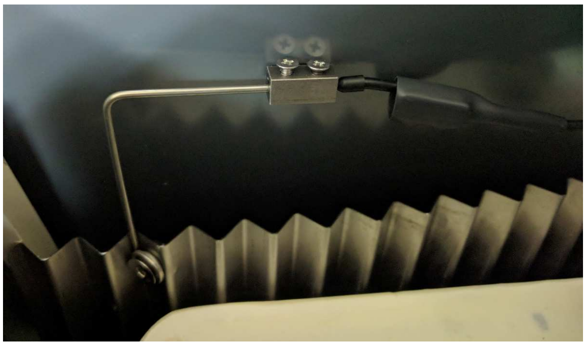


Figure 98. Connection inside the working tank between the cathode and the negative wire. *Source: Own*

Even though those terminals are protected with a plastic cover (can be seen in the Figure 98. Connection inside the working tank between the cathode and the negative wire. *Source: Own*8), due to the movement of the sliding brush the compound goes inside the terminal, corroding mainly the copper wire. This causes that after some time, the connector of the wire can break because of the corrosion of the copper. The compound (with resins) that goes inside the stainless-steel terminal, also recover all the inside walls, increasing the electrical resistance.

The main objective is change the electrical transmission between the cathode and the negative wire, in order to avoid electrical problems due to the compound splashing.

5.2. Mechanical resizing

5.2.1. Sliding brush

The sliding brush is mainly composed by:

- Bearings

  A metallic machined piece on top which allows the location of a pair of bearings. This piece joints the sliding brush with the moving driving head. It also gives another degree of freedom to the brush; giving the possibility to rotate.

- Brush structure

  A stainless-steel structure composed by two shafts welded, perpendicular one from the other. Actually, the vertical shaft (which is fitted in the bearing mentioned before) is 10 mm diameter. The other one is a stainless-steel M-5 bar which goes through a hole of the other shaft. Those two shafts are welded with some nuts in order to joint them permanently.

- Hair brush

  The hair brush is used to move the resins and break the isolating layer of the pieces. This hair is 0,2 mm diameter; as more diameter less flexible and less corners will reach. After tests, it is possible to say that this is the optimum diameter for jewellery because the hair can go to all the insides.

- Bicomponent resin

  A bicomponent resin used to grab the hair brush to the metallic structure.

Due to all the resistant forces that the compound makes to the sliding brush, and the friction between booth brushes, after some time the moving one breaks. Those extreme forces basically appear due to bad maintenance of the compound. It becomes too viscous so the needed force to move the compound is too high, and the brush breaks prematurely.

The first objective is to find an easy way to maintain the viscosity of the compound. The second one is increase the diameter shaft and remove all the welded parts from the structure in order to improve the life of the sliding brush.

5.2.2. New motor

The actual machine has a motor which has not the enough power when the compound gets too much viscous. When this happens, the motor fails and the process stops. Although I find a way to maintain the viscosity of the compound, it is also necessary to change the engine in order to not force the motor while it is working.

The characteristics of the actual motor are:

Actual motor used	
Brand motor	VEM
Phases	Triphasic
Motor case	MSE 63
Fastening flange	B14
Power	0,25 CV / 0.18kW
Number of poles	4
Cos ϕ	0.65
Velocity	1500 rpm
Voltage	230 / 400
Frequency	50 Hz
Protection grade	IP 55
Weight	4.2 kg

Table 16. Characteristics of the actual motor installed in the EN-34. *Source: www.cosgra.com*

This component is fixed in the main structure of the machine thanks to a steel piece of 8 mm. This plate allows hanging the motor to the aluminium structure, and the position of the shaft is looking up, raising from the electrical cabinet in vertical position. This allows the fixation of the driving head with the motor.

The main objective is look for a motor that can work with higher forces (in order to prevent the failures), and also do all the necessary modifications in the machine to install this new model.

5.3. Splashing of the compound

The EN-34 machine has a lot of problems with the splashing of compound to all the interior parts of the machine. Due to the semi-liquid compound and the sliding brush, which mix it, a lot of waves are produced causing that the compound goes out from the working tank.

The main moments of the process where there is some splashing are:

- <u>The machine starts a process after some time stopped</u>

  After some time without mixing the compound it divides in two phases:

  - Liquid on the top of the compound
  - Particles mainly in the bottom

  Before those parts mix and form a uniform liquid, it is easy that the most liquid part splashes because of its viscosity and the sudden movement of the brush.

- <u>The sliding brush moves near to the fix brush.</u>

When the sliding brush arrives near the fixed brush, this last one acts like a wall, causing a wave in the middle of both brushes. This one is the heaviest and most visible splashing produced, because normally some compound arrives at the polycarbonate cover.

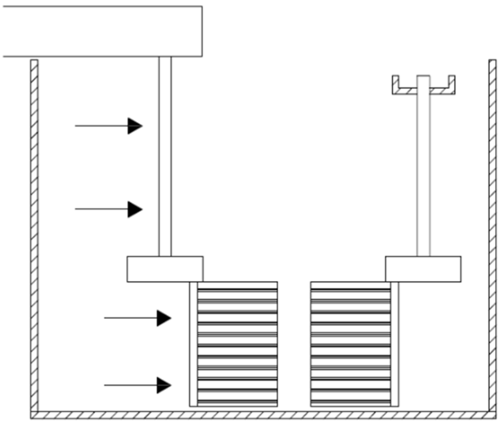


Figure 99. Approaching of the sliding brush to the fix brush. *Source: Own*

- <u>The sliding brush moves near to the working tank wall</u>

  With the approaching of the sliding brush to the rear wall of the working tank, it occurs the same as in the previous case, a big wave is created between these two parts.

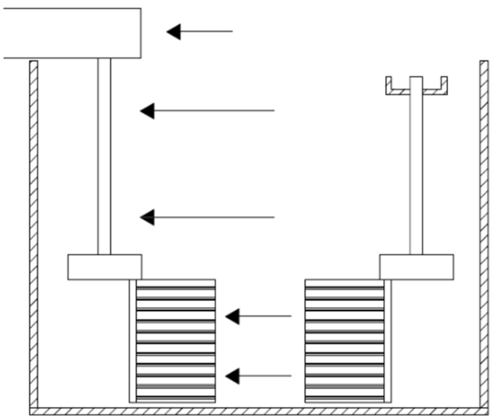


Figure 100. Approaching of the sliding brush to the working tank. *Source: Own*

In the following list there are described some problems that the splashes produce:

- Compound goes to all the electrical connections that are inside the machine, giving problems at the anode as well as in the cathode.
- Compound splashes arrives to inside the upper part of the electronical cabinet, damaging the programming plate. This is a very common spare of the machines due to all the compound that arrives to this plate.
- The plastic support and the metallic pressuring plate of the rack are totally wet with compound and particles. This gives a lot of problems to move the metallic plate over the rack.
- The splashes are so huge that there is compound in all the proximities of the working tank, also in the polycarbonate cover of the machine. Most of these parts are made of stainless-steel, but with the continuous contact with the compound get rust.

Nowadays those problems are partially solved basically with the following two accessories:

- Metallic plate used to cover the top of the working tank.

  This plate is fitted in the structure of the machine. It is not a completely closed plate in order to allow to the operator to fit the rack on the plastic supports of the working tank. This opening is in the middle of the working tank so a lot of compound comes out from this place when the sliding brush moves near to the fix brush.

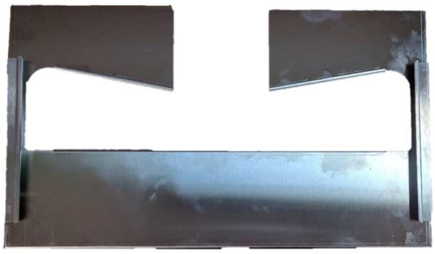


Figure 101. Metallic plate which covers the working tank. *Source: Own*

- Splashing plastic protectors.

  It is composed by a pair of plastic parts that can be fitted in the metallic plate before described (thanks to a pair of guideways). One of the protectors is placed behind the shaft of the sliding brush. The other one is placed in the front part of the brush and it is possible to slide it in order to leave the opening free for fitting of the rack.

  This accessory is designed to cover the hole that the metallic plate has. When the two plastic protectors are assembled, forms a circle in the middle, which allows that the shaft of the brush goes to inside the working tank.

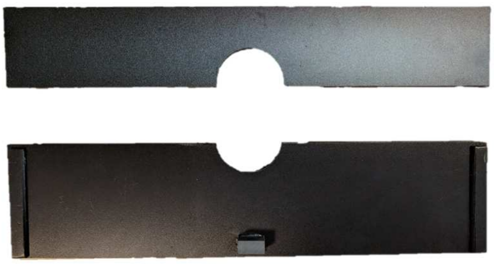


Figure 102. Splashing plastic protectors, fitted over the metallic plate. *Source: Own*

The first objective is removing the splashes. As this would not be possible at all, because the composition of the compound cannot be changed and the rotational velocity of the motor has to be the same, I will try to avoid that the splashes produced by the movement of the brush do not go outside the working tank, getting dirty the whole machine and damaging some parts.

Figure 103. All the protections against the splashing fitted in the machine. *Source: Own*

5.4. Pressure spring for rack

The rack needs something that makes an upper force when it is fitted in its plastic support. This is needed in order to guarantee a good electrical contact with the metallic pressuring piece. The function is made by the pressure spring of the rack which has a U shape and it is fitted in the hole of the plastic support.

Figure 104. Pressure spring for the rack. *Source: Own*

Actually, this handmade spring is made up by:

- Stainless-steel wire 1.6 mm

  This wire is moulded with a U shape, and all the other materials are assembled on it. Acts like the internal structure of the spring giving the desired shape to the whole assembling.

- Silicone tube of 6x4 mm

  This silicone tube recoats all the stainless wire and gives some thickness to the spring.

- Silicone tube of 8x6 mm

This silicone tube only recoats only the upper part of the U, in order to give more thickness at the part where the rack touches. Thanks to this extra thickness, the rack touches the metallic pressuring piece.

- Hexagon socket set screw M4x6 DIN 913

  There are a pair of this pieces fitted at the end of the silicone tube. They are used to not allow that the compound goes inside of the silicon tube.

The function of all this assembly is make force over the rack fitted on it (thanks to its elasticity). This can be done easiest, so the objective is to simplify this spring in order to do not manufacture it so manually and without so many different materials.

5.5. Rinsing tank

Nowadays the rinsing tank is made of PVC in order to avoid scratches when the pieces are rinsed. If the metal pieces hit the walls or the bottom, they will not be affected (PVC is a softer material than gold, silver, brass or bronze).

The rinsing tank has a pair of ears to hold the tank from two screws of the machine. As this material is not very resistant those parts break very easily when the customer tight the screws over the ears (to avoid that the rinsing tank falls down). In conclusion, this tank is a common spare after some time of working.

Figure 105. Ears that holds the tank to the machine. *Source: Own*

The objective is to make a more resistant rinsing tank and take advantage of the new material to have a better finishing of the rinsing tank.

5.6. Junction between working tank and electrical cabinet plate separator

For a constructive purpose, the working tank has a wider base, causing that the rear wall does not touch with the electrical cabinet plate separator where has to been fixed. As there is some space (3 mm) between the plastic wall and the metallic structure, appears some bending of the plastic wall.

Countersunk screws are used to fix the working tank, and are placed very close to the wall edge. Those screws are used in order to hide the head with the surface of the plastic wall. Nowadays, the tank is only fixed with a pair of screws, and this is not enough for all the surface that have to hold (360 mm).

In conclusion, due to the position and the number of the screws, it is usual that the PVC wall can crack, even break, on the top of the wall, where the screws are tightened.

Actually, to solve this separation problem between the metallic structure and the working tank, there is a foam rubber junction with a pair of plastic washers that coincide with the screws. Thanks to it, when both are tightened there is something elastic which not allows the bending of the plastic wall.

Figure 106. Junction used between the working tank and the electrical cabinet plate separator, which prevents wall bending. *Source: Own*

This junction is also used to prevent that the compound (liquid and resins) does not goes to the rear part of the working tank. After some uses this foam is full of liquid from the splashes of compound and becomes not very useful because cannot retain more liquid. At his point needs to be changed.

The first objective is look for some solution that avoids this breaking of the top of the working tank due to the screws, and the second one is changing the actual system of rubber junction.

Chapter 6. Suggestions for improving the EN-34.

After see all the problems in the machine, I will give some suggestions for improving the actual design of the machine.

Before enumerate the possibilities, it is important to follow a premise for all the modifications of the machine. Due to some customers only want one machine to produce different kind of metals (which means different compounds used), it is necessary to have an easy assembling of the working tank.

It is very important to do not mix compounds inside the working tank in order to avoid possible contaminations. This can only be made if the whole set of the working tank and all the things in contact with the compound (brushes, cathodes, etc.) are changed. With some practice, the estimated time for doing the change of the working tank and all the components is approximately 1:30 hour.

Nowadays, this is not very easy because it is needed to remove a lot of different connections and screws. In this project all the improving suggestions of the machine will be done thinking on make an easier and faster assembling of the working tank.

As there is no need to maintain the actual dimensions of the machine, all the following suggestions for improving are made considering that the actual dimensions and the structure of the machine will be studied and can be resized after all these changes.

6.1. Electrical isolation of the connections

6.1.1. Anode connections

As explained in chapter 5.1.1, the actual electrical connection is made inside the working tank. Considering that the system always splashes, it is necessary to think a way to move away the anode connections from the compound. The best way is to make the connections outside the working tank and transmit the voltage to the pieces thanks to the metallic pressuring rack piece.

Having this in mind, by only changing the design of the anodic plastic support of the rack, will be enough to avoid the corrosion of the copper wire. In the new design, this part will be divided in two:

- Half of the piece outside of the working tank

  This part will have two threaded holes: one where the connection screw of the copper wire is assembled and the other one which will be used as a stopper of the metallic pressuring piece.

  As the screw is longer than the support plastic piece, it is possible to make the connection at the end of this screw (like is done until now). The wire will be fitted at the screw with a rounded terminal covered with PVC (for M-3 screw, Ref: BM00207), between a pair of washers to ensure a good contact and a nut holding it in its place.

Figure 107. Connection for the anodic wire. *Source: www.tme.eu*

To transmit the current from plastic support to inside of the working tank, a metallic pressuring piece for the rack will be fitted on the tops of the screw. This component will be different from the actual in order to allow this electrical transmission from outside the working tank.

- Half of the piece inside the working tank.

  At the centre of the plastic support will be a hole to place the pressure spring for the rack. This part will be only used to place the rack on it.

If it is needed to remove the working tank, to disassemble easily the anode connections it can be helpful to divide the anodic wire in two different parts, and put a special electrical component to do the connection.

- The anodic wire that came from the electrical cabinet

  This is the wire connected directly to the power supply, which comes through the plate separator. At the end of this wire will be fitted a female terminal covered with PVC (Ref: BM00240).

Figure 108. The female terminal proposed. *Source: www.tme.eu*

- The anodic wire connected to the working tank screw.

  This is the wire used to connect the working tank to the wire that comes from of the electrical cabinet. To connect it to the other wire, one end of this wire will have fitted a male cylindrical terminal covered with PVC (Ref: BM00230).

Figure 109. The male terminal proposed. *Source: www.tme.eu*

  The other end will be connected to the connection screw of the working tank thanks to a rounded terminal (Ref: BM00207, as explained before).

In conclusion, with these improvements we will:

- Move away the anode electrical connections from the compound.
- Facilitate the connection and disconnection of the anodic wire from the working tank (only unplugging the male-female terminal).

6.1.2. Cathode connection

As explained in the chapter 5.1.2, the actual electrical connection of the cathodes is made inside the working tank (it is in contact with the compound). To improve it, I have taken an idea from some models of jewellery plating machines.

Figure 110. A plating machine, with cathodic bars. *Source: www.sempsajp.com*

The principle of this new connections is having a metallic bar connected to the cathode wire, so placing the cathodes on this bar will be enough to be connected to the negative of the power supply (see Figure 110. A plating machine, with cathodic bars. *Source: www.sempsajp.com*10). In this case, the connection of the wire can be made outside the working tank (behind the electrical cabinet plate separator), so there is no problem about the corrosion due to splashing.

As there are two cathodes, a pair of stainless-steel bars (one for each cathode) will come from the rear part of the machine (from the electrical cabinet) and will rest over the working tank. The cathodes will need also some kind of connection; they will have a pair of hooks to hang the cathode from the negative stick and give the electrical contact.

The cathodic metallic bars will be of 8 mm diameter. An isolating piece is needed while the bars are crossing the metallic plate separator. good material for this purpose is nylon, so those 4 holes will be recovered with these electrical isolating pieces.

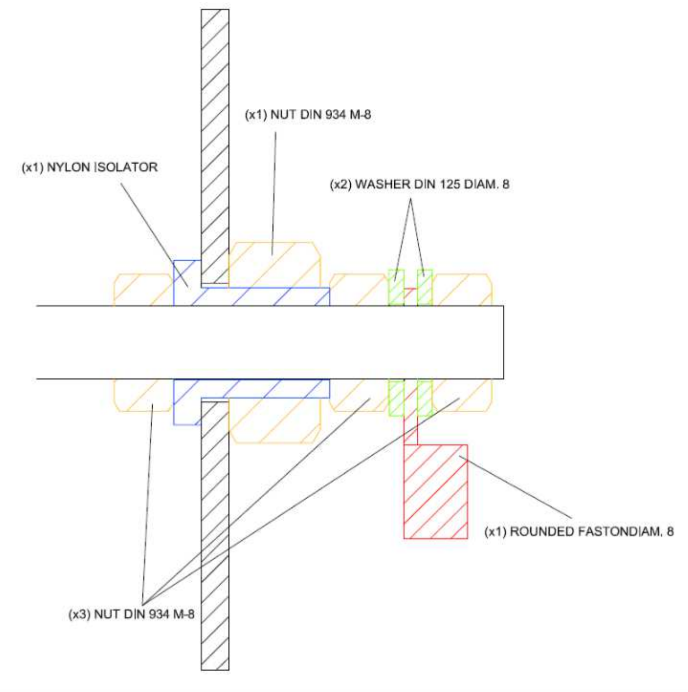


Figure 111. Schematic drawing of the new cathode connection. *Source: Own*

As told before, the cathodes will need a new connection to hang them from the metallic stick. Considering that there are two different kind of cathodes (depending on the metal needed to be polished):

- Stainless-steel cathode.

  They are 1.5 mm thickness and in order to have more surface, those cathodes have some folds. To hang them from the bar they will have a pair of prolongations that will be used as hooks. This prolongation will have a folded part (like all the cathodes, just in order to get more rigidity) and the final part will be curved to allow the hanging from the metallic bar.

  This curvature at the end, will allow to the hook to enter by pressure at the stainless-steel bar (thanks to its elasticity).

- Organic cathode.

  They are 6 mm thickness and as they are made by a mesh of material, they have a lot of surface. To hang them from the bar, a compressed copper plate with a pair of copper welded hooks will be placed on top of the cathode.

  In this case, when the cathodes are placed on the bar it will be necessary to make pressure over the copper hook to close it and ensure a good electrical contact between the cathode and the metallic bar (copper is a ductile material).

Thanks to this redesign of the cathodes connection we will:

- As the electrical connection between the stainless-steel stick and the wire is made in the electrical cabinet, we will move away the electrical connection from the compound.
- As there is more surface in contact between the bar and the hooks (in comparison with the old connection system with a stainless-steel terminal), we can ensure a better electrical contact
- As there is not any wire inside the working tank, we will avoid their breaking.
- As there is no necessity to loosen up any screw, it is easier and faster to remove the cathodes.

6.2. Mechanical resizing

6.2.1. Sliding brush

As explained in the chapter 5.2.1. the main fatigue problems of the sliding brush come from a bad compound maintenance, and as consequence the brush fails very often.

Figure 112. Broken sliding brush due to fatigue. *Source: Own*

I will give a solution for maintaining the viscosity of the compound, as good as a new resizing brush structure.

a) Maintaining the level compound

To have the electrolyte in good working conditions and with the correct viscosity, it is only necessary to maintain the compound level. This level decreases due to the evaporation of water and due to sweep along some compound when we remove the rack from the working tank.

As described in chapter 4, the compound is made by the following different components:

- <u>Ion exchange resins</u>

  The most part of the particles will be in the first rinsing tank. Thanks to the compound added into it, we can recover those particles with a filter and add them again into the working tank.

- <u>Water</u>

  Due to the high temperatures of the working room (specially in summer) and the heat of the engine, there is some water evaporation.

- <u>Surfactants and chemical additives</u>

  Those components will sweep along with the rack after removing the rack from the working tank. I assume that those components loss is a minor percentage, and I can disregard it.

In conclusion, to reach again the initial level it is necessary to first of all, add the resins from the first rinsing tank. Once resins have been poured, then add deionized water until reaching the initial level.

Actually, the machine does not have any mark of the initial level but can be made in some part of inside's working tank. This mark can be engraved in the PVC working tank. To do it visible for the operator, the best place is in both lateral walls, where there is not anything that can cover the mark.

The mark has to be at the level reached when a new compound is poured inside the working tank. After doing this operation into a machine, I have measured the level so the mark has to be at 140 mm from the bottom of the tank. To ensure that there is some tolerance when water is added, it is necessary to have a line of some thickness.

To have an idea of the thickness dimension of the line, first of all I will calculate the equivalence of how many centilitres are needed to increase 1 mm the compound height. As the interior dimensions of the working tank are 355x208 mm:

$$V_{1mm\ increasing} = Base\ x\ Width\ x\ 0{,}01\ (l) \tag{1}$$

$$V_{1\ mm\ increasing} = 3{,}55\ x\ 2{,}08\ x\ 0{,}01 = 0.07384\ l = 7.384\ cl \tag{2}$$

I can consider that a tolerance of 15 cl is enough, which is equivalent to a 2mm thickness mark line. It is better to centre this line into the initial height of 140 in order to give tolerance in both ways; when there is too much or not enough water. In other words, the engravement will start at the height of 139 mm (from the bottom of the working tank) and will be 2 mm tall (will arrive at the height of 141 mm).

This tolerance will ensure a good working of the compound and good viscosity. This will also ensure less splashing of compound with the brush movement.

b) Increasing the sliding brush life

Actually, most customers' needs to change the brush before the hair is damaged due to working. There are mainly two aspects to improve the life of the brush against the fatigue.

RESIZING THE BRUSH STRUCTURE

In this chapter we will calculate which is the diameter needed in order to avoid breaking due to fatigue. The actual brush shaft is only 10 mm diameter, so provably for the load that has to hold (compound opposite force) is not enough. Provably, to ensure a better performance it will be advisable to use a shaft of 12 mm diameter.

In this case is not possible to know the forces that acts over the brush, but we can determine that the moment created by the compound will be always the same (independently on the diameter shaft). Thanks to the main formula of stress and taking this in mind, it is possible to do the following relation. That formula relates the moment and the inertia of the chosen profile.

$$\sigma = \frac{M}{I} \tag{3}$$

$$M_{10} = M_{12} \tag{4}$$

$$\sigma_{10} \cdot I_{10} = \sigma_{12} \cdot I_{12} \tag{5}$$

The σ_{12} and the S-N graphic, will allow us to look for the total cycles that the shaft can hold before breaking due to fatigue.

1) σ_{10}

First of all, it is necessary to calculate the total cycles that the brush made before breaking. From customers experiences, the brush breaks approximately after 3 months, which is equal to 63 days of work. Assuming that the machine works during 8h per day, the total minutes are 30.240 min.

The velocity of the sliding brush is easy to calculate it. With a machine working, it is possible to count that in 10 seconds, the total spins are 30, so the velocity is 180 rpm. Knowing all this previous information, we can say that before breaking, the sliding brush has done 5.443.200 cycles (from now $5{,}5 \cdot 10^6$ cycles).

Once we know the total cycles before failing, thanks to the graphic of stress – cycles it is possible to relate the maximum cycles worked by the brush with its stress.

For each material there is a different curve. The actual material used for the sliding brush shaft is AISI 316. Looking at the point of $5{,}5 \cdot 10^6$ cycles, we see that the maximum stress for the actual shaft is 155 MPa.

$$\sigma_{10} = 155\ MPa = 155\ N/mm^2 \tag{6}$$

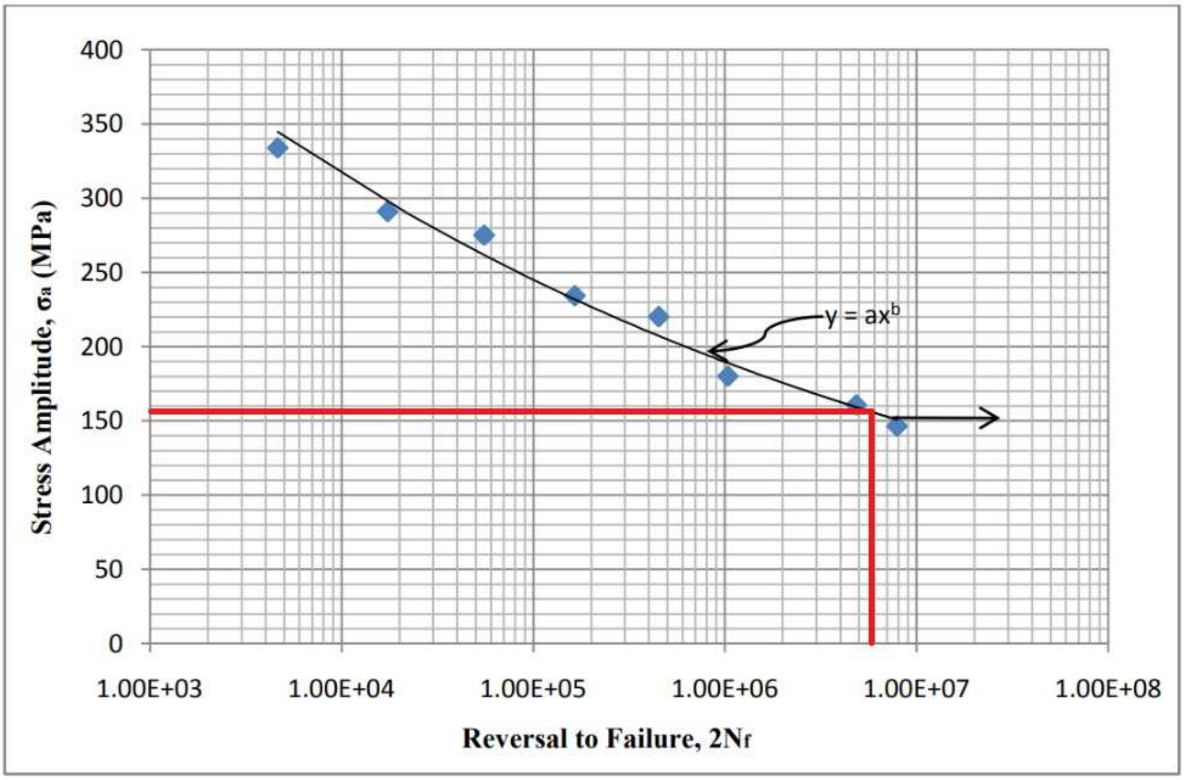


Figure 113. Graphic of S-N for AISI316. *Source: paper "Fatigue behaviour of Austenitic Type 316L Stainless Steel"*

2) I_{10}

Nowadays, the shaft is 10 mm diameter and it is totally solid. With these two conditions it is possible to calculate the inertia of the shaft.

$$I_{10} = \frac{\pi \cdot r^4}{4} = \frac{\pi \cdot 10^4}{4} = 7853.98\ mm^4 \tag{7}$$

3) I_{12}

The new designed shaft is 12 mm diameter. As tubes are more expensive and it is necessary to manufacture a cheap machine, I decide to use a solid stainless-steel bar. With those two conditions it is possible to calculate the inertia of the shaft.

$$I_{12} = \frac{\pi \cdot r^4}{4} = \frac{\pi \cdot 12^4}{4} = 16286.02\ mm^4 \tag{8}$$

4) σ_{12}

With the formula, the stress of this new designed shaft is equivalent to:

$$\sigma_{12} = \frac{\sigma_{10} \cdot I_{10}}{I_{12}} = 74.75\ N/mm^2 \sim 75\ MPa \tag{9}$$

Looking at the graphic S-N (see Figure 113. Graphic of S-N for AISI316. *Source: paper "Fatigue behaviour of Austenitic Type 316L Stainless Steel"*3), it is possible to see that 75 MPa does not corresponds to any number of cycles. In conclusion, this confirms that thanks to this new vertical shaft diameter (12 mm), it will not break due to fatigue.

REMOVE WELDING FROM THE BRUSH STRUCTURE

From the actual sliding brush, the most critical part is the welding between the vertical shaft and the horizontal bar. Welding different parts always produces:

- Stress concentration due to the welding contour.
- Variation of the physical properties between the metal base and welding metal.
- Variation of the metal composition, producing not homogenic composition of welded metal.
- Variation in the crystallographic structure due to heating.
- Inclusions and porosity.
- Residual stresses.

It is possible to fit the two shafts in perpendicular without the welding. For example, by milling the end of the horizontal shaft and fitting it inside the horizontal part, it is possible to joint them. Considering this, the final design of the structure has two separated parts that can be assembled thanks to a screw.

The vertical shaft will be 12 mm diameter (as described previously) and the horizontal shaft will not have a circular section. It will have a rectangular profile of 16 mm in order to fit the main shaft on it and also for an easier machining and assembling.

Thanks to the new design for joining both shafts (perpendicularly one from the other) is possible to avoid the welding, which easily fails with the brush moving inside the compound.

6.2.2. New motor

As explained in chapter 5.2.2., the actual motor has not enough power to move the compound when it is too viscous, so a new powerful motor is needed. As the actual motor is 1/4 HP, it will be useful to install a motor of the following power range, and maintaining the speed. The chosen motor is 1/3 HP and its characteristics are shown in the following table:

New motor for EN-34	
Brand motor	VEM
Phases	Triphasic
Motor case	MSE 63 (reduced case)
Fastening flange	B14
Power	0,33 CV / 0.25kW
Number of poles	4
Cos ϕ	0.66
Velocity	1500 rpm
Voltage	230 / 400
Frequency	50 Hz
Protection grade	IP 55
Weight	5.0 kg

Table 17. New motor chosen for the EN-34. *Source: www.cosgra.com*

The electrical cabinet (where the motor has to be placed) is optimized for the actual machine model. In other words, the actual motor is fitted with few spaces on its surroundings. Normally, increasing the power means increasing the total dimensions of the motor, so more space will be needed to place the new component to the machine. Those motors have the possibility to be manufactured with reduced case, which means that the total dimensions of the old motor are the same than the 0,33CV model.

In conclusion, there is no need to make any change at the electrical cabinet in order to ensure that the motor can fits inside it.

The motors are controlled by a variable frequency device (AFD), and depending on the power of the motor the AFD's model will change. In our case, the motor is commanded by the model ATV12H018M2, and its maximum power is 1/4HP. In conclusion, it is needed to increase the AFD's model in order to command the new motor (1/3 HP). The chosen one is also manufactured by Schneider Electric, and its model is ATV12H037M2.

It is important to know if this new frequency device can be fitted inside the electrical cabinet. Their dimensions will determine if it is necessary to make more space inside the electrical cabinet.

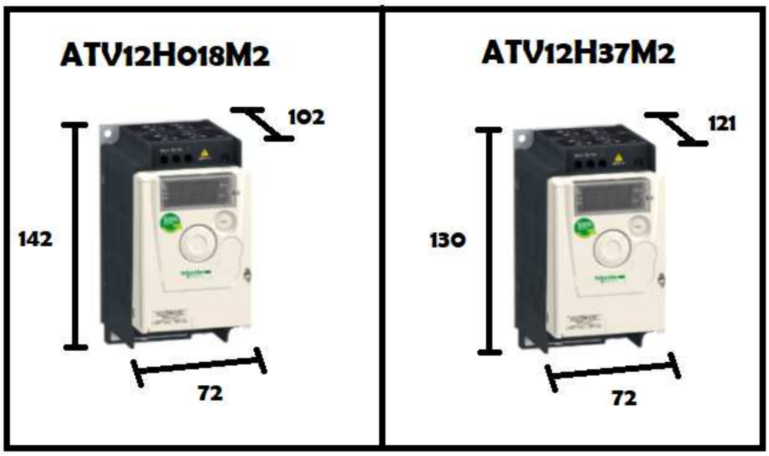


Figure 114. Sizes of the old and new variable frequency device. *Source: www.schneider-electric.es*

In conclusion, after looking for their dimensions (see Figure 114.), we can maintain the actual disposition of all the electric components because looking at booth AFD, it is possible to conclude that the new variable frequency device has quite the same dimension.

Thanks to these changes (not only the motor, also as the ADF), the motor will not work forced, preventing the failure while it is working in not perfect compound conditions. There is no need to change expressly the total dimensions of the electrical cabinet, because booth components changed are not bigger than the ones used until now.

6.3. Splashing of the compound

As explained in chapter 5.3, the system has a tank with compound and a pair of brushes (one of them moving). Due to the continuous movement a lot of splashes are created. Considering that the composition of the compound cannot be modified (in order to have a more viscous electrolyte), and the velocity of the brush must be 180 rpm (in order to guarantee a high polishing speed), it is needed to look for some way to decrease splashing, or a system that retains the compound inside the working tank.

6.3.1. Increase the working tank height

Actually, the working tank is 200 mm tall and the level of the compound reaches 140 mm. By looking the machine while it is working, it is possible to conclude that the waves created with the movement of the brush reaches 190 mm of height. In conclusion, the difference between the maximum height of the working tank and the waves created of compound is only 10 mm. This difference is not enough, so the first possibility is made a higher working tank, without modifying the brush height (if it is made longer, more strains will appear at the shaft).

The maximum height of the future working tank will be 250 mm, but not in all the walls, only in the parts where there are more splashes. Those walls are the rear wall, which is used to fix the tank to the metallic structure, and the lateral walls where it is fitted the rack.

- Rear wall

If the rear wall of the working tank is taller, it will need an opening in order to let the brush arm going inside the PVC compartment.

Taking advantage of this height increasing, it would be practical that the screws which fix the working tank with the structure of the machine are fitted in a higher position because this will avoid that the resins go inside the screw head. This would be also an advantage for the operators when it is needed to change the working tank, as the screws will be placed in a more accessible part of the machine.

To fix the screws in this new position, it will be necessary to do some changes in the separator plate of aluminium. We will have to put some welded plates with rivet nuts on top of the plate where the sliding arm is fixed. It is also necessary to change the shape of the upper metallic cover plate of the machine, in order to allow this new desired design (will need more space).

- Lateral walls

  Not all the length of the lateral walls will reach 250 mm, because it would mean that the plastic support for the rack will also be in this higher position. If the plastic support is in a higher point and the pieces have to be in the middle of the brushes, it is necessary to do longer hooks. Otherwise is preferable to avoid higher moments on hooks because due to the movement of the brush the titanium wire can breaks.

  In conclusion, only the rear part of the lateral walls of the tank will be 50 mm higher in order to do not do longer titanium hooks. This higher PVC wall will avoid that the splashes created by the movement of the brush go outside of the working tank.

  Thanks to this change in the PVC working tank, most part of the splashes created by the movement of the brush will remain inside.

6.3.2. Changes in the metallic structure

For the operator is important to have an easy way to clean the machine after finishing the process. Nowadays, due to the design of the plates and the actual set up of the machine, most part of the machine gets dirty. That means that a very accurate cleaning is needed after some hours of work.

As it is explained before, the metallic structure of the machine can be modified for this study. Changing the whole metallic cover of the machine will allow us to move away the compound, not only from this metallic plate, also as from the plastic polycarbonate cover.

There is a newest model of polishing machines, called EN-44. It has a cover design which allows that the compound is further away from the top of the machine. It can be useful to copy the shape of the machine to avoid that the compound reaches so easily the cover.

Do the same design for the EN-34 cover is also a good idea because this we will homogenize the machines made by Hispana de Maquinaria. To have the same esthetical is important to make your own brand and be recognized overseas.

Thanks to this new design, the stainless-steel cover is higher so it is more difficult that the splashes reach the metallic plate. It is possible to increase the distance about 30 mm, moving away the cover from splashes. There is also a cost advantage, because it is cheaper doing only one cover, than dividing it into two different parts.

As the pieces must be removed from the machine through an opening in the metallic cover, in this case, a new design for the plastic cover it is needed. It will be placed on the top of metallic piece, and will be opened with a pair of hinges. This new polycarbonate cover design is simplest than the older, which means also a lower manufacture price (it is only a rectangular polycarbonate plate)

Thanks to this new design, the machine will have a similar shape to the EN-44, at the same time that the splashes will not reach so easily the machine's cover. This new structure will avoid the use of:

- The metallic plate used to cover the top of the working tank.
- The splashing plastic protectors.

6.3.3. Avoid splashes inside the electronic cabinet

When the brush approaches to the tank wall, a wave is created. It is important to find a way to avoid that the compound goes inside the hole of the driving head due to the splashing. This compartment has some electronical components, like the programming board, which have to be replaced often because of the compound splashes.

The first change is put some deflectors in the lower part of the hole (made specially for the driving arm) of the PVC's working tank. Deflectors are used to break the waves created by the brush. In conclusion, those plastic accessories will stop the wave, impeding that the wave arrives to its higher point.

To ensure even better protection for the electronical cabinet, it could be convenient to weld a pair of plates in the rear part of the driving head. This pair of plates will move like the arm, approaching or moving away from the hole. Those metallic pieces will be useful to stop all the splashes that the deflector cannot retain.

6.4. Pressure spring for rack

As explained in chapter 5.4, the actual spring system of the rack is manufactured completely manually and requires a lot of work. The easiest way to make this upper force above the rack is with a silicon piece make with a mould. This piece has to be made by a specialist but can be produced easily and without being very expensive.

The piece will be cylindrical with two different diameters:

- The 6,5mm diameter will be fitted inside the hole of the plastic support of the anode (6.8mm diameter) and joined with glue. The plastic support will have a blind hole in order to fit this silicon part.
- The 10mm diameter will stand over the basis of the plastic support. Its function is to do the force over the rack, allowing the contact with the metallic pressuring piece. The length of this part is very important to guarantee the enough pressure.

The thickness of the rack is 12mm, and the total space inside the plastic support is 17mm. Considering that this part has to do some force over the metallic pressuring piece, means that the total height of the silicon pressuring spring and the rack must be higher than 17 mm.

After make some trials with prototype springs, I can determine that for the silicon part of 10mm diameter, the best height is 6mm.Thanks to this improvement, this component can be made with a mould, so all the old assembling will not be necessary.

6.5. Rinsing tank

As explained in chapter 5.5, the actual rinsing tank is totally made with PVC in order to avoid scratches of the pieces while they are rinsed. To avoid these scratches in the new tank, it is necessary to maintain the compartments of PVC, but by making an exterior structure of stainless steel will give to the plastic more protection. In conclusion, the rinsing tank will be holt by the metallic structure, avoiding breaking problems.

The new rinsing tank will be made by two differentiated parts:

- PVC compartments

  For rinsing the pieces inside without scratching them with the walls. This PVC compartments will have the valves necessaries to evacuate the water from tank insides.

- Metallic exterior structure

  Stainless steel will be used to contain the PVC compartments and hold them on the structure of the machine with a pair of ears.

The metallic structure can be also used as a beauty part. It is possible to use the laser cut of the plates to do some inscription on the walls. A good option, for example, is put the name of the machine: EN-34.

This external metallic structure will increase the price of the rinsing tank considerably. To reduce the price of the rinsing tank one option is manufacture a smaller tank. Thanks to it, it will be used less material (stainless steel and PVC) so the rinsing tank will be more economical.

For rinsing the rack, the actually width of the compartment with water is 100 mm, but it is not necessary this space to rinse the pieces hanged in the hooks. Only 70mm for compartment will be enough to clean correctly the pieces of the rack. Thanks to this change, the total wide of the rinsing tank will be reduced 60 mm, measuring the new tank only 396x140x125 mm.

Thanks to all these improvements the machine will look better and the PVC tank will not break so easily when is hanged on the machine.

6.6. Junction between working tank and electrical cabinet plate separator

As explained in chapter 5.6, nowadays fixing the working tank with the metallic structure of the machine can involve the breaking of the upper part of the PVC wall.

To give more rigidness to the working tank, in order to not break it when the screws are tightened, it could be convenient to put a horizontal plastic reinforcement with the thickness of the empty space between the wall and the metallic structure (3 mm). This reinforcement will have matching holes with the screws which have to been tightened.

Also add two more screws for fixing the working tank (4 total screws) will improve the fastening to the structure. This improvement will ensure that the wall doesn't bend when the screws are tightened at the metallic structure of the machine.

This reinforcement placed on the top of the working tank can be used also for avoiding that the compound goes behind the wall, substituting the foam junction, which is a very typical spare.

Another junction will be needed on the opening window for the arm. This junction will be made also with PVC of the same thickness than the horizontal reinforcement, in order to cover the space between the working tank and the metallic structure. This frame, added to the deflectors in the same zone, will avoid that the compound goes to the rear part of the working tank.

Thanks to these changes, the splashes of compound will not go to behind the rear wall, and the use of the foam junction will be avoided.

Chapter 7. Discussions and conclusions

In almost all industrial sectors it is very important the polishing result in the final surface. Most metallic pieces that surround us in our daily life are shiny, but **only for decorative purposes**. Doorknobs, watches, glasses, rings, earrings, pens, decorative parts of electronic devices, plumbing accessories, etc. are some examples with different materials.

In naval industry there are a lot of furniture parts made with brass and bronze because of their good performance against marine environment. Hinges, locks, door handles, etc. are some examples.

There are also many situations, where the surface has to be very polished in order to have a **good performance while it is working,** as for example:

- All the valves assembled in a motor (manufactured with stainless), in order to allow a good seat in the cylinder head.
- All the nuts and screws must have a minimum rugosity in order to allow the assemble between them.
- All the keys must be polished in order to open the locks. Some rugosity can modify the shape which opens the mechanism.
- The bearings balls, in order to allow a great sliding between the balls and the rings.
- The bullets and the guns barrel in order to get a more precision when is fired. A not polished surface can produce deviations of the bullet.
- The turbine blades must be polished to minimize the rugosity (in order to have less friction, which means more efficiency).

A very important bronze part of a ship must be polished for an excellent operational. In order to have a good efficiency while it is working, the **rugosity of the propeller surface must be minimized**. If the screw surface has not been properly polished, the fuel consumption of the motor can increase.

For the propeller, it is not only important the rugosity surface, it is also important the polishing process because the original shape of the propeller must be respected. If some parts are too much polished, the thickness will change, so more cavitation can appear at the blades.

As commented in the project, there are many different processes for polishing, but **not all of them are appropriate for all kind of pieces**. Depending on the size, weight and design of the piece there are more suitable machines than others. There are also other parameters like cost of the machine, consumables, etc., that can be important in order to decide which process is better.

In the following table I have collected all the punctuation data of all the processes described, to see which of all those methods is more suitable, for polishing brass and bronze in naval industry. By comparing all the aspects (cost of the machine, consumables cost, polishing time, etc.) I will be able to decide which of all those methods is better.

Polishing method	Cost of machine	Consumables cost	Polishing time	Polishing quality	Automatic process	Number of pieces / process	Use in big pieces	Use in small pieces	Noise
Manual polishing	+ +	+	-	-	- -	- -	+ +	-	-
Disc finishing	+	-	-	+	+	+ +	-	+ +	- -
Vibratory finishing	-	-	- -	+	+ +	+ +	-	+ +	- -
Barrel finishing	-	-	- -	+	-	+ +	- -	+ +	- -
Electro-polishing finishing	- -	- -	+ +	+	+	-	- -	+	+ +
Electro-mechanical finishing	- -	+	+	+ +	+	-	- -	+	+

Table 18. Comparison of all polishing methods described. *Source: Own*

I can divide the brass and bronze pieces used for naval industry depending on their size and weight. In other word, between big and small pieces. In next paragraphs I will look for the best method for each kind of pieces.

- **Angular manual polishing machines** are often used for **propellers** (big pieces). There is not any other machine able to polish a piece of this weight and dimensions. Thanks to their manoeuvrability, it is possible to access to all the corners of the blades. It is very important that the operators have experience in order to do not modify the geometry of the propellers, affecting the efficiency of the same.
- For all the **smaller pieces**, which normally have decorative purposes, it is possible to use other machines. Most used and recommended are **disc finishing and vibratory machines**, because they are easy to use and it is also easy to automate the processes, saving time and operators.

The apparition of new systems like electro-mechanical polishing are positive in order to have another possibility. In this case, it is a faster system than any other (excepting electro-polishing) and with great quality surface.

Nowadays this system is only used with some kind of alloys used in jewellery, and **there is no experience in metals alloyed with aluminium, phosphor, silicon, manganese, etc.** In conclusion, some tests must be done with the brasses and bronzes used in naval industry, in order to see the chemical reaction between the compound and the alloy.

By **changing the weak points** of the machine (the efficiency, operation, maintenance and quality) and **resizing the working area**, it is possible to make a **more commercial machine**. This will be positive in order to expand its market to other industries, included all kind of bronze and brass pieces used in naval industry (testing before that there are good results with those specials alloys).

As a summary, it is possible to see the problems and the solutions in the following table.

	PROBLEMS	SOLUTIONS
1	The electrical anode connection is made inside the working tank, and gets wet due to splashing of compound. This causes corrosion in the copper wire.	New anodic plastic supports are designed, in order to do the electrical connection outside of the working tank, avoiding compound splashes.
2	The electrical cathode connection is made inside the working tank, and gets wet due to splashing of compound. The negative wire can break due to the movement of the sliding brush.	There will be a pair of cathodic bars on top of the working tank, where the cathodes can be hold. A new design for the cathodes (stainless and organic) is needed.
3	The sliding brush breaks very often due to fatigue.	I have given different solutions: - Maintain the level compound (in order to do not have a high viscosity) by marking level of the compound inside the working tank. - Resizing the brush shaft - Making another kind of junction between both perpendicular shafts (avoiding the welding)
4	If the compound is too viscous, the motor stops working.	As well as make the marks inside the working tank (as described before), change the motor for another one more powerful.
5	Due to the movement of the sliding brush, there are a lot of splashes. This causes that the whole machine gets dirty.	I have given different solutions, in order to avoid that the compound goes out from the working tank: - Make the working tank higher. - Make a different metallic and plastic cover, in order to move away those parts from the compound. - Put deflectors for avoiding that the waves created by the brush goes inside of the electrical cabinet.
6	The pressure spring for the rack is made manually and requires a lot of work and materials (high cost).	A moulded cylindrical piece can be made of silicon, substituting the old spring.
7	The rinsing tank is made of PVC, which is a fragile material.	As the pieces must be rinsed inside a PVC tank (in order to do not scratch their surface), the rinsing tank will be divided in: - External metallic structure. - Two PVC tanks fitted inside the structure.

8	The PVC working tank breaks on its upper part when it is fixed with the foam junction into the metallic structure of the machine.	By giving more rigidness with a plastic reinforcement (where the screws are tightened) the breaking will be avoided. The foam junction will be removed and substituted for this PVC reinforcement. This part will be useful to avoid that the compound goes to behind the machine.

Table 19. Summary of the problems and solutions for the EN-34

In conclusion, in a future it could be interesting to create a new machine with the system developed by Hispana de Maquinaria (electro-mechanical polishing), in order to have a bigger working area, but maintaining the same excellent surface results as in the EN-34.

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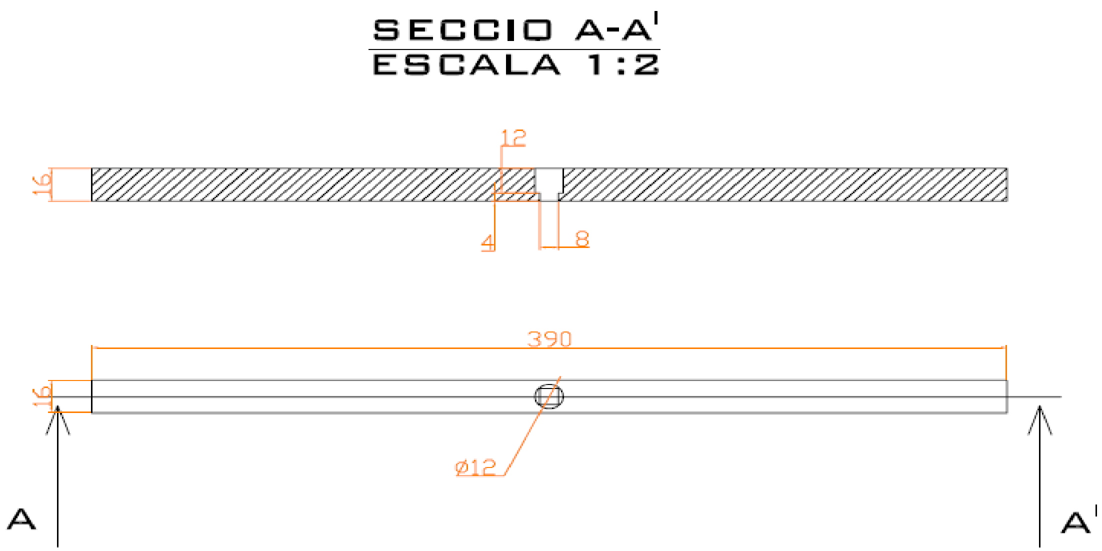
Attachments and Appendices

In chapter 6, suggestions for improving the EN-34, I have given some possibilities in order to improve the actual machine. Some of them needs a new piece, or a modification of someone existing.

All the attachments in this chapter are drawings and schemes of new parts necessaries to solve all the problems that the machine has, making a new and improved EN-34.

- **EN001**. Horizontal Bar for sliding brush
- **EN002**. Shaft for sliding brush
- **EN003**. Metallic structure for rinsing tank
- **EN004**. Plastic rinsing tank
- **EN005**. Silicon spring
- **EN006**. Exterior plastic part for rack support
- **EN007**. Interior plastic part for rack support
- **EN008**. Tightening PVC wall to structure
- **EN009**. Right PVC wall
- **EN010**. Left PVC wall
- **EN011**. Left rack contact
- **EN012**. Right rack contact
- **EN013**. Isolating nylon
- **EN014**. Stainless steel cathode
- **EN015**. Organic cathode
- **EN016**. Driving arm structure
- **EN017.** Cathodic bar
- **EN018.** Schema of metallic EN-34 cover
- **EN019.** Plastic cover for EN-34

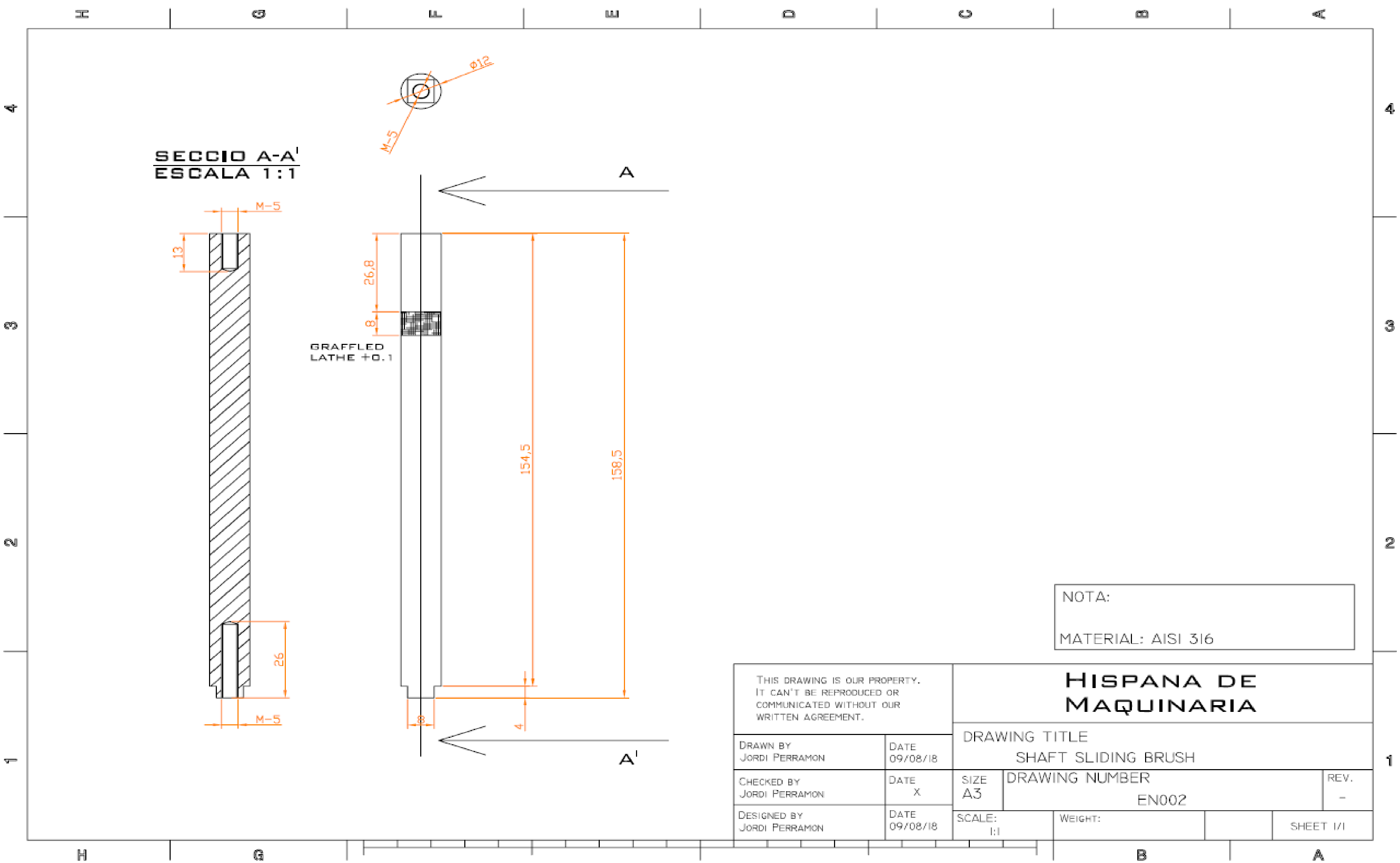


NOTA:

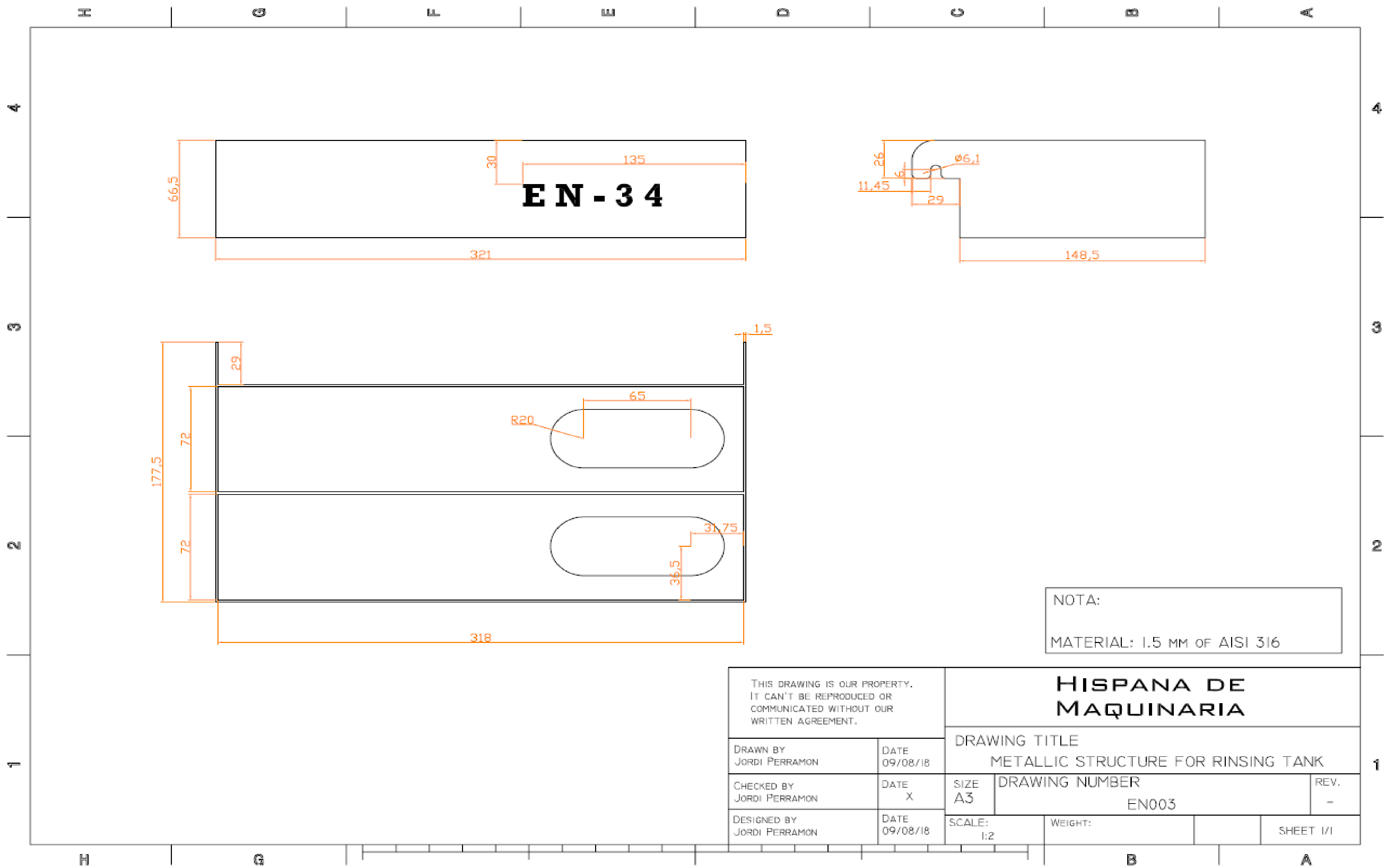
MATERIAL: AISI 316

HISPANA DE MAQUINARIA

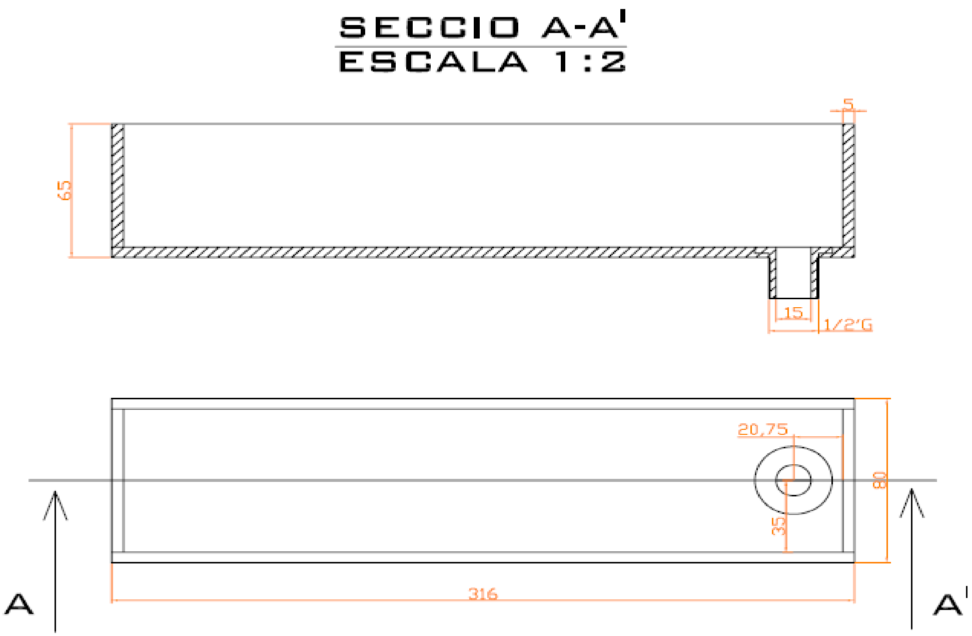
DRAWN BY JORDI PERRAMON	DATE 09/08/18	DRAWING TITLE	HORITZONTAL BAR FOR SLIDING BRUSH
CHECKED BY JORDI PERRAMON	DATE X	SIZE A3	DRAWING NUMBER EN001 — REV. -
DESIGNED BY JORDI PERRAMON	DATE 09/08/18	SCALE: 1:2	WEIGHT: — SHEET 1/1



SECCIO A-A'
ESCALA 1:1
M-5
13
26
M-5
Ø12
M-5
A
26,8
8
GRAFFLED
LATHE +0.1
154,5
158,5
8
4
A'
NOTA:
MATERIAL: AISI 316
THIS DRAWING IS OUR PROPERTY.
IT CAN'T BE REPRODUCED OR
COMMUNICATED WITHOUT OUR
WRITTEN AGREEMENT.
HISPANA DE
MAQUINARIA
DRAWN BY
JORDI PERRAMON
DATE
09/08/18
DRAWING TITLE
SHAFT SLIDING BRUSH
CHECKED BY
JORDI PERRAMON
DATE
X
SIZE
A3
DRAWING NUMBER
EN002
REV.
-
DESIGNED BY
JORDI PERRAMON
DATE
09/08/18
SCALE:
1:1
WEIGHT:
SHEET 1/1



EN-34
66,5
30
135
321
26
ø6,1
6
11,45
29
148,5
1,5
29
65
R20
72
177,5
72
31,75
36,5
318
NOTA:
MATERIAL: 1.5 MM OF AISI 316
THIS DRAWING IS OUR PROPERTY. IT CAN'T BE REPRODUCED OR COMMUNICATED WITHOUT OUR WRITTEN AGREEMENT.
HISPANA DE MAQUINARIA
DRAWN BY JORDI PERRAMON
DATE 09/08/18
CHECKED BY JORDI PERRAMON
DATE X
DESIGNED BY JORDI PERRAMON
DATE 09/08/18
DRAWING TITLE
METALLIC STRUCTURE FOR RINSING TANK
SIZE A3
DRAWING NUMBER
EN003
REV.
-
SCALE: 1:2
WEIGHT:
SHEET 1/1



NOTA:

MATERIAL: PVC

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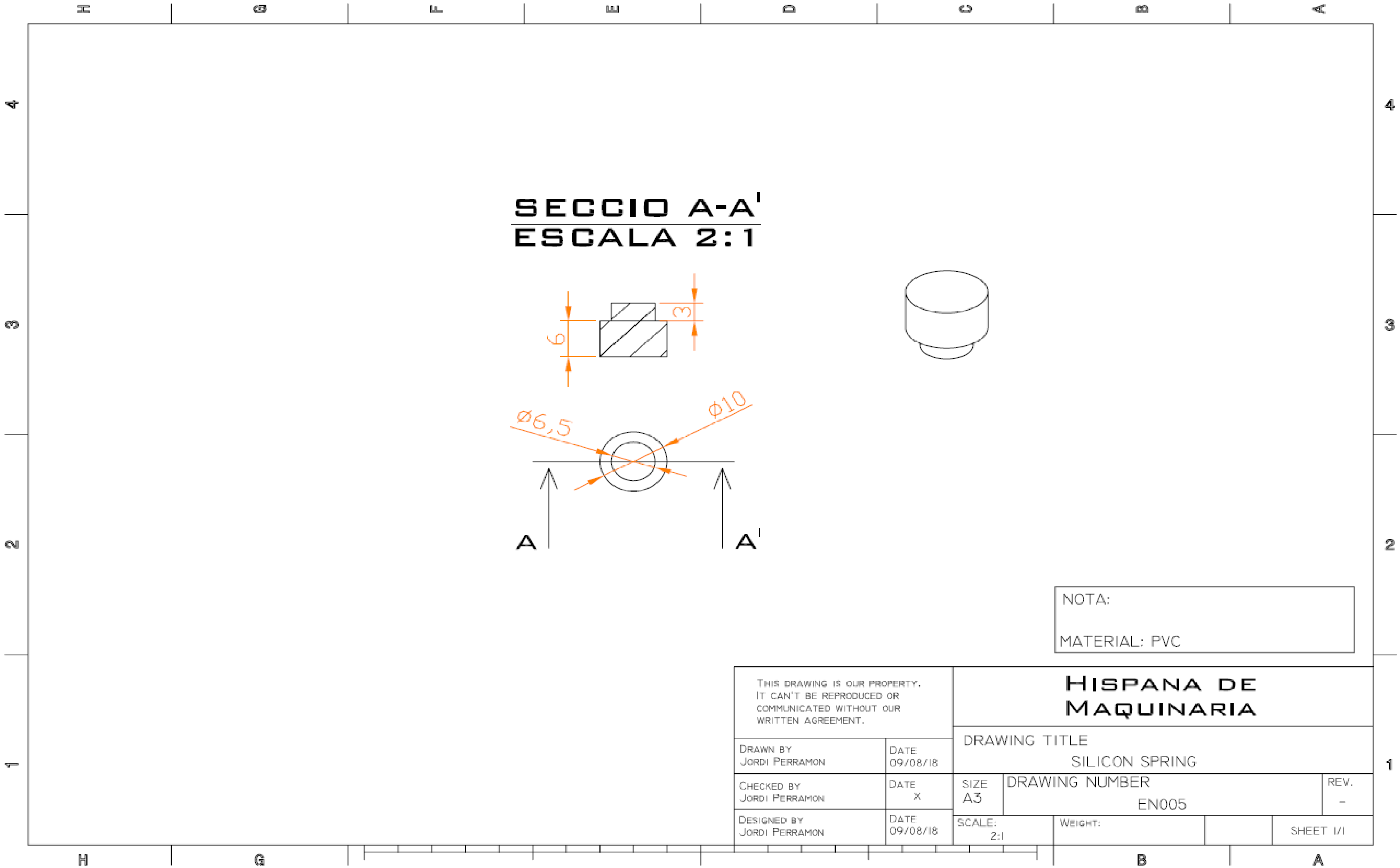
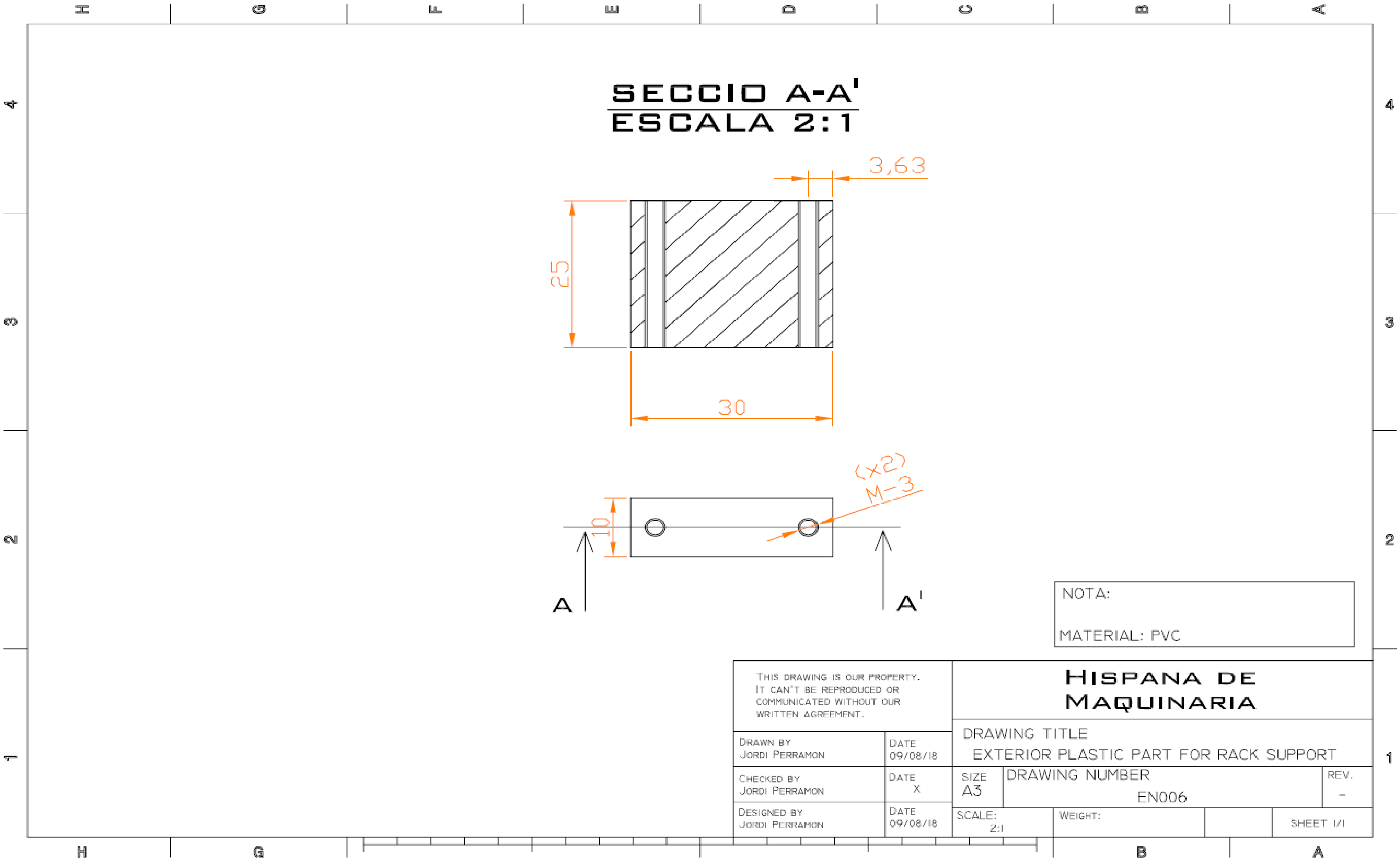
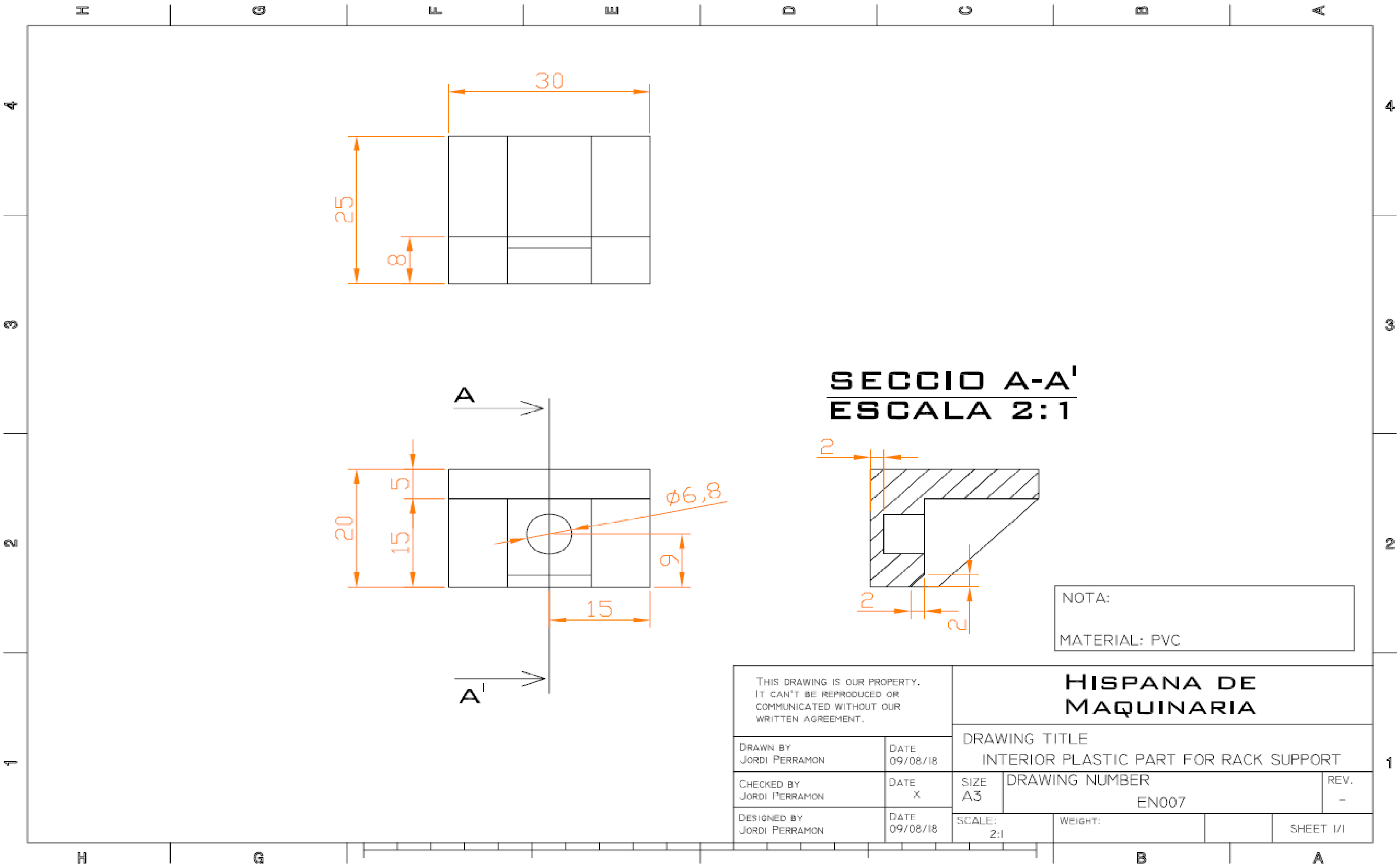
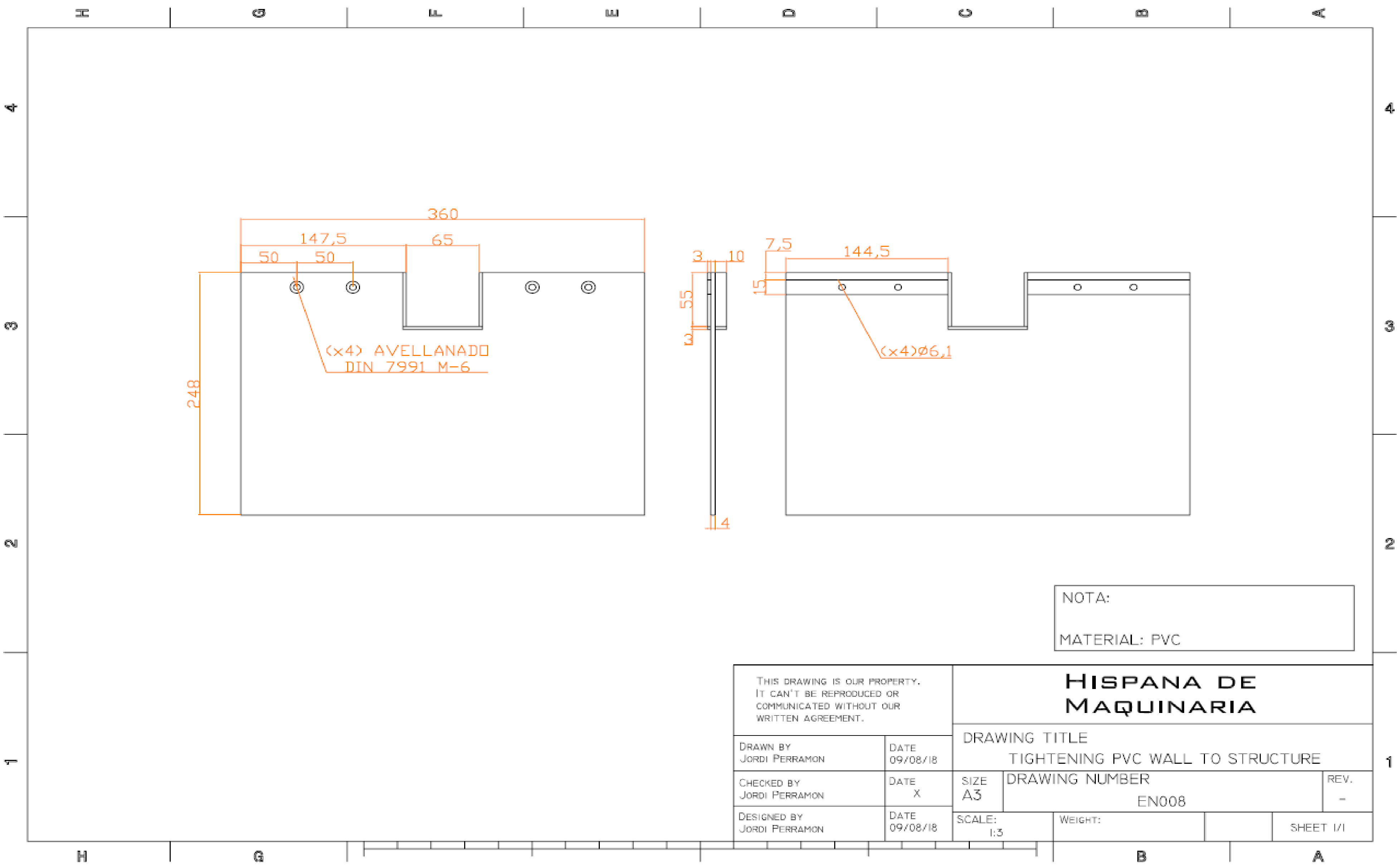
HISPANA DE MAQUINARIA

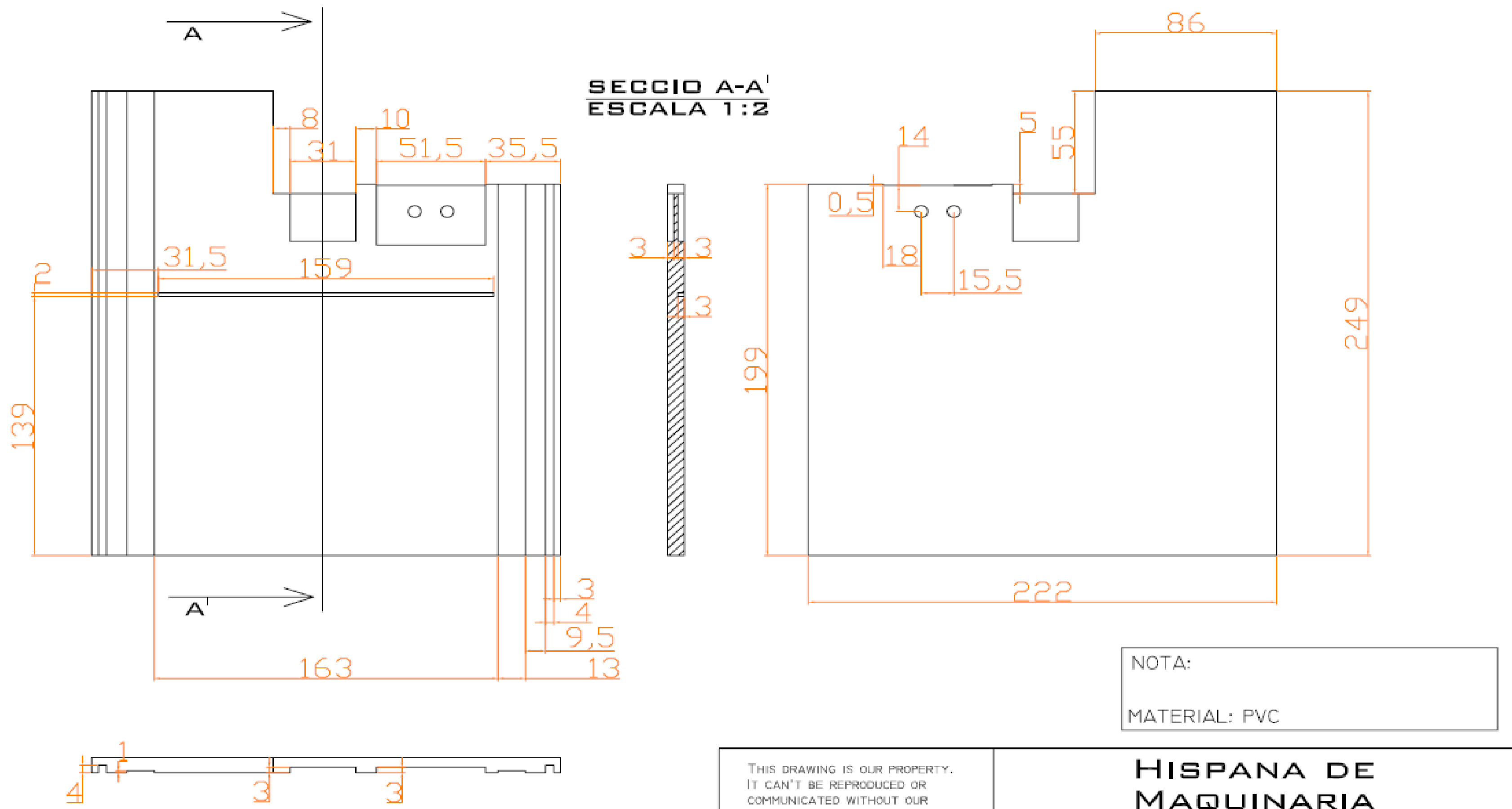
DRAWN BY: JORDI PERRAMON	DATE: 09/08/18	DRAWING TITLE: PLASTIC RINSING TANK	
CHECKED BY: JORDI PERRAMON	DATE: X	SIZE: A3	DRAWING NUMBER: EN004	REV.: -
DESIGNED BY: JORDI PERRAMON	DATE: 09/08/18	SCALE: 1:2	WEIGHT:	SHEET 1/1


H
G
F
E
D
C
B
A
4
3
2
1
SECCIO A-A'
ESCALA 2:1
6
3
Ø6,5
Ø10
A
A'
NOTA:
MATERIAL: PVC
THIS DRAWING IS OUR PROPERTY. IT CAN'T BE REPRODUCED OR COMMUNICATED WITHOUT OUR WRITTEN AGREEMENT.
HISPANA DE MAQUINARIA
DRAWN BY JORDI PERRAMON
DATE 09/08/18
CHECKED BY JORDI PERRAMON
DATE X
DESIGNED BY JORDI PERRAMON
DATE 09/08/18
DRAWING TITLE
SILICON SPRING
SIZE A3
DRAWING NUMBER
EN005
REV. -
SCALE: 2:1
WEIGHT:
SHEET 1/1


SECCIO A-A'
ESCALA 2:1
3,63
25
30
(x2)
M-3
10
A
A'
NOTA:
MATERIAL: PVC
THIS DRAWING IS OUR PROPERTY. IT CAN'T BE REPRODUCED OR COMMUNICATED WITHOUT OUR WRITTEN AGREEMENT.
HISPANA DE MAQUINARIA
DRAWN BY JORDI PERRAMON
DATE 09/08/18
CHECKED BY JORDI PERRAMON
DATE X
DESIGNED BY JORDI PERRAMON
DATE 09/08/18
DRAWING TITLE
EXTERIOR PLASTIC PART FOR RACK SUPPORT
SIZE A3
DRAWING NUMBER EN006
REV. -
SCALE: 2:1
WEIGHT:
SHEET 1/1


30
25
8
A
5
20
15
ø6,8
9
15
A'
SECCIO A-A'
ESCALA 2:1
2
2
2
NOTA:
MATERIAL: PVC
THIS DRAWING IS OUR PROPERTY. IT CAN'T BE REPRODUCED OR COMMUNICATED WITHOUT OUR WRITTEN AGREEMENT.
HISPANA DE MAQUINARIA
DRAWN BY JORDI PERRAMON
DATE 09/08/18
DRAWING TITLE
INTERIOR PLASTIC PART FOR RACK SUPPORT
CHECKED BY JORDI PERRAMON
DATE X
SIZE A3
DRAWING NUMBER EN007
REV. -
DESIGNED BY JORDI PERRAMON
DATE 09/08/18
SCALE: 2:1
WEIGHT:
SHEET 1/1


360
147,5
65
50
50
248
(x4) AVELLANADO
DIN 7991 M-6
3
10
55
3
4
7,5
144,5
15
(x4)Ø6,1
NOTA:
MATERIAL: PVC
THIS DRAWING IS OUR PROPERTY.
IT CAN'T BE REPRODUCED OR
COMMUNICATED WITHOUT OUR
WRITTEN AGREEMENT.
HISPANA DE
MAQUINARIA
DRAWING TITLE
TIGHTENING PVC WALL TO STRUCTURE
DRAWN BY
JORDI PERRAMON
DATE
09/08/18
CHECKED BY
JORDI PERRAMON
DATE
X
DESIGNED BY
JORDI PERRAMON
DATE
09/08/18
SIZE
A3
DRAWING NUMBER
EN008
REV.
-
SCALE:
1:3
WEIGHT:
SHEET 1/1



NOTA:

MATERIAL: PVC

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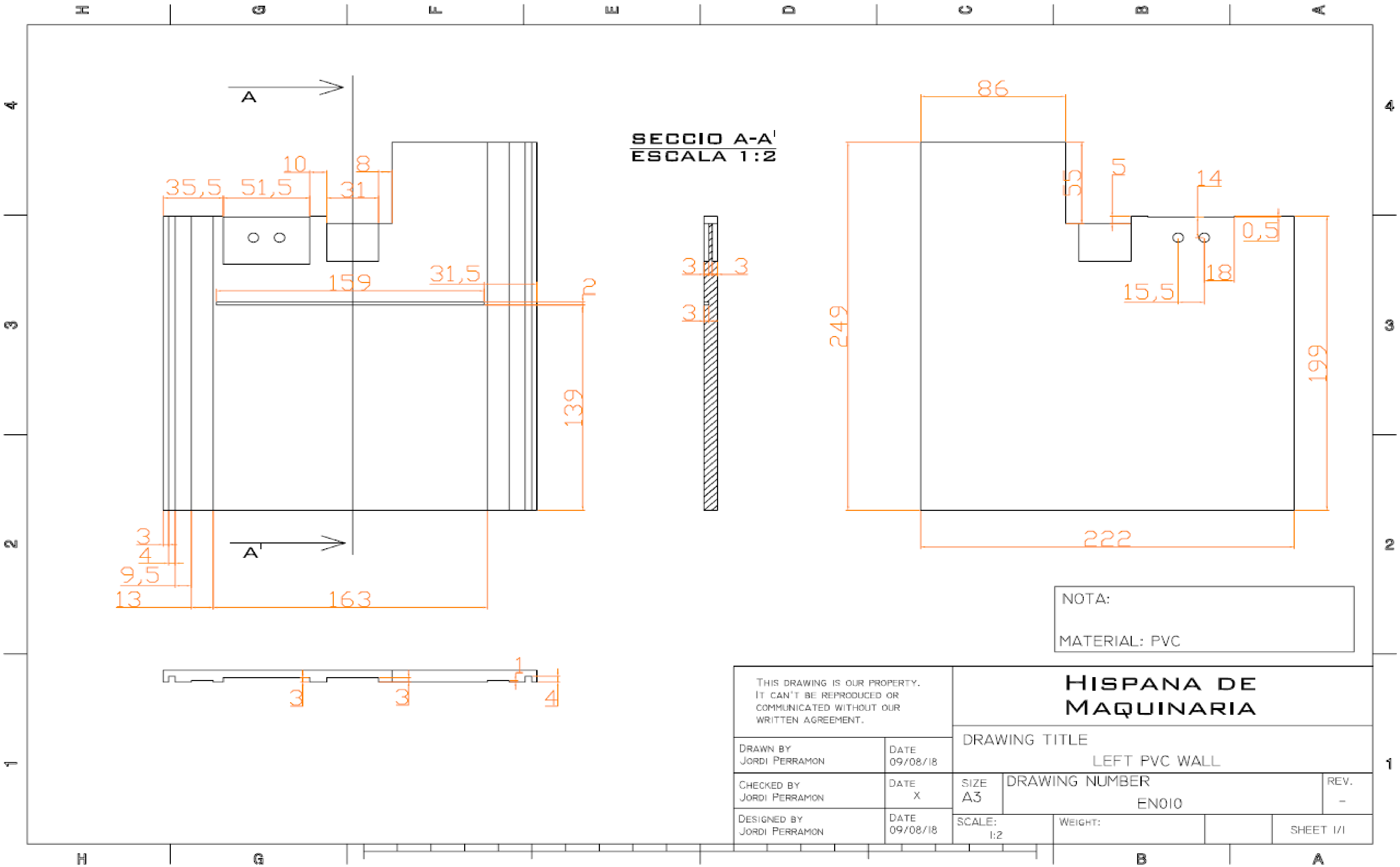
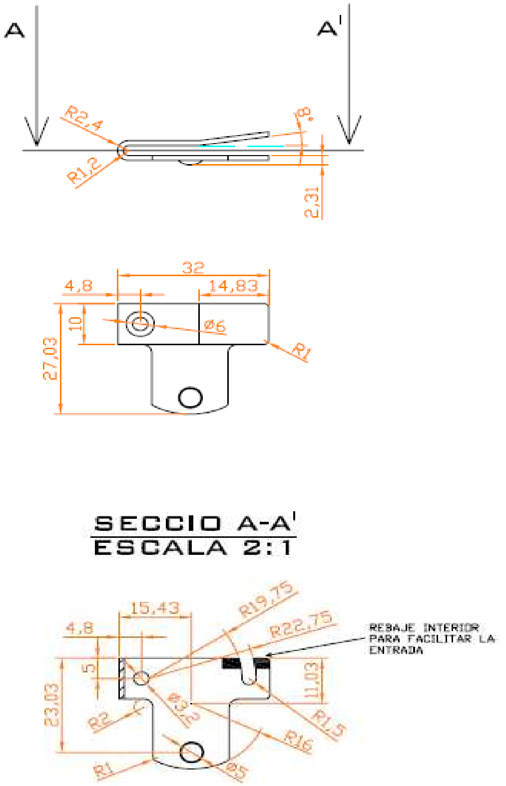
HISPANA DE MAQUINARIA					
DRAWN BY JORDI PERRAMON	DATE 09/08/18	DRAWING TITLE: RIGHT PVC WALL			
CHECKED BY JORDI PERRAMON	DATE X	SIZE A3	DRAWING NUMBER EN009	REV. -	
DESIGNED BY JORDI PERRAMON	DATE 09/08/18	SCALE: 1:2	WEIGHT:		SHEET 1/1


SECCIO A-A'
ESCALA 1:2
NOTA:
MATERIAL: PVC
THIS DRAWING IS OUR PROPERTY. IT CAN'T BE REPRODUCED OR COMMUNICATED WITHOUT OUR WRITTEN AGREEMENT.
HISPANA DE MAQUINARIA
DRAWING TITLE
LEFT PVC WALL
DRAWN BY JORDI PERRAMON
DATE 09/08/18
CHECKED BY JORDI PERRAMON
DATE X
DESIGNED BY JORDI PERRAMON
DATE 09/08/18
SIZE A3
DRAWING NUMBER
EN010
REV. -
SCALE: 1:2
WEIGHT:
SHEET 1/1



NOTA:

MATERIAL: AISI 316

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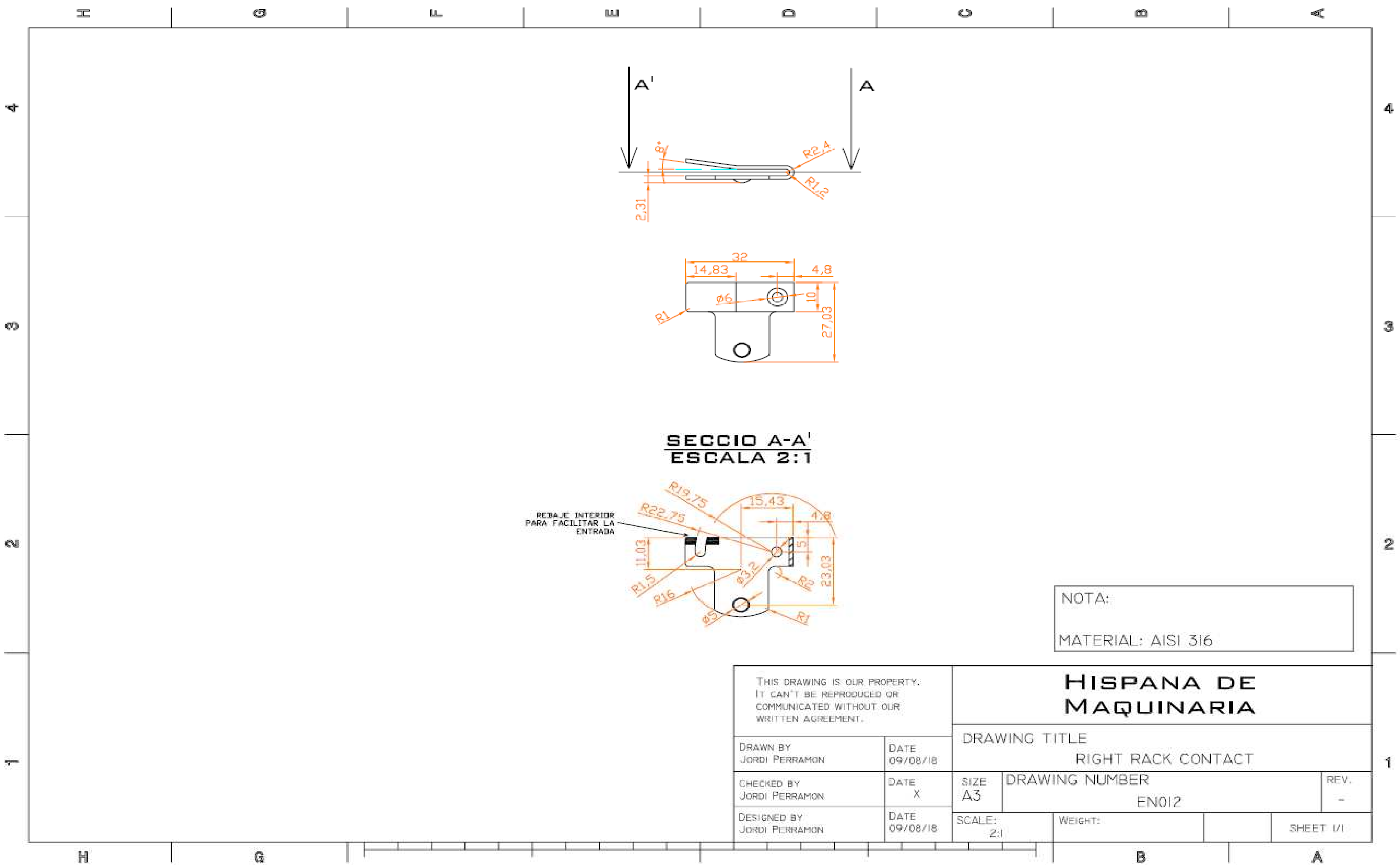
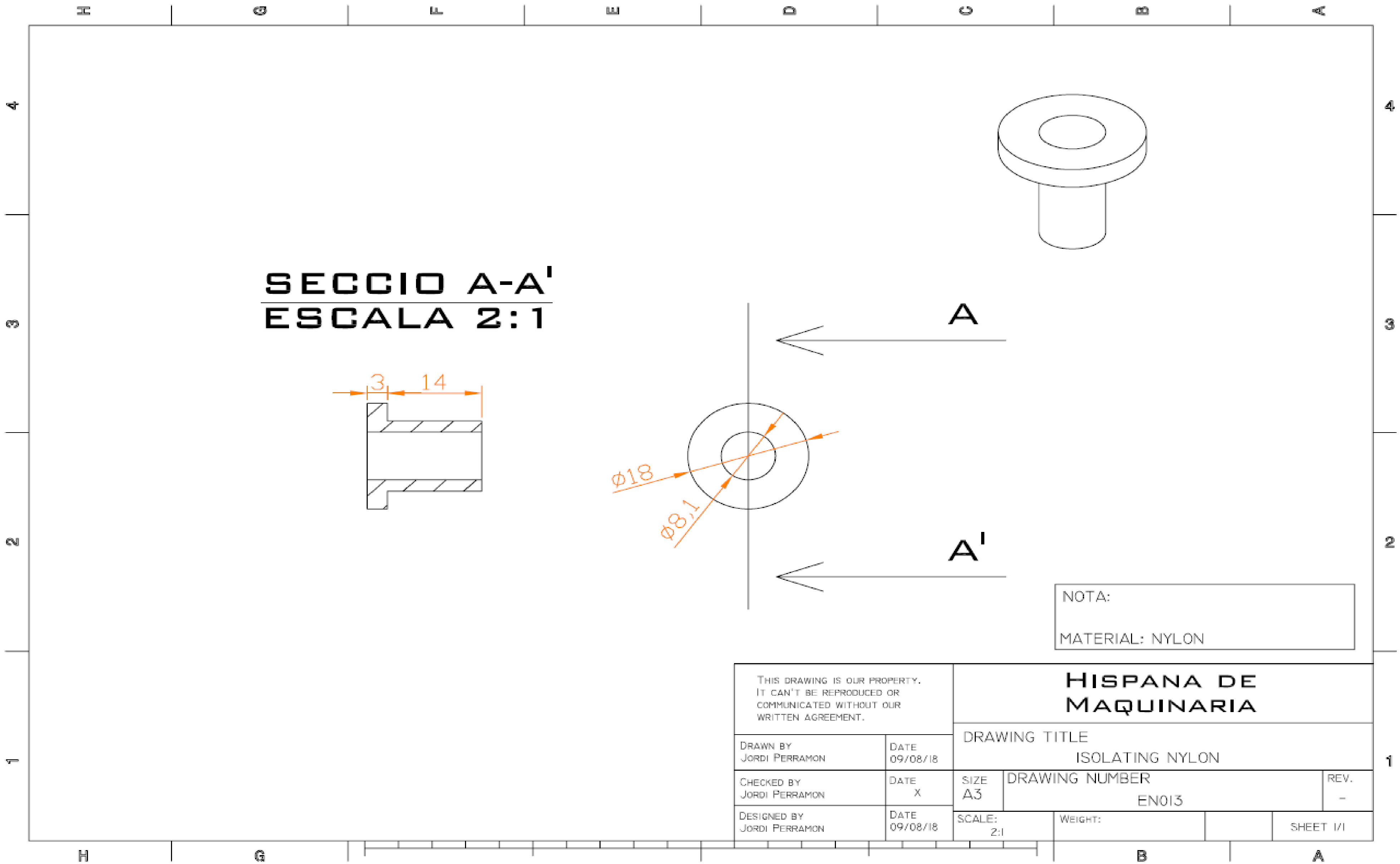
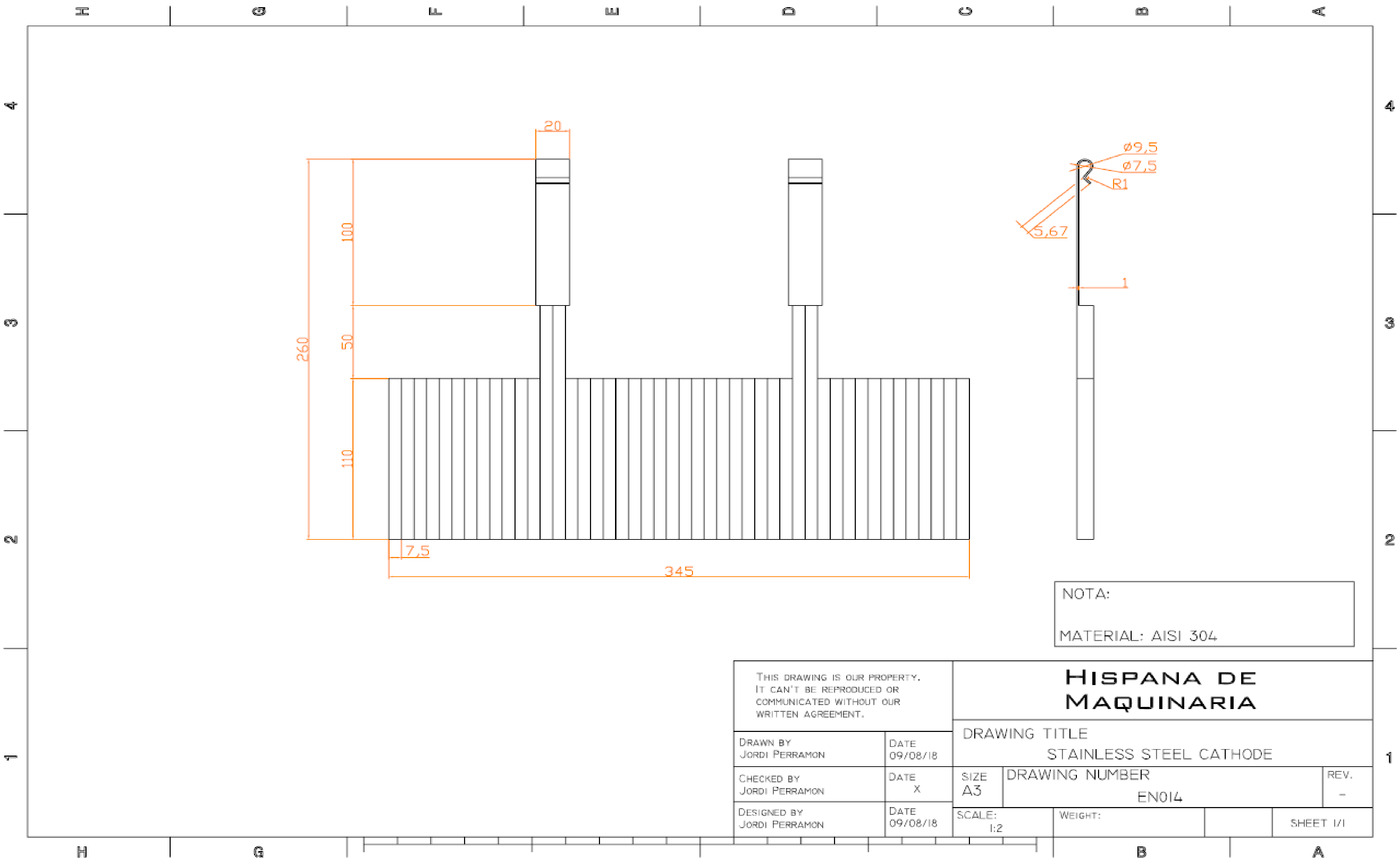
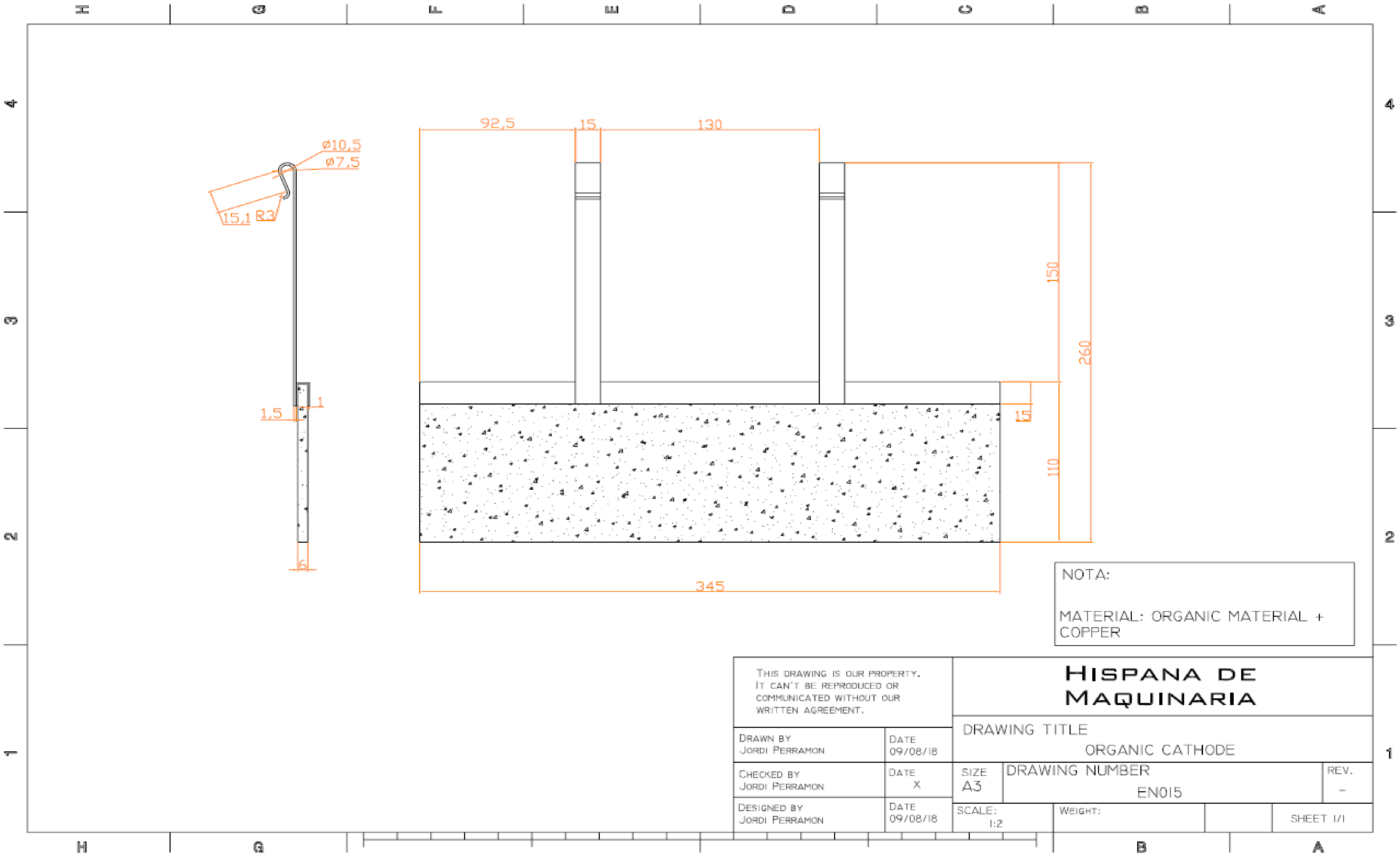
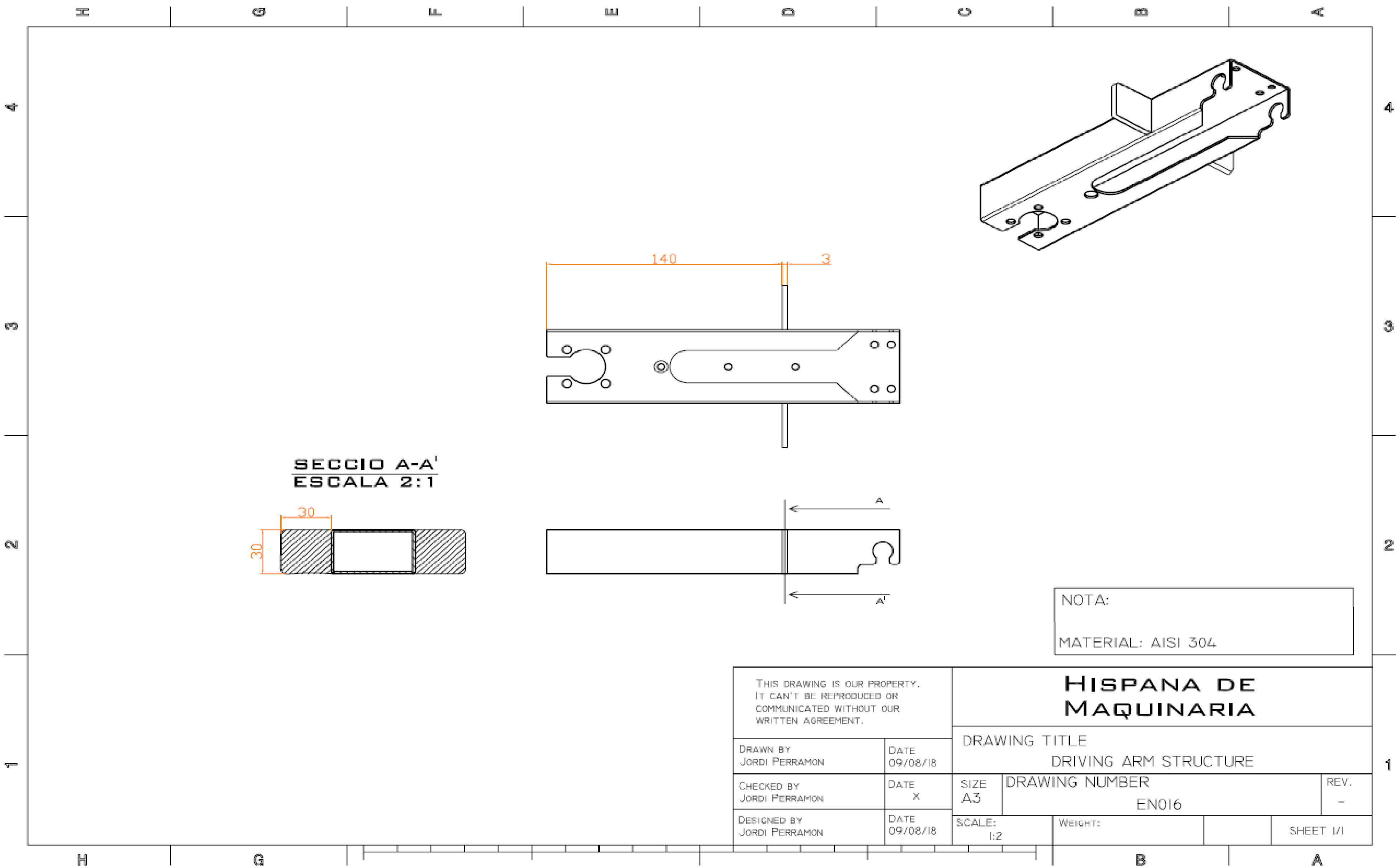
DRAWN BY JORDI PERRAMON	DATE 09/08/18	DRAWING TITLE LEFT RACK CONTACT	
CHECKED BY JORDI PERRAMON	DATE X	SIZE A3	DRAWING NUMBER EN011 — REV. -
DESIGNED BY JORDI PERRAMON	DATE 09/08/18	SCALE: 2:1	WEIGHT: — SHEET 1/1


A'
A
8°
R2,4
R1,2
2,31
32
14,83
4,8
ø6
10
R1
27,03
SECCIO A-A'
ESCALA 2:1
R19,75
R22,75
15,43
4,8
REBAJE INTERIOR PARA FACILITAR LA ENTRADA
11,03
15
23,03
R1,5
ø3,2
R2
R16
ø5
R1
NOTA:
MATERIAL: AISI 316
THIS DRAWING IS OUR PROPERTY. IT CAN'T BE REPRODUCED OR COMMUNICATED WITHOUT OUR WRITTEN AGREEMENT.
HISPANA DE MAQUINARIA
DRAWN BY
JORDI PERRAMON
DATE
09/08/18
CHECKED BY
JORDI PERRAMON
DATE
X
DESIGNED BY
JORDI PERRAMON
DATE
09/08/18
DRAWING TITLE
RIGHT RACK CONTACT
SIZE
A3
DRAWING NUMBER
EN012
REV.
-
SCALE:
2:1
WEIGHT:
SHEET 1/1

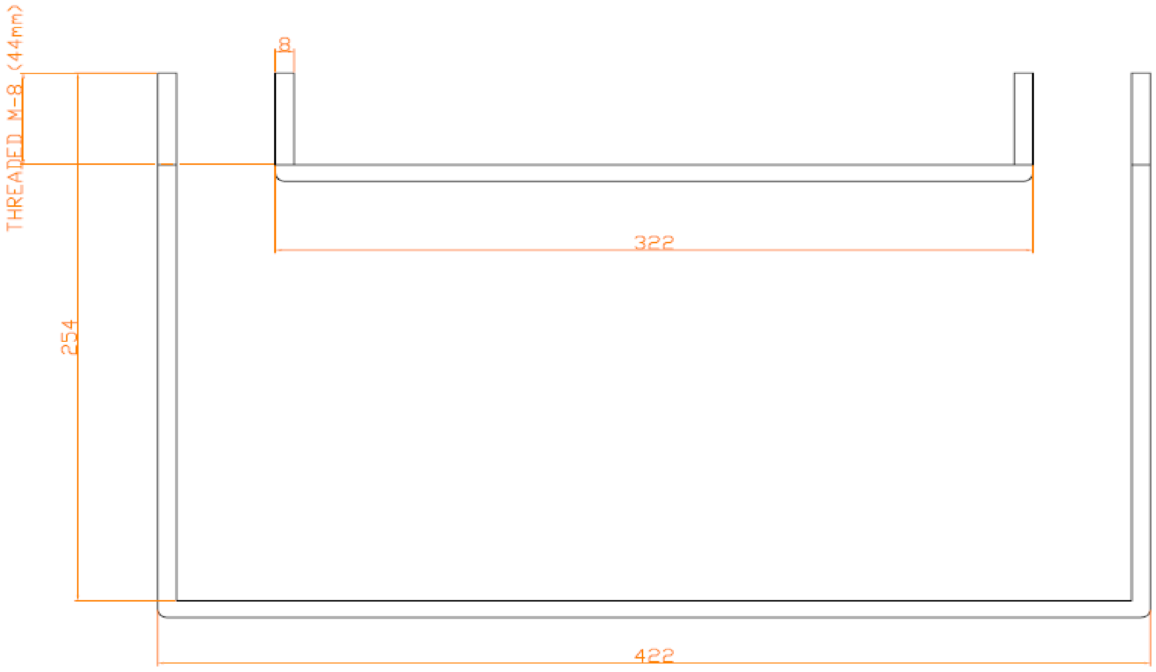

SECCIO A-A'
ESCALA 2:1
3
14
ø18
ø8,1
A
A'
NOTA:
MATERIAL: NYLON
THIS DRAWING IS OUR PROPERTY. IT CAN'T BE REPRODUCED OR COMMUNICATED WITHOUT OUR WRITTEN AGREEMENT.
HISPANA DE MAQUINARIA
DRAWN BY JORDI PERRAMON
DATE 09/08/18
DRAWING TITLE
ISOLATING NYLON
CHECKED BY JORDI PERRAMON
DATE X
SIZE A3
DRAWING NUMBER
EN013
REV. -
DESIGNED BY JORDI PERRAMON
DATE 09/08/18
SCALE: 2:1
WEIGHT:
SHEET 1/1


H
G
F
E
D
C
B
A
4
3
2
1
20
100
50
260
110
7,5
345
ø9,5
ø7,5
R1
5,67
1
NOTA:
MATERIAL: AISI 304
THIS DRAWING IS OUR PROPERTY. IT CAN'T BE REPRODUCED OR COMMUNICATED WITHOUT OUR WRITTEN AGREEMENT.
HISPANA DE MAQUINARIA
DRAWN BY JORDI PERRAMON
DATE 09/08/18
CHECKED BY JORDI PERRAMON
DATE X
DESIGNED BY JORDI PERRAMON
DATE 09/08/18
DRAWING TITLE
STAINLESS STEEL CATHODE
SIZE A3
DRAWING NUMBER
EN014
REV. -
SCALE: 1:2
WEIGHT:
SHEET 1/1


ø10,5
ø7,5
15,1
R3
1,5
1
6
92,5
15
130
150
260
15
110
345
NOTA:
MATERIAL: ORGANIC MATERIAL + COPPER
THIS DRAWING IS OUR PROPERTY. IT CAN'T BE REPRODUCED OR COMMUNICATED WITHOUT OUR WRITTEN AGREEMENT.
HISPANA DE MAQUINARIA
DRAWN BY JORDI PERRAMON
DATE 09/08/18
CHECKED BY JORDI PERRAMON
DATE X
DESIGNED BY JORDI PERRAMON
DATE 09/08/18
DRAWING TITLE
ORGANIC CATHODE
SIZE A3
DRAWING NUMBER EN015
REV. -
SCALE: 1:2
WEIGHT:
SHEET 1/1



140
3
SECCIO A-A'
ESCALA 2:1
30
30
A
A'
NOTA:
MATERIAL: AISI 304
THIS DRAWING IS OUR PROPERTY. IT CAN'T BE REPRODUCED OR COMMUNICATED WITHOUT OUR WRITTEN AGREEMENT.
HISPANA DE MAQUINARIA
DRAWING TITLE
DRIVING ARM STRUCTURE
DRAWN BY
JORDI PERRAMON
DATE
09/08/18
CHECKED BY
JORDI PERRAMON
DATE
X
DESIGNED BY
JORDI PERRAMON
DATE
09/08/18
SIZE
A3
DRAWING NUMBER
EN016
REV.
-
SCALE:
1:2
WEIGHT:
SHEET 1/1

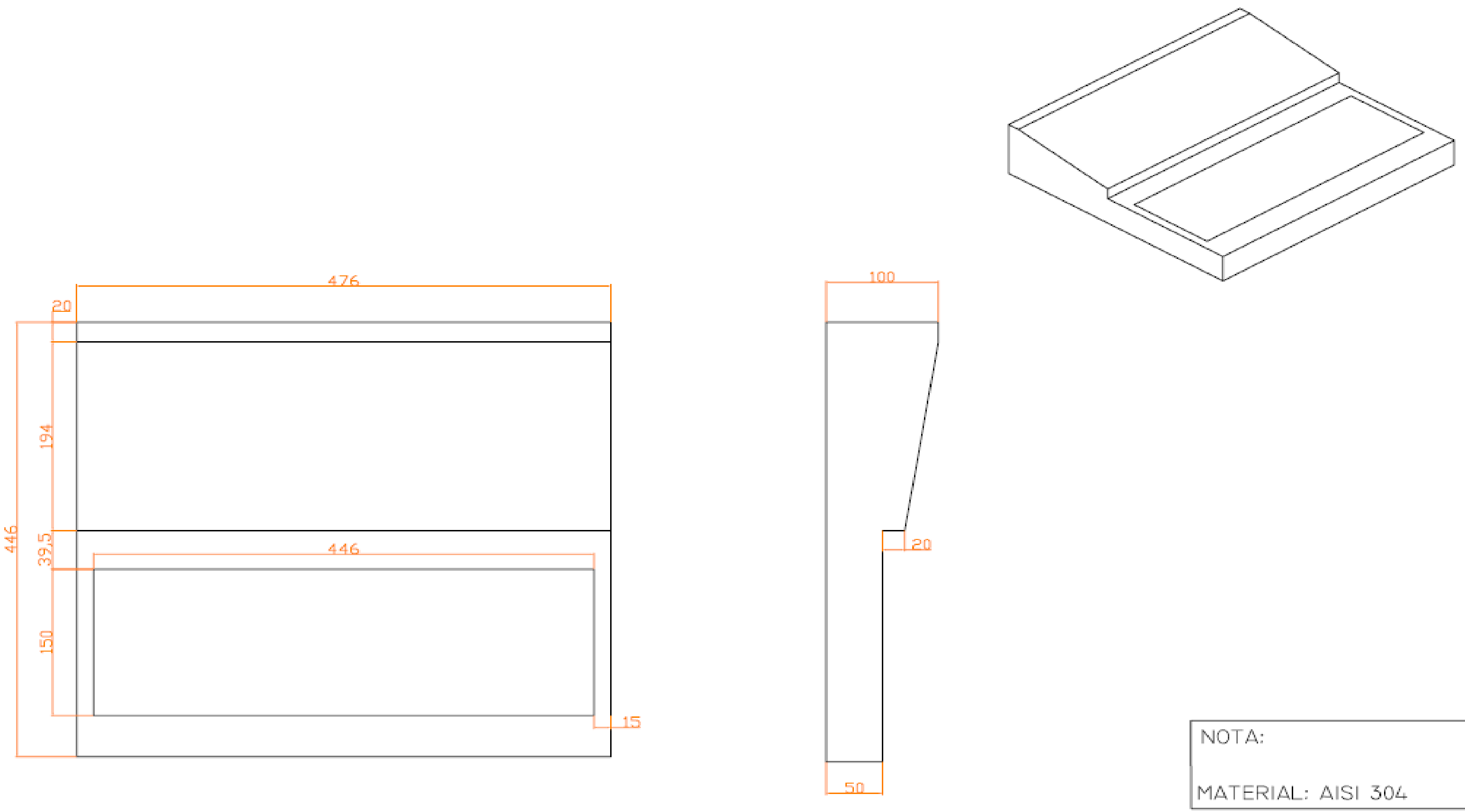


NOTA:

MATERIAL: AISI 316

HISPANA DE MAQUINARIA

DRAWN BY JORDI PERRAMON	DATE 09/08/18	DRAWING TITLE	CATHODIC BARS
CHECKED BY JORDI PERRAMON	DATE X	SIZE A3	DRAWING NUMBER EN017 — REV. -
DESIGNED BY JORDI PERRAMON	DATE 09/08/18	SCALE: 1:2	WEIGHT: — SHEET 1/1

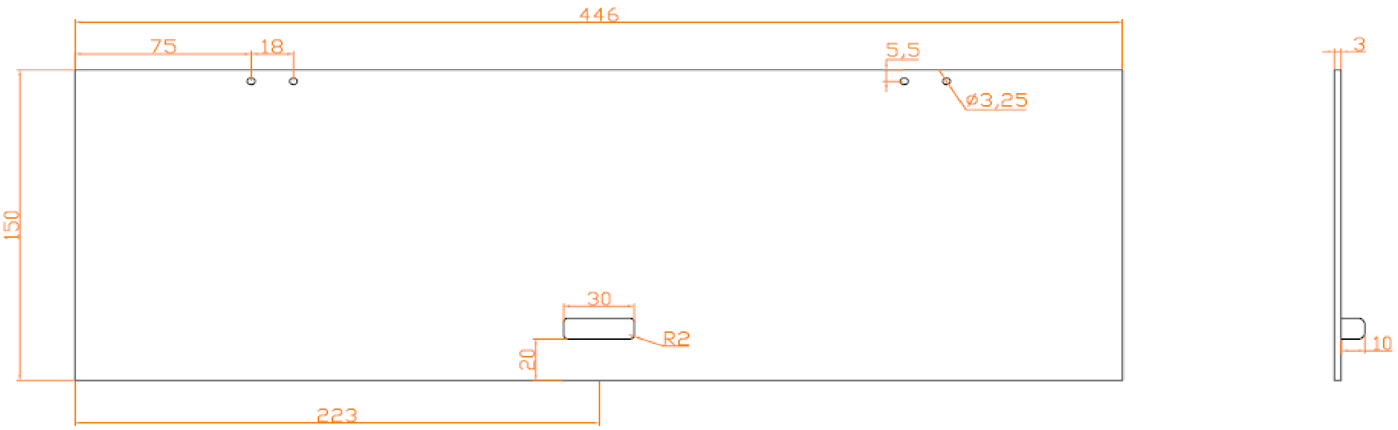


NOTA:

MATERIAL: AISI 304

HISPANA DE MAQUINARIA

DRAWN BY JORDI PERRAMON	DATE 09/08/18	DRAWING TITLE	SCHEMA METALLIC EN-34 COVER
CHECKED BY JORDI PERRAMON	DATE X	SIZE A3	DRAWING NUMBER EN018 — REV. -
DESIGNED BY JORDI PERRAMON	DATE 09/08/18	SCALE: 1:2	WEIGHT: — SHEET 1/1



NOTA:

MATERIAL: POLICARBONATE

HISPANA DE MAQUINARIA

DRAWN BY JORDI PERRAMON	DATE 09/08/18	DRAWING TITLE PLASTIC COVER EN-34	
CHECKED BY JORDI PERRAMON	DATE X	SIZE A3	DRAWING NUMBER EN019 / REV. -
DESIGNED BY JORDI PERRAMON	DATE 09/08/18	SCALE: 1:2	WEIGHT: / SHEET 1/1