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Redução do custo de manutenção e aumento da eficiência na secção de estampagem a quente

Maintenance cost reduction and process optimization of the Hot Stamping line – Gestamp Aveiro case study

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Relatório de Estágio apresentado à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia Mecânica, realizada sob a orientação científica do Doutor Tiago Manuel Rodrigues da Silva, Investigador do Departamento de Engenharia Mecânica da Universidade de Aveiro e supervisão do Engenheiro Miguel Nunes, Diretor de Manutenção da Gestamp Aveiro.

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o júri

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palavras-chave

Estampagem a quente, rolos cerâmicos, prensas mecânicas, prensas hidráulicas, forno industrial, corte laser, marcação a laser, marcação em contraste, marcação em relevo, manutenção preventiva, redução custos, melhoria do processo

resumo

O presente trabalho foi desenvolvido no âmbito de um estágio curricular na Gestamp Aveiro, com o principal objetivo de reduzir os custos de manutenção associados à linha de produção de estampagem a quente.

Para a execução deste relatório foi feito um estudo profundo de toda a linha (desde a entrada da matéria-prima no processo até ao término da peça final), com o objetivo de identificar o maior número possível de problemas existentes, relacionados com desgaste precoce ou falha repetitiva dos equipamentos. Investigaram-se as causas e consequências dessas falhas. De seguida, foi avaliado o impacto de cada um dos problemas identificados, sendo o critério a percentagem do orçamento de manutenção que representavam. Também foram analisadas tentativas de melhoria e outras investigações realizadas pela própria empresa.

As áreas de atuação catalogadas como mais relevantes foram o desgaste dos rolos cerâmicos no forno e as suas implicações, o desgaste excessivo das prensas de referenciação dos formatos e a contaminação excessiva do chão de fábrica por pó metálico, proveniente do corte laser, com especial impacto no desgaste dos componentes da cabeça de corte laser.

Após a análise e avaliação preliminar, foram propostas e implementadas melhorias para eliminar ou minimizar os problemas identificados. Procuraram-se critérios para avaliar estas propostas e analisaram-se os resultados obtidos. Devido a fatores externos, nem todas as propostas foram aplicadas, sendo que se concebeu um plano de implementação para posterior análise e avaliação dos seus resultados.

Foram feitas propostas de revisão dos planos de manutenção preventiva e desenvolveu-se um procedimento interno, como parte das propostas de melhorias.

Em conclusão, os objetivos principais propostos neste trabalho foram concluídos com sucesso, resultando poupanças significativas nos custos de operação da empresa. Foram identificados e propostos trabalhos futuros que procedem a este trabalho desenvolvido.

keywords

Hot Stamping, ceramic rollers, mechanical presses, hydraulic presses, industrial furnace, laser trimming, laser referencing black marking, preventative maintenance, cost reduction, process optimization

abstract

This work was developed as part of a curricular internship at Gestamp Aveiro, to reduce maintenance costs associated to the hot stamping production line.

For the development of this report, an in-depth study of the entire production line was carried out (from the entry of raw material in the process to the exit of the final part), to identify the possible existing problems. These problems were related to early wear or repetitive equipment failures. The causes and consequences of these failures were investigated. The impact of each of the problems was studied to access which of those were to be worked on. The selected criteria were the percentage of the maintenance budget each represented. Research to implement new solutions and improvements carried out by the company were also analysed.

The areas identified as most relevant were the wear of ceramic rollers in the kiln/furnace and its implications, the excessive wear of the blank referencing presses and the excessive contamination of the shop floor by metallic dust from the laser cutting process, with special impact on the laser tool head's components.

Then, a research was conducted to discover and propose improvements, to eliminate or minimize the problems identified and to implement those proposals. Criteria were sought for the evaluation of these proposals and the results were analysed. Due to external factors, not all proposals or solutions were applied. Therefore, a plan was developed for their implementation and subsequent analysis and evaluation of their results.

Revisions to preventive maintenance plans were made and an internal procedure was developed as part of the improvement propositions.

In conclusion, the main objectives of this work were achieved and considering all proposed solutions, significant costs reduction was achieved. Future research and work were proposed to proceed and improve some of the problems identified in this thesis.

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1 Introduction

1.1 Background and motivation

The passion for heavy machinery and production processes is something deep inside my character. Being born to a father whose job was producing moulds for thermoplastic injection for the automotive industry, my interest in this area began at a very early age, when contemplating the magnitude of the CNC-full factory floor.

The automotive industry is definitely the one that catches my attention the most, not only because of the resulting product, the cars we love, but as well for the cutting-edge technology and innovation necessary to produce those masterpieces.

As one of the highest value markets in the world, the automotive industry has immense competition. This competition leads companies to fight fiercely for profits through process optimization and increasing efficiency through automation, new material discovery and application and by innovating on how parts are produced, experimenting with new, pioneer production processes. All of this at an increasingly fast pace.

The pursuit of this interest culminated in the study path I took, a master's degree in mechanical engineering, leading to this thesis on my curricular internship at Gestamp Aveiro. This gigantic company, which belongs to an even bigger group, is the perfect example of industrialization.

All the factory-floor is filled with diverse, enormous, and expensive machines and robots to perform various processes. Every day, there are people devoted to exploring this machines flaws and finding ways to increase their availability and efficiency through mechanical or programable upgrades. These optimizations, not only to the machinery but the whole production cycle of the components produced so that demand is met.

The autonomous fraction where this internship was developed, the hot stamping line, is a cutting-edge process in Portugal, and the opportunity to study it up close was definitely a win situation. The internship allowed me to watch in first person the processes and their inherent problems, providing insight that I believe could not be achieved through reading or investigating theoretically/conceptually only. This resulted in a very enriching experience. The problems approached in this work were very challenging. Some of them were already known by the company, but some of the root causes and possible solutions were missing.

Through this work, I hope to both solve some of the problems studied and or to exclude some of the situations that were thought to be solutions but that bring no benefits, bring us one step closer to figuring out what is wrong and how to solve the problem.

1.2 Objectives

The general objective of this thesis is <u>the reduction of the maintenance costs on the factory floor</u>, through the improvement of the production processes, specially focusing the hot stamping line. This allowed the identification of the existing problems that led to machine failure and frequent maintenance interventions.

There are a large number of approaches regarding how this objective can be achieved. One of them is by making the machinery more robust to wear and tear. Another way is replacing older equipment with new, more sophisticated ones, which operate through more reliable industrial processes or have increased production flexibility. In addition, the search for more durable consumables can increase maintenance periodicity, thus lowering maintenance time and cost.

Furthermore, prevention of machinery wear due to dust and other abrasive particles is a must, through better sealing and improved aspiration systems.

During the study of both the processes and the facility, several areas of actuation were identified such as the ceramic rollers in the furnace, the referencing/marking presses and the laser cutting machine's dust contamination. To optimize and reduce maintenance costs of those areas, some measures were considered and proposed: **1)** measures were taken to increase the durability of the ceramic rollers, thus decreasing the frequency at which they must be replaced, **2)** actions to reduce the contamination of the laser's tool head with dust, to increase the longevity of its lenses and mirrors, **3)** ways of diminishing the needed maintenance of the referencing presses by reducing its wear or **4)** eliminating them, by replacing them with another more reliable process. Lastly, by **5)** updating and implementing preventative maintenance programs increase machine longevity as well as increasing machine availability. This gives more responsibility to the operators as it reduces the margin of error if the protocol is followed.

Decreasing maintenance costs makes the production process more efficient and viable due to the increase in the machine's performance. It makes it possible as well to produce components cheaper and increase profits.

1.3 Thesis contribution

Presently, we are more and more aware of our environmental impact and its consequences on the people who inhabit it. Two of the most concerning aspects of this awareness are pollution causes and people safety. I believe these two aspects can be overcome by one principle: by increasing how efficient we are in our daily activities. This will result in lower raw material consumption and less energy required to transform it. Through this, less pollution is generated as well, increasing people's life quality and environmental wellbeing.

Regarding pollution, it is known that one of its main contributors is the automotive industry. Even though the paradigm is changing, combustion engine vehicles were the preferred choice for decades, and their exhaust emissions are known to negatively impact the greenhouse effect and ozone layer as shown in (Gemeinschaften e Forschungsstelle, 2016)

The weight of a vehicle is heavily connected to its fuel or energy consumption, as for a bigger mass, more energy is needed to provide the same acceleration and velocity.

Another important aspect of the vehicle's pollution is the required amount of raw material needed to produce its components. Acquiring such materials, such as iron, which is a non-renewable material, heavily impact the environment as enormous landscapes need to be destroyed. Considering this, lighter vehicles must be produced to reduce not only overall fuel consumption in combustion engine cars but in other powertrain variants such as electric or hybrid.

Also, having driver and passenger's safety in mind, there is a necessity to develop stiffer and more impact-resistant materials. Increases in crash test regulations make it imperative to search for alternatives to the outgoing materials and production processes for the development of the vehicle's chassis and structural components. The development of these materials and processes increases car safety, thus preventing injuries in accidents on the road, saving thousands of people.

For these materials and components to be implemented in the industry, the processes used to produce them must be reliable and effective. This allows the necessary parts to have the required quality at an acceptable price, to be usable in mainstream vehicles and affordable to the consumer.

This thesis comes to respond to these points. This research was applied to the maintenance and process optimization of the hot stamping process, which is required to produce high strength/low weight structural components for vehicles.

Providing more insight and increasing the efficiency of this process leads to production performance gains and increases its viability and implementation desire. Having fewer maintenance costs leads to lower overall production costs. This decreases the components cost and makes its implementation in new vehicles easier for the manufacturer and consumer.

1.4 Thesis outline

For a better understanding and ease of reading of the discussed matters, this thesis was structured in 6 chapters. They are as follows:

- Cap. 1, Introduction: serves as an initiation to the thesis. Here, personal motivations, objectives and thesis contribution are exposed.
- Cap. 2, Literature review: An exposition of the studied information considered to develop this thesis. It is focused on the processes of the Gestamp Aveiro's hot stamping line. This will allow us to framework the thesis development and give us the knowledge needed to develop this work. The exposure of the present processes and machinery involved gives insight into the process and exposes possible areas of failure, necessary to develop the work. The compiled data from available literature is important to understand what causes the failures and evidence possible solutions.
- Cap. 3, Gestamp's Hot Stamping line. This chapter begins with Gestamp Aveiro's HS line description. This is followed by the identification of the most noticeable problems present in the line. Here, both the causes and consequences of these problems are exposed, providing information on how it affects production. This is followed by the prioritization of the problems, evidencing which are the ones who need the most focus and which are more relevant to solve. Lastly, already executed studies and strategies made by the Gestamp group to solve these problems are indicated, providing information on what has already been tried with and without success.
- Cap. 4, Case study development and analysis: This chapter begins with a summary of which problems are most relevant to solve. This is followed by exploring possible solutions and their implementation on the factory floor. Finally, the implementation of the proposed solutions is analysed and quantified, to decide whether they are a viable solution to the problem.

- Section 5, Preventative maintenance revision: changes to the maintenance plans were developed and presented, with the solution implementations in mind. A developed internal procedure is presented as well, regarding preventative maintenance.
- Section 6, Conclusions: Conclusions are made about the achieved results. Factors that might have influenced this research are presented, as well as possible future areas of research.

2 Literature review

2.1 Hot Stamping Line

Gestamp Aveiro's production line uses a direct HS process, where the forming and quenching processes are performed at the same stage when the press closes. Therefore, it uses one single tool with a cooling system. Comparing it to the indirect hot stamping, which requires an additional press and tool, to give an initial form to the metal sheet. Only then the already formed material austenitizes in a furnace. Lastly, it goes through another stamping step but only as a calibration method, which occurs at the same step as the quenching. Both processes' stages are shown in Figure 1. In Table 1, the advantages and disadvantages are evidenced, according to Hu, Liang e He, Bin, 2016.

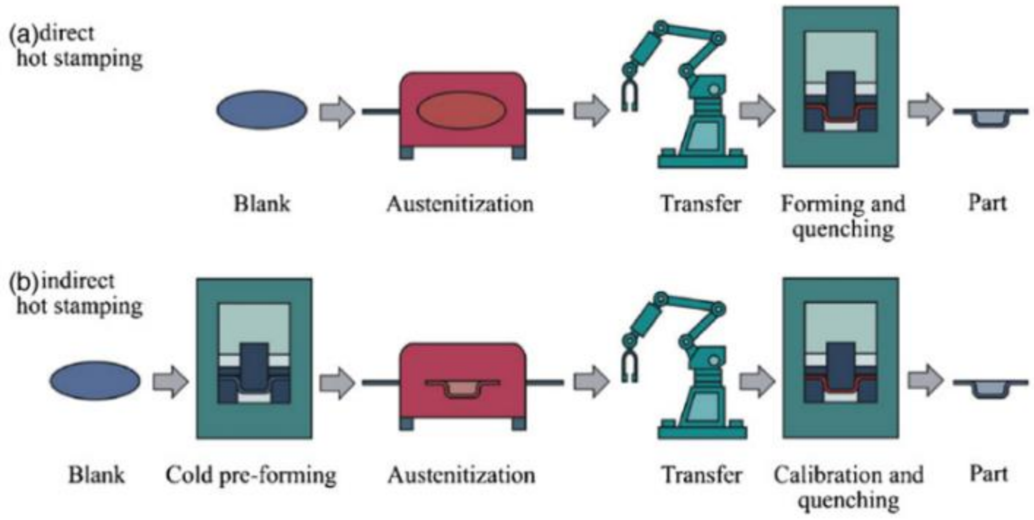


FIGURE 1: COMPARISON BETWEEN A) DIRECT AND B) INDIRECT HS (Hu, Ying e He, 2016)

The HS procedure is characterized by three main transformations, which are blank austenitization, hot-stamping and quenching. Regarding the direct hot stamping variant, laser cutting is as well used as a post-processing technique to finalise the part shape.

Table 1: Advantages and disadvantages of direct and indirect HS

Hot Stamping process (HS)	Advantages	Disadvantages
Direct	➢ Only one tool is needed, saving performing costs and accelerating production. ➢ The blank is flat which allows it to be heated in different forms, such as induction.	➢ Requires laser cutting after the stamping so that complex shapes can be accurately produced.
Indirect	➢ More reliable to form complex parts. ➢ The blank can be processed by usual stamping processes such as flanging and puncturing after pre-formed, which eases the post-processing of the quenched part, discarding laser cutting machines.	➢ Need of a cold stamping production line to work along with the hot stamping production line, increasing equipment costs.

Hot Stamping material

The material used in the studied facility was developed by one of the biggest metal producers in the world, Arcelor Mittal. Arcelor Mittal develops and sells one of the most used materials in this field, known as USIBOR1500, a boron steel alloy coated with an additional AlSi layer. The blank's composition varies slightly, according to client specifications and the two utilised varieties, at the moment of this research, are presented in Table 2.

TABLE 2: USIBOR1500 COMPOSITION - GESTAMP MATERIAL ORDER

			TRACCIÓN				r	n	REVESTIMIENTO		RUGOSIDAD		EMB	COMPOSICIÓN QUÍ MICA %											
BOBINA	HRB	P (1)	S (2)	Re N/mm2	Rm	A% 1(3)			CARA 1 # (4)	CARA 2 # (4)	Ra (µm)	Otr.Med. (5)	mm	C	Si	Mn	P	S	Cr	Ni	Al	Cu	Nb	Ti	V
B07	C32	C01	C02	C11	C12	C13	C14	C15	C60	C60	C61	C62	C63	C71	C73	C72	C74	C75	C82	C81	C76	C83	C77	C78	C80
39476795	88,0	P	T	384,00	555,00	23,5			25,0	27,0				0,2219	0,2548	1,1431	0,0106	0,0024	0,1737		0,0299	0,0214		0,0315	
39477260	86,0	P	T	406,00	586,00	21,9			24,0	22,0				0,2281	0,2257	1,1343	0,0091	0,0021	0,1713		0,0487	0,0135		0,0396	

Other companies which have developed hot stamping materials were: i) SSAB, a Swedish company responsible for the development of the Domex series which include materials such as 20MnB5, 27MnCrB5 and 30MnB5, ii) the Japanese companies Nippon Steel and Kobe Steel, iii) South Korea's Pohang Iron and Steel and iv) the Chinese Baosteel group which developed the cold-rolled B1500HS and hot-rolled BR1500HS (Hu, Ying e He, 2016).

Table 3 compares the Arcelor Mittal's Usibor 1500 with other suppliers and materials.

TABLE 3: DIFFERENT BORON STEEL COMPARISONS (Hu, Ying e He, 2016)

Code	C	Mn	P	S	Si	Al	B	Cr
22MnB5	0.19–0.25	1.10–1.40	0.025	0.015	0.015	0.08	0.0008–0.005	0.30
30MnB5	0.27–0.33	1.15–1.45	0.025	0.010	0.10–0.40	0.015–0.08	0.001–0.005	0.01–0.30
USIBOR1500	0.2210	1.2110	0.019	0.003	0.2580	0.0360	0.0037	0.1910
Docol Boron02	0.2–0.25	1.0–1.3	0.0019	0.01	0.20–0.35	–	0.0050	0.14–0.26

According to EN10027 (European Committee for Standardization, 1992), similar high strength steels (HSS) are commonly known as 22MnB5 being the 22 related to the material's carbon content, B and Mn representative of the element's boron and Manganese, respectively, and 5 regarding the B and Mn elements (Hu, Ying e He, 2016).

The 22MnB5 is divided according to their production method, into the cold and hot rolled variants, being the cold-rolled variant the one that presents higher thickness accuracy.

To analyse the mechanical properties between the stock material and after its quenching (Hu, Ying e He, 2016), three materials have been studied regarding their mechanical properties: HFBG (cold rolling), HFTG (cold-rolling), and HFSG (hot-rolling). The results are shown in Figure 2.

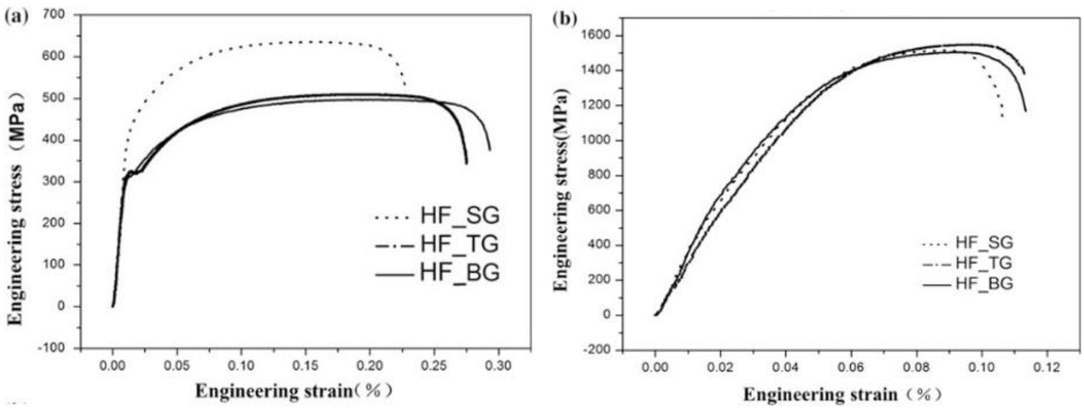


FIGURE 2: EXPERIMENTAL STRESS/STRAIN CURVES (Hu, Ying e He, 2016)

Austenitization

The blank austenitization process starts as soon as the blank enters the furnace, heating up to 920ºC. Under the austenitization process, the blanks tend to oxide and de-carburize as they are in permanent contact with hot air. To avoid these phenomena, a special coating is desired to prevent the formation of scales in the blanks, a factor of extreme importance for prior soldering and painting of the products. An alternative to using a coating would be a process known as shot blasting, which would remove the oxidation and scale formation from the produced parts, but it is an undesired extra step, so the coating is industrially preferred. This coating is usually aluminium-based (AlSi) (Karbasian e Tekkaya, 2010) but studies show that zinc-based coating can be as well usable (Costa Ximenes, Da *et al.*, 2020).

Gu *et al.*, 2011 shows that the aluminium coating and the exposure to high temperatures are enough to provide the iron with its activation energy, which allows its layer to diffuse into the aluminium layer, creating a diffuse substrate of Fe-Al compounds such as FeAl3 at an early stage (between the Fe and Al layers) and Fe2Al5 (between the Fe and the FeAl3 layer). This recently formed compound has an increased melting point over aluminium, making it harder to melt inside the furnace and cause aluminium bleeding to the furnace rollers. These compounds provide the metal with the desired coating, suitable to prevent oxidation, whose effect is boosted by elevated temperatures.

(Hu, Ying e He, 2016) presents various tests were realised to find the most suitable heating temperature for the blanks, concluding that the best properties could be achieved in the temperature range of 900-920ºC, which can be seen in Figure 3.

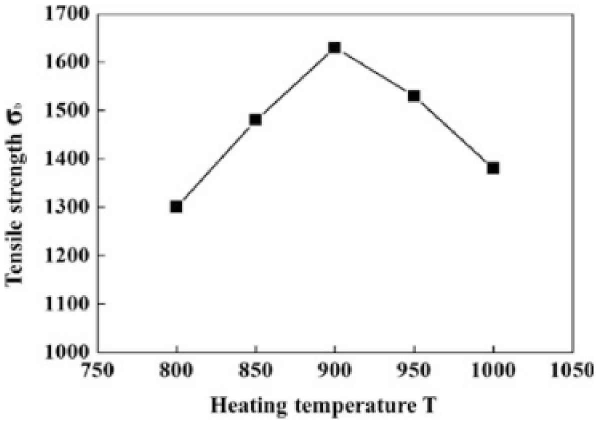


FIGURE 3: TENSILE STRENGTH FOR VARIOUS AUSTENITIZATION TEMPERATURES (Hu, Ying e He, 2016)

The dwell time inside the furnace is another variable of major importance as the size and homogeny of the austenitic grains has a heavy influence on the final cold product. It has been considered that the most suitable dwell time is about 5min, and the acceptable range is 3 to 6min (Figure 4). Before the 3min mark, there is not enough time for the austenite to form. After 6 min the grains are too coarse. The desired dwell time causes the creation of fine, uniform austenite, which potencies the martensite formation during quenching, as well as material elongation during the forming stage, decreasing the likelihood of fractures or tearing in the blanks (Hu, Ying e He, 2016) (Figure 3 and Figure 5).

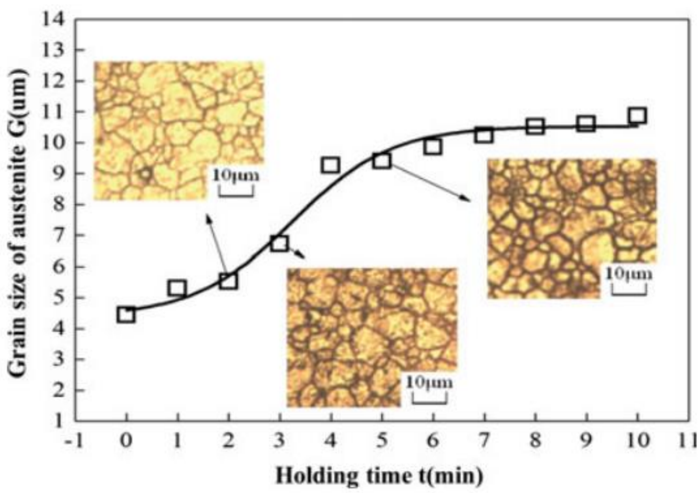


FIGURE 4: DWELL TIME IN FURNACE EFFECT ON 22MNB5'S MARTENSITIC GRAIN SIZE (Hu, Ying e He, 2016)

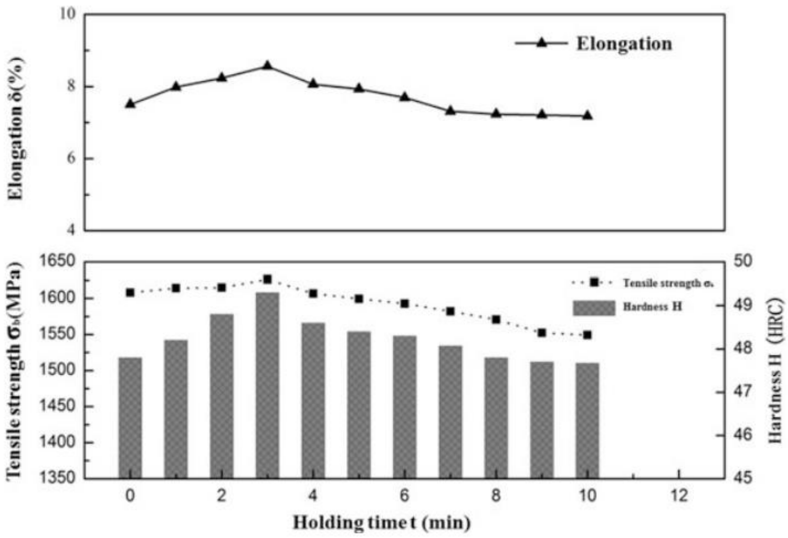


FIGURE 5: EFFECT OF DWELL TIME IN THE FURNACE ON 22MNB5S'S TENSILE STRENGTH (Hu, Ying e He, 2016)

In Gestamp Aveiro's production line, a furnace is responsible for the heating of the blanks. These blanks are transported through ceramic rollers, this being a roller hearth furnace. To prevent AlSi coating from bleeding through the whole furnace, special coatings are used in the ceramic rollers and special temperature curves are considered to focus the drooping in a zone of the furnace, instead of random drooping in every stage of the furnace. There are various heating methods, such as the following (Karbasian e Tekkaya, 2010):

- Regarding the heating method, radiation in a furnace is the most commonly used. The furnace is fuelled with natural gas, though the blanks are never in contact with the flame. The gas combustion process occurs inside radiators that emit heat to the blanks.
- Secondly, there is the conduction heating method, based on Joule's law. Here, 2 electrodes are connected to the blanks and an electrical discharge flows through the metal sheet, which acts as a resistance and produces heat. The main disadvantages of this process are the difficulty in maintaining the necessary conditions to provide uniform heating of the metal sheet, such as surface quality and contact pressure from the electrodes (Kolleck *et al.*, 2008).
- Lastly, there is the induction heating method, where a magnetic field heats a conductive material due to the induction effect. The main influences on the efficiency of this process are the geometry of the inductor and the distance between the inductor and the blank. Although it has very high efficiency, several circumstances can cause problems in the system, such as jamming of the heated blank that leads to heating system damage, electrical insulation must be guaranteed, and some blanks can be deformed due to the magnetic field's forces(Kolleck *et al.*, 2008).

Although being the least efficient, due to the energy that leaves the system through the exhaust, the furnace is the most convenient of the 3 methods. It provides homogeneous heating, ease of operation and control.

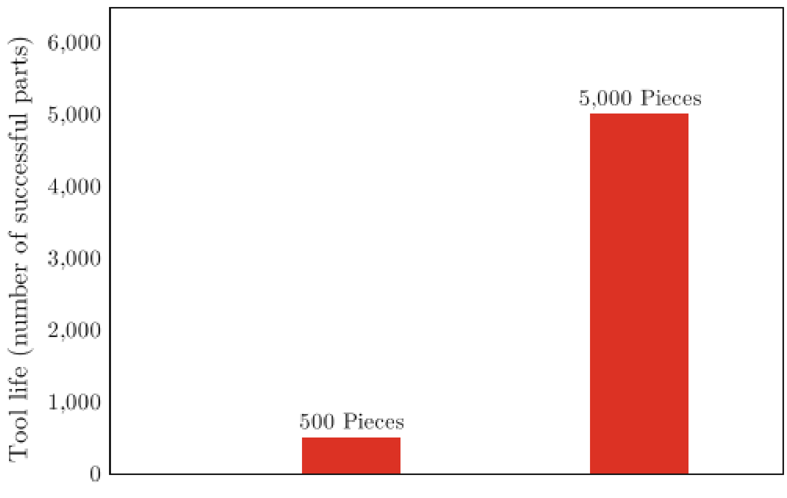
Forming

The stamping part of HS is different from the CS as it only needs one forming stage. Due to the blank's temperature, the metal is thin, more elastic, increasing its formability up to a point where only one pressing step is needed to acquire the desired format. To take advantage of this, the blank must be transferred to the die and the press drops as quickly as possible. As soon as it is formed the cooling system is activated and the martensitic transformation occurs, to harden the produced piece with the die still closed. This technique has a major advantage over the CS process, as stiffer parts can be produced at lower loads, but at a cost of tool wear (Schwingenschlögl, Niederhofer e Merklein, 2019). According to (Schwingenschlögl, Niederhofer e Merklein, 2019), the key factors of the tool material are its stiffness and thermal conductivity. These 2 ideas conflict with each other as an increase of stiffness regarding heavier alloying of steel (increased percentages of elements such as Si, Mn, and Ni) are known to decrease thermal conductivity.

Recent researches carried out by (Wilzer *et al.*, 2013) have shown that precipitated alloying elements, such as carbide compounds like Cr_3C_2, do not detriment thermal conductivity's properties significantly.

Due to the high temperatures involved, both adhesive and friction wear is increased, as well as additional factors such as rapid temperature variation and risk of oxidation and breakage of the tool. More studies have been made to investigate the effects of HS tool wear, leading to the creations of new tool materials such as hot work steel 1.2383, which has a similar wear effect with standard 1.2367 but increased the thermal conductivity (Schwingenschlögl, Niederhofer e Merklein, 2019).

As evidenced in (Hot Stamp. Ultra High-Strength Steels, 2019) tool/die coating is of high relevance and can have major impacts on the tool's lifespan (Figure 6).



Tool Material	1.3394	1.3394
Tool Coating	PVD TiN	PVD AlCrN
Blank Thickness	n/a	n/a
Blank Coating	AlSi	AlSi

FIGURE 6: IMPACT OF COATING UTILIZATION ON STAMPING TOOLS (*Hot Stamp. Ultra High-Strength Steels*, 2019)

It is noticeable that a simple application of a coating increased the tool life 10 times for the same base die material.

Quenching

One of the most relevant and characteristic processes in HS, compared to CS, is the quenching of the blanks. This process begins once the blank enters the production line's furnace, where the blanks reach up to 920°C. During the heating, austenitic transformation occurs, changing the properties of the blanks. As soon as the heated blank is ejected from the furnace and transferred to the press, the stamping and quenching processes occurs, cooling the blank down rapidly. The dies have an integrated cooling system to lower both the die and blank's temperature down. The rapid cooling of the heated blanks will reorganize its microscopic structure, developing mostly martensite which will increase the material's strength. To develop a fully martensitic microstructure, as stated in (Merklein, Lechler e Geiger, 2006), 22MnB5 has to have a minimum cooling rate of 27 $K.s^{-1}$ to achieve the desired result, as provided by Arcelor® (Figure 7) datasheet.

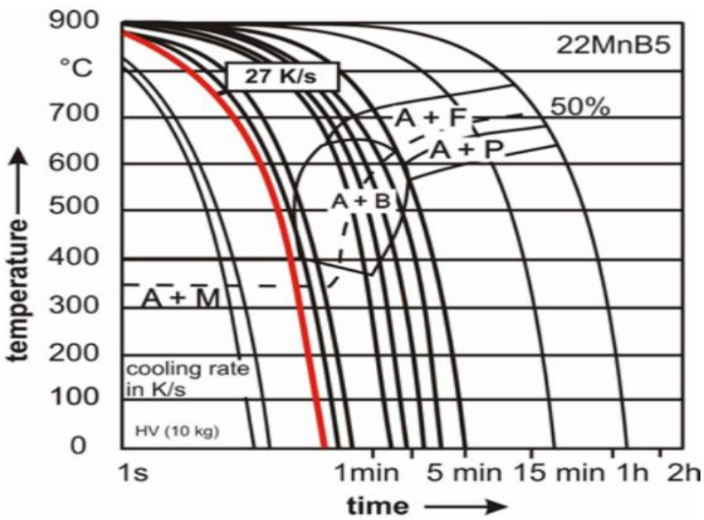


FIGURE 7: 22MNB5'S CCT DIAGRAM PROVIDED BY THE PRODUCER (ARCELOR®)

As stated by (Hu, Ying e He, 2016), there is a relation between the cooling rate and the hardness of the formed part where an increase in cooling rates increases the hardness. However, increasing the cooling rate creates stresses in the press's tool, which can lead to fracture over time. The authors made experiments/tests to determine the optimum cooling rate. Figure 8 shows the main results obtained.

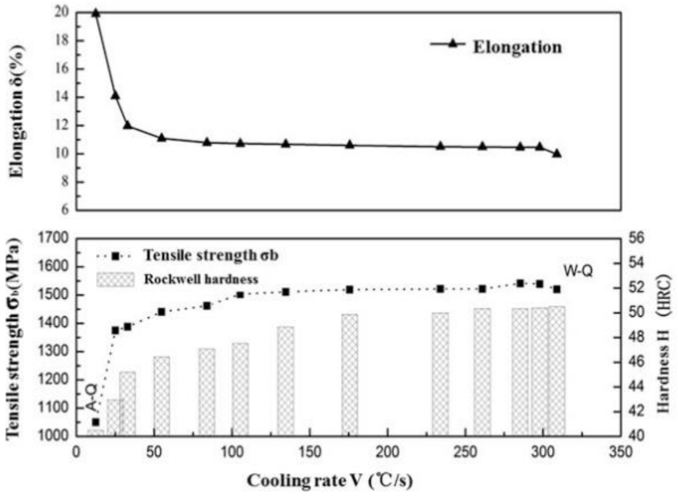


FIGURE 8: COOLING RATE EFFECT ON ELONGATION AND TENSILE STRENGTH (Hu, Ying e He, 2016)

As stated, there is a major hardness increase when the cooling rate is about 30 $K.s^{-1}$, marking the stage at where martensitic transformation is mostly developed and representing close to 85% of the maximum tensile strength (about 1600MPa). From an economical perspective, this is the cooling rate that makes the most sense to produce the parts, as it has most of the quenching mechanical properties benefits at the lowest dwell time possible. This allows the production of components with relatively high strength in a short time, making the components more affordable and increasing the production rate.

Tailored quenching

The available equipment in the production line can produce parts with variable strength, resulting in a soft zone, a stiff zone, and a transition zone in the same component. This is achieved due to the press tool being connected to a series of resistances (b), decreasing the temperature difference between the desired soft zone and the tool, and decreasing the cooling speed of the produced component. This will result in a stiff zone, which is normally cooled or quenched at the desired 30 $K.\ s^{-1}$, reaching full martensitic transformation. Contrasting with this idea, due to the resistors' heat, the soft zone will cool at a slower pace, leading it to a more bainitic composition, thus being softer with increased ductility. In Figure 9 it is shown both the effect of this process and the property/temperature variation with the formed blank.

A variation of this process consists of differential heating inside the furnace, resulting in the blanks entering the press's die with temperature variations along the blank (a).

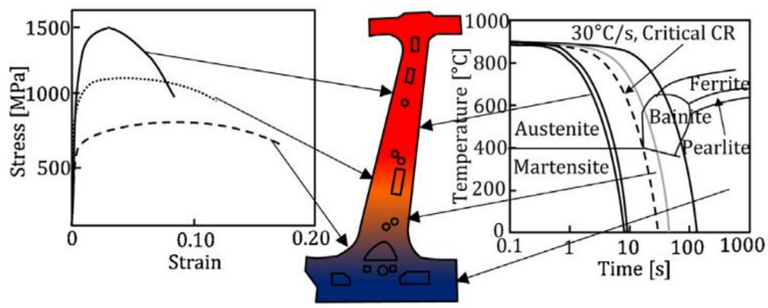


FIGURE 9: DIFFERENTIAL HEATING EFFECT ON TAILORED QUENCHING (Mori *et al.*, 2017)

Another technique to produce tailored parts is by varying the blank's thickness. Increasing the thickness in parts of the sheet where more force will be applied will result in a stronger component. These thickness variations can be attained through patching extra material in the base blank, a process known as cladding (c) or variations in the sheet rolling process(d) (Figure 10) (Mori *et al.*, 2017).

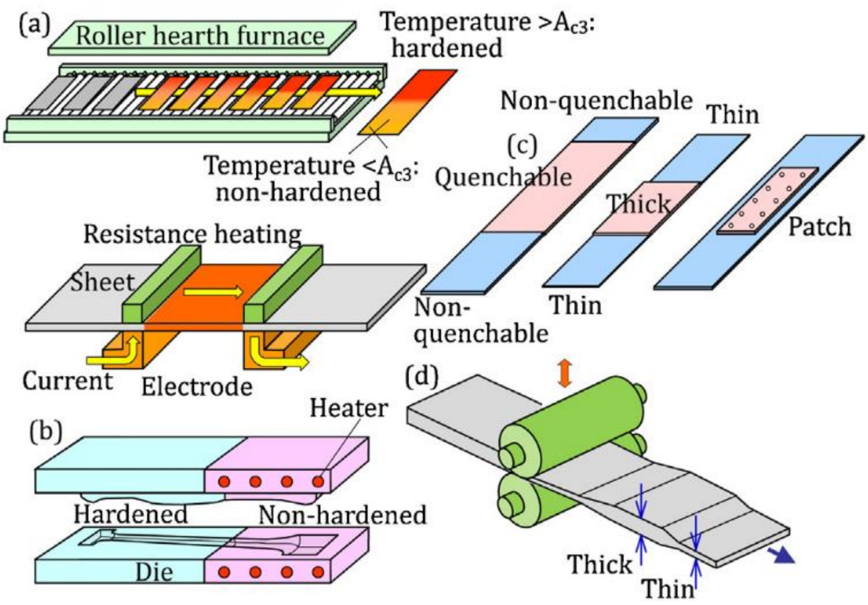


FIGURE 10: DIFFERENT TAILORED QUENCHING PROCESSES A) FURNACE DIFFERENTIAL HEATING; B) DIE ELECTRODE-HEATING; C) PATCHING; D) CUSTOM SHEET ROLLING (Mori et al., 2017)

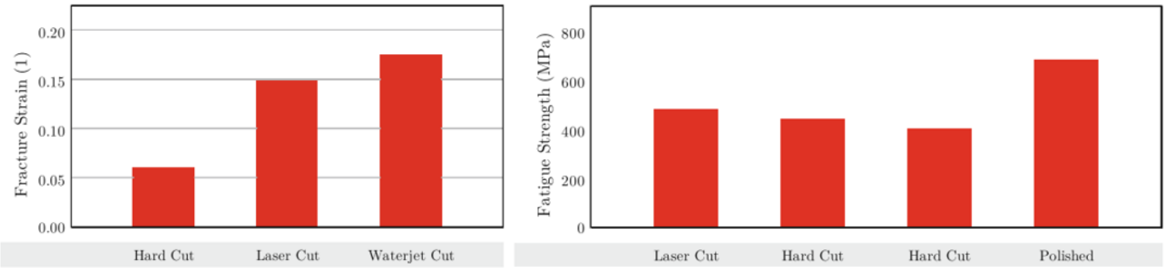
Laser cutting

Regarding (*Hot Stamp. Ultra High-Strength Steels*, 2019), the laser cutting method is very versatile as it can cut the blanks with complex contours, increasing the production cycle, and adding one extra stage to the production line.

The laser cutters are based on a 5/6 axis motion system, resembling those of the multi-axis CNC machines, as in the case of Gestamp Aveiro, but robots with laser cutting tool heads are available on market as well.

These laser cutting stations have integrated rotary tables. In these tables, a fixture is positioned so that formed blanks can be inserted. Once the blanks are placed, the table rotates, which brings the uncut formed bank inside the machine and simultaneously removing the already cut blank.

The cutting operation happens when excessive heat is focused through radiation on a surface, causing it to melt. The usage of a reactive gas removes the molten steel. One of the advantages of laser cutting is its ease of automation. Another of the advantages is the property alteration that occurs in the laser cut parts which show increased fatigue strength and failure strains, presented in Figure 11 a) and b) (*Hot Stamp. Ultra High-Strength Steels*, 2019).



a) b)

FIGURE 11: A) STRAIN UNTIL FRACTURE AND B) FATIGUE STRENGTH FOR SEVERAL CUTTING PROCESSES (*Hot Stamp. Ultra High-Strength Steels*, 2019)

2.2 Technical solutions

Different production processes such as machining, CS and HS are used for shaping metal. In this subject, a comparison between these processes is made to identify the advantages and disadvantages of the type of production method.

What sets apart the components produced in Gestamp is their thickness and geometry, requirements that have to be considered before producing the components.

CNC machining is a process that can produce various shapes by removing excess material from an initial block of material. To attain the desired chassis part's shape with CNC machining, a solid block of material with the dimensions of the bounding box of the piece must be used. The machining of this block would consist mostly of wasted material after long hours to produce one single piece at a time, for each CNC machine available, thus increasing material and operational costs.

Cold Stamping is one of the main methods to produce this type of components and is a well know process due to its long presence and use in industry. The sequential press steps required to produce the component are easily scalable and suitable for mass production at a cost-effective pace. Despite the large initial investment in machinery, thousands of parts can be produced per day with minimal wasted material, resulting in a low cost per part produced.

The only inconvenience is this method is the die wear. For tougher applications in the automotive industry, very thick metal sheets or stronger materials need to be processed, which cause extensive wear in the die, decreasing its lifespan.

In the automotive industry, recent regulations regarding fuel consumption and safety require lighter and stiffer components to ensure the reduction of fuel consumption and passenger safety.

To solve this issue, the industry departed from using big quantities of lower grade materials to thinner and lighter components of high-grade materials such as high strength steels, with increased stiffness. This resulted in both reduced component weight and increase passenger safety. Some disadvantages are identified in this process, such as the spring-back effect and cracks during the forming steps (Hu, Ying e He, 2016).

The Hot Stamping process comes to solve these issues since it produces stiffer components with very low wear of the tools. The used Ultra High Strength Hot Stamping Materials (UHSHSS) allow both the ease of forming and increased resultant high strength components. As the quenching process occurs after the forming process, the materials are shaped before reaching the desired stiffness properties. UHSHSS can have their stiffness increased up to 250% after quenching making this process ideal to produce high strength structural components (Table 4)(Karbasian e Tekkaya, 2010).

TABLE 4: BEFORE AND AFTER QUENCHING IN VARIOUS STEELS PROPERTY COMPARISON (Karbasian e Tekkaya, 2010)

Steel	Martensite start temperature in °C	Critical cooling rate in K/s	Yield stress in MPa		Tensile strength in MPa	
			As delivered	Hot stamped	As delivered	Hot stamped
20MnB5	450	30	505	967	637	1354
22MnB5	410	27	457	1010	608	1478
8MnCrB3	–*	–*	447	751	520	882
27MnCrB5	400	20	478	1097	638	1611
37MnB4	350	14	580	1378	810	2040

* There is no possibility to have fully martensitic microstructure.

3 Gestamp's Hot Stamping line

As shown in Figure 1, Gestamp's hot stamping production line is composed of forming and laser cutting areas. The forming line is subdivided into 7 areas (Figure 12): 1. the destaker, 2. furnace, 3. centring bed, 4. loading feeder transfer arms, 5. Loire medium press, 6. unloading feeder transfer arms and 7. exit transporter.

In stage 1, blanks are fed into the system, being firstly referenced and thickness verified in a hydro-pneumatic press. In stage 2, the blanks are heated to the desired temperature to be completely austenitized. At stage 3, the blanks are centred and put in an easy grabbing position, to be inserted in the press (5) by the loading arms (4). After the forming and quenching processes, made by the press's pressure and cooling system, the formed parts increased the strength properties due to the martensitic microstructural changes. Lastly, the formed components are removed from the press by the unloading arms (6) into the exit conveyor belt (7) and carried to the operators to be stacked and transported to the laser cutting zone where trimming will occur.

3.1 Production details

Focused production line and its relevance

This internship report focuses on one of the production lines present in Gestamp Aveiro, more precisely the Hot-Stamping (HS) line. The HS line acts as an autonomous section of the company, where the logistics, production and accountability are handled separately from the main and older Cold Stamping (CS), painting, and soldering sections.

The HS production line was first introduced in Portugal in 2019, being the first amongst the national industry. The HS line was built with an investment of about 12 million euros and represents close to 9% of the company's total yearly revenue, about 10 million euros/year.

Despite being the youngest member of the Gestamp's group HS facilities, it is one of the most productive and has the best continuous improvement rates.

Production line description

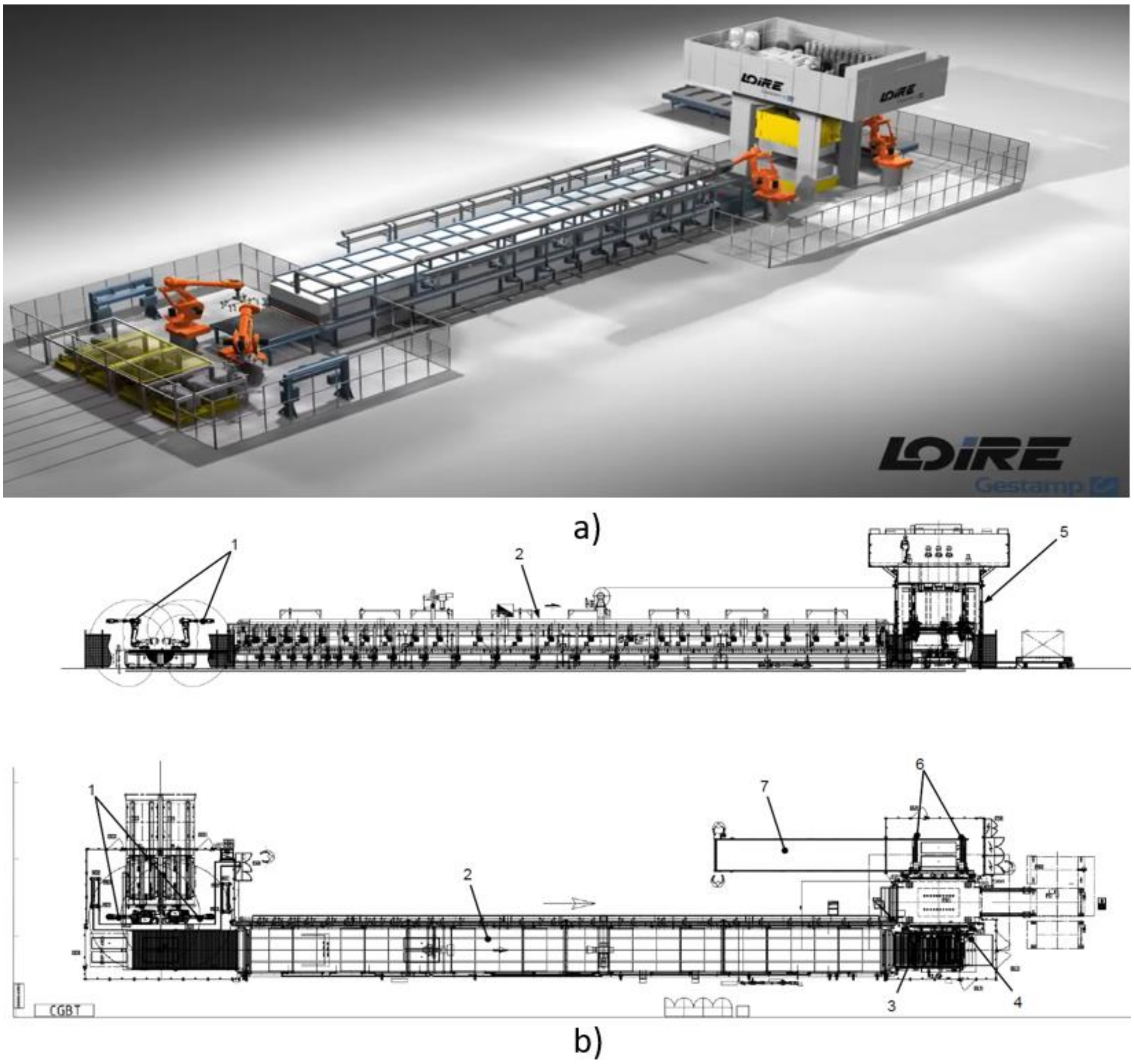


FIGURE 12: A) GESTAMP HS LINE RENDER IMAGE AND B) HS SCHEMATIC

As shown in Figure 12 b), the production process begins in the destacker (1). There are 4 stacks of blanks aligned that are picked up by 2 robot arms with pneumatic suction cups, which transfer the blanks to a small "C" shaped hydropneumatic TOX® press. In this step, a thickness sensor verifies the blank's thickness and references the blank by the TOX® press simultaneously. The reference allows the blank to be traced back if there are quality issues. The thickness control serves as a method of prevention from the robot arm inserting 2 stacked blanks at the same time in the system. The robot arms then proceed to drop the blanks on the conveyor rollers, so the blanks go through the furnace's (2) heating circuit.

The furnace has a total of 274 ceramic rollers, controlled by servomotors, which transports the blanks up to a maximum of 11 minutes up to 930°C, time that if surpassed will degrade the blanks mechanical properties. The batches are controlled by photo barriers inside the furnace. After the heating process, the blanks are expelled from the furnace into the centring bed (3). The centring bed is responsible for aligning the blanks with the assistance of linear rail, servo-controlled claws and lifted to an easy collection position to be grabbed by the press loading transfer feeding arms (4) and placed inside the cold hydraulic forming press's die, the Loire® medium forming press (5).

If there is any reject from a faulty blank because of over-exposure to temperature, a "stopper" plate is lifted, causing the faulty blank to leave the system immediately to a scarp container. Despite their simplicity, the stoppers have a very important function. Once the blank leaves the furnace, the rollers move the blanks until they hit the stoppers. The special format the stoppers have allows the blanks to be semi-aligned and prevents more delicate contours of the blank from warping/bending due to the impact. Stoppers are shown in Figure 13.

a) b)

FIGURE 13: A) BLANK HITTING A STOPPER AND B) STORED STOPPERS

The Loire® medium forming press is composed of 2 individual carriages, which means 2 dies/tools can be used at the same time independently, in the same press. Other Gestamp's HS lines use Loire® small presses, which contain one single carriage or Loire big presses, which use 4 carriages. Once it forms the blanks a water-based cooling system is activated to refrigerate the tool and consequently lower down the formed blank's temperature rapidly to about 200ºC.

As of the opening of the press, the unloading feeder transfer arms (6) proceed to collect the recently formed components. Once lifted from the die, they are dropped in the conveyor belt system in the exit transporter (7) to be accessible to operators from the production line. Those operators are responsible for removing the formed blanks from the system and stack them to be sent to the laser cutting machines.

Once the pieces are carried to the laser cutting stations, they are positioned in specific fixtures to be properly cut. Once cut and removed from the laser machine, the operators verify if the piece corresponds to the desired shape. Here, a proprietary fixture helps the operator understand if the cut blank has every necessary contour. If everything was correctly cut, the operators proceed to stack the cut parts to later be shipped to Gestamp Vendas Novas. All the scrap and rejected parts are gathered and collected by Gescrap, a company that belongs to the Gestamp group whose function is to collect and recycle waisted metallic material.

The final product

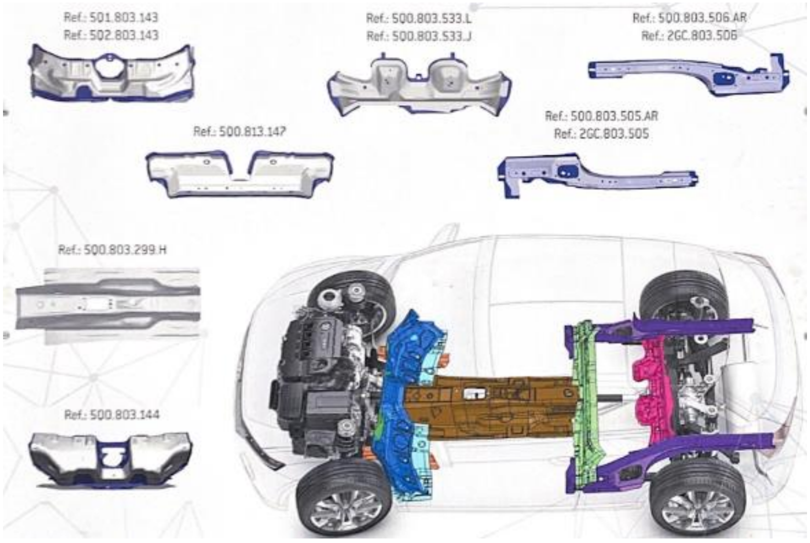


FIGURE 14: VW T-ROC HS PRODUCED COMPONENTS.

As shown in Figure 14, in the HS production line, a total of 9 parts are produced, with 8 references (one of the references has 2 components produced simultaneously, which are later split. These parts are chassis components of VW T-roc, which will be sent to Gestamp Vendas Novas to be pre-assembled (soldered) before heading to Autoeuropa to be integrated into their assembly lines and produce the complete car. They have both a structural function and serve as mounting sites to other car components such as lateral panels.

It is relevant to mention that there are partial differences in the production process of these components, where the purple components are conceived through a tailored quenching technique, and the remaining 7 components are conceived through the more common full quenching procedure.

3.2 Problem identification, consequences, and causes

To identify the main problems, an exploratory analysis of the production line was developed. Also, conversations with operators and maintenance personal were made to identify and register opinions and different points of view of problems. It is relevant to mention that systematic problems caused by the normal wear of the machine's components were not considered, such as chains/gears wearing out. According to the research, the main problems are as follows:

TOX referencing press

In the early stages of the production line, the small "C" shaped hydro-pneumatic press (Figure 15) responsible for the referencing and thickness verification of the blanks breaks repeatedly. When maintenance is being performed, to enter the destaker area, a safety gate cuts the pressurized system once open. At this point, the press starts losing pressure and its tool head drops, often abruptly.

FIGURE 15: TOX HYDRO-PNEUMATIC REFERENCING PRESS

One of the most evident consequences is related to the blank's references. These references are needed for tracing purposes, essential for problem identification. It has been noticed that, with time, the markings in the blanks lose depth, reaching a point where they are barely visible and impossible to trace back.

Secondly, it can be hazardous to the operators. As the compressed air system is automatically cut once someone enters the area, as a safety measure, every time maintenance is being performed it is very likely that the press's tool head will drop, which can happen when being calibrated by an operator/maintenance personal, increasing the risk of crushing their hands.

Upon closer inspection, a slight bending was noticeable in the press once it was referencing a blank. Due to the press's shape, the force from the marking process generates momentum in the press, causing the tool head movement to be misaligned. Being the most fragile component of the machine, the tool head's shaft starts to warp. At this point, seals and other components of the press start to fail and cause air leakage, which results as well in lower operating pressures and unseeable markings in the blanks.

Furnace's ceramic rollers

a) Roller layout inside the furnace

b) Aluminium encrustations

c) Contaminated rollers inside the furnace

FIGURE 16: CERAMIC ROLLERS USED IN THE FURNACE.

One of the major problems of the production line is the premature wear and break of the ceramic rollers. The periodic maintenance associated with the replacement of the ceramic rollers is one of the biggest expenses, rounding about 100.000 €/year. There are a total of 274 rollers in the furnace, which are divided into several heating areas. There are two types of rollers: massive (used at the beginning and end of the furnace) and hollow as shown in Figure 16 a). It is known that the blanks leak aluminium and contaminate the ceramic rollers which are very porous, evidenced in Figure 16 c). The presence of aluminium in the rollers causes the blanks to start deviating and possibly getting stuck in the furnace, leading to a clog in the furnace. Another consequence is that the blanks travel slower inside the furnace, due to skidding in the aluminium contaminations.

These aluminium encrustations can as well infiltrate the rollers deep inside. It is in these places where the breakage usually occurs, so the encrustations, simultaneously with the high-temperature gradient when being replaced, are thought to be the breakage cause (Figure 16 b). The breakage makes refurbishing the rollers impossible, meaning that for each roller that breaks a new one must be used.

This contamination can as well be seen by the number of interventions needed to clean the tools. The excess aluminium in the rollers starts forming aluminium blobs that sometimes stick to the blanks. Once inside the Loire's press tools, they leave those aluminium excesses in the tools, resulting in defects in both the formed blanks and the tools. Once these markings start getting too noticeable, the operators must intervene to clean the aluminium contaminations from the tools.

Furnace cover's seal

The furnace is equipped with several openings along its length, making each heating area of the furnace accessible during maintenance interventions. These openings are lifted manually by operators with the assistance of a hoist system with chains and a hook in 4 locations for each of the 4 openings. Between the cover and the furnace's structure, there is a layer of sand that provides sealing to keep the heat trapped.

There was an occurrence where two of the covers were poorly sealed, which caused temperature gradients inside the furnace, lowering its efficiency. To properly close the covers, the furnace had to be shut down, which led to the rupture of 24 ceramic rollers.

The fact that the hook was left in both the corners of the covers that were partially lifted, which did not grant the necessary seal, led to believe that its cause was the operator fault.

Centring bed claws breakage

After the austenitization process, the blanks leave the furnace and are expelled to the centring bed to be properly positioned. The centring process consists of the "claws", which are linear rail-guided by metal cylinders. Moving towards the blank from each side, and locking in place, aligned with the transfer leading arms. Then, geared plates elevate the blanks to ease the grabbing process by the transfer leading arms. The centring and elevation process is demonstrated in Figure 17 and Figure 18.

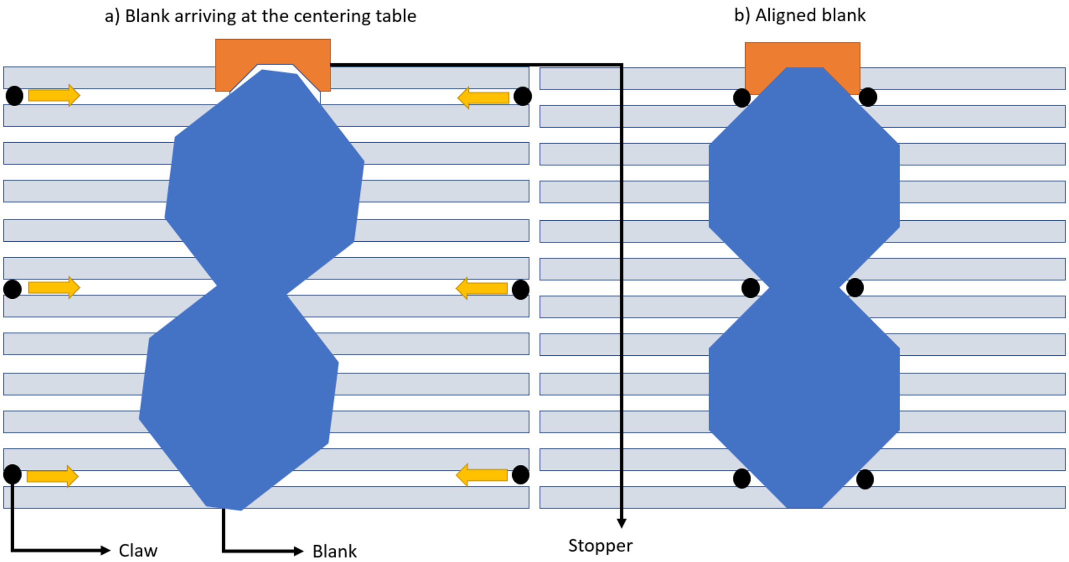


FIGURE 17: BLANK ALIGNMENT IN CENTRING TABLE SCHEME

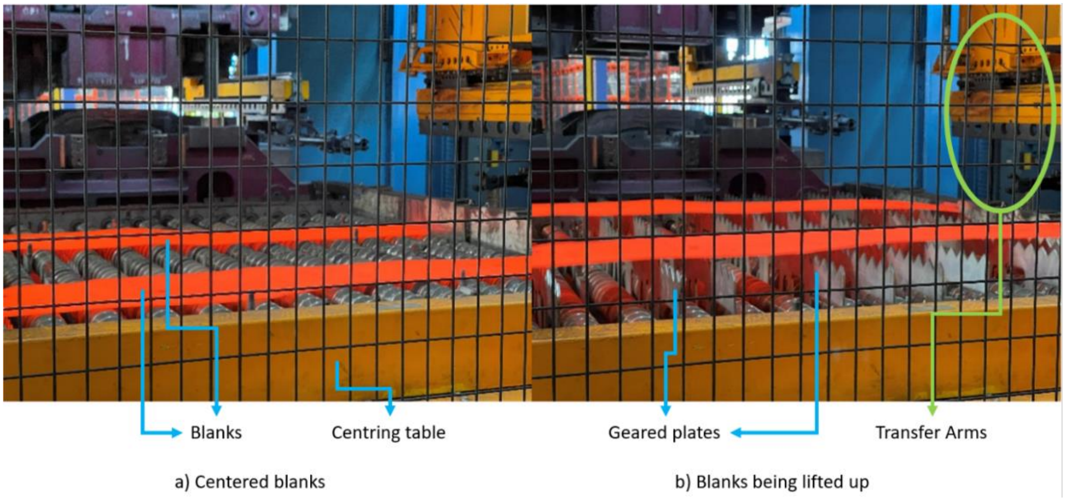


FIGURE 18: CENTRING BED'S GEARED PLATES

Several events occurred where the claws break, causing miss-alignments in the blanks, which cause wear of the tool and defective parts.

The centring bed is one of the most component dense parts of the stamping line, where there is minimum margin space between its various moving parts. The breakage of the claws has been reported to be caused because of the impact between the claws and the geared plates, which are often found warped. Even the lightest bend is enough to cause impact between these two components, as they are very close and there is little to no margin for error.

The point of failure of the claws is the linear rail, which represents a replacement cost of 1100 €/unit.

Oil temperature control system

The hydraulic press has a complex oiling system. This oil is used by the machine's hydraulic cylinders to perform the pressing movements.

A major problem occurred where the oiling temperature dropped too low, increasing viscosity to a level that the pressure rose too high and caused severe damage to motors and reservoirs. This, as well as the amount of spilt oil, resulted in a very time-consuming repairing service, coupled with significant repairing costs and impairing the production line for a long time.

This event was due to the cold temperatures outside, paired with a production line interruption, which causes a temperature loss inside the factory floor. The available oil temperature control system is only capable of cooling down the oil, which caused it to reach temperatures below the recommended, increasing its viscosity.

Rupture of the exits transporter's chain

The last major problem identified in the HS line is the rupture of the chain, responsible for the movement of the exit transporter. This transporter is a conveyor belt that brings the produced parts to the operators. Along the conveyor belt, there is an air-cooling conduct that cools the parts, so as not to harm the operators once they start handling the components.

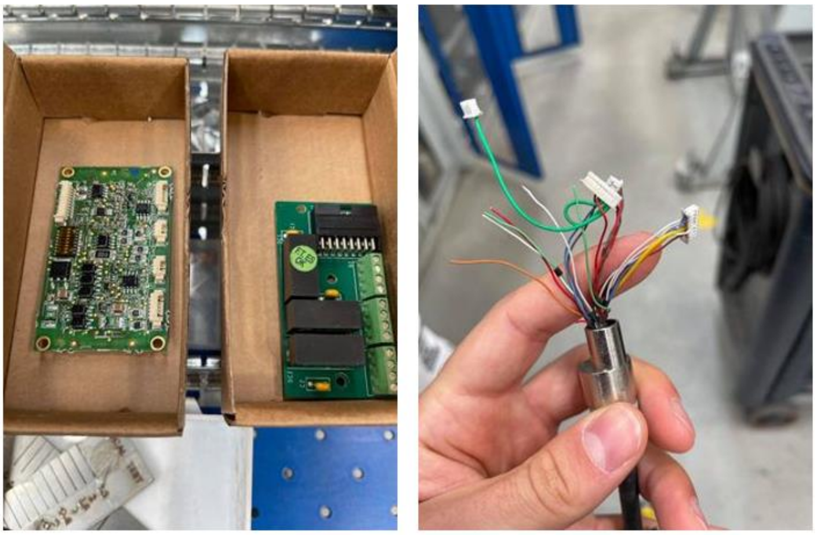
The rupture of the chain results in the conveyor being immobilized, therefore the produced parts would start to be stacked on top of each other, increasing the possibility of damaging the transfer arms. This bottleneck would happen inside a no trespassing area (a safety measure, present because of the movement of the transfer arms), operators do not have conditions to maintain their functions and the whole production line must be stopped for the arms to be repaired.

After investigation, it was noticeable that the drive chains were completely dry, which caused a rupture. This was due to the ineffective lubrication system, which failed to properly oil the chains.

Laser constant maintenance

a) Laser lens b) FPC Mirror

FIGURE 19: LASER TOOL HEAD COMPONENTS.



a) Hermes and Prima Power boards, respectively. b) Worn out Prima Power cable.

FIGURE 20: PRIMA POWER LASER WORN-OUT ELECTRONICS

The laser cutting machines are located after the stamping process and are constantly failing due to mirror, lens and cables wear, components shown in Figure 19 and Figure 20. Maintenance interventions revealed that the lenses get dirty with ease and operators reject several parts, which do not meet the requirements.

Regarding the lenses, maintenance personal has acknowledged that the optical components in the tool head, such as the lenses (Figure 19 a) and FPC mirrors (Figure 19 b)) often get scratched with ease and are replaced, costing about 245€ and 3400€ respectively.

In the case of the electrical components, when maintenance actions are being performed, signal cables (Figure 20 b) are found with loose ends. Personal proceeds to replace them with new ones, as well as replacing some of the circuit boards associated with them, as seen in Figure 20 a).

Focusing on the quantity of rejected parts, it has been reported that it is due to misalignments between the laser tool head and the formed blank. These misalignments not only result in rejected parts but cause damage to the tool head, as it hits the mispositioned formed blank.

Despite being equipped with a pressurized air system to shoot away metallic dust from the lenses, and an aspiration system, the environment the laser equipment works in is still very dusty. This dust is found in the lenses and is believed to be the main cause of the scratches that lead to their replacement. This causes efficiency in the cutting process to reduce, which makes it take longer to cut the same length of material, as well as more imprecise cuts.

The cause of premature wear of the signal cables was reported to be due to the normal movement of the laser's tool head. This leads to believe this problem is related to a production issue or a poorly developed machine component.

Both the motives on why the circuit boards are damaged or where they are damaged are unknown.

Excessive metallic dust on the factory floor

Another major problem on the factory floor is the amount of metallic that contaminates all the manufacturing plant. The dust is not noticeable when airborne, but as soon as it reaches surfaces, during cleaning interventions, it is very prominent.

This dust is produced mostly during the laser cutting process, due to the large amounts of vaporized metallic particles, inherent to the process.

Metallic dust is very harmful in 2 different ways. Regarding machinery, it is responsible for premature wear, causing equipment malfunctions and failure (Khruschov, 1974), as commented in the last topic, Laser constant maintenance, destroying lenses and other equipment, resulting in increased maintenance costs. Secondly, it presents itself as being hazardous to people present in that work environment. If safety measures aren't taken, it can lead to several and severe pulmonary diseases in the long term (Mahurpawar, 2015).

3.3 Problem prioritization

Despite the large number of problems that could use some attention, a prioritization must be made to understand the relevance of each problem's consequences. Indicators such as energy, time or money spent are linked and can be used according to the company's preference. As one of the main objectives in this work is to reduce the maintenance costs involved in the HS line, the most relevant criteria is the costs related to replacing/fixing components and parts from the machinery and the maintenance service costs associated.

First, yearly spendings were compared to understand if there has been a tendency over the years. By analysing trends, the most relevant areas that impact the yearly costs can be identified.

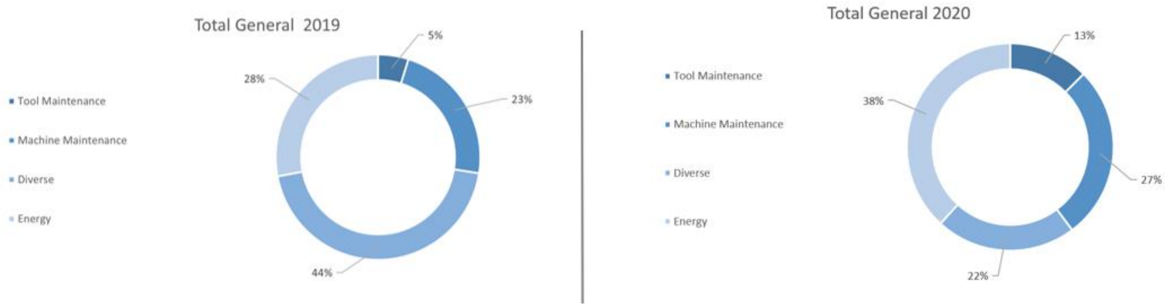


FIGURE 21: RELATIVE GENERAL COSTS 2019 AND 2020

Figure 21 presents the main processes costs during the last two years. To respect the companies demands, the absolute values of the total spendings are not shown. It must be considered that Gestamp Aveiro's HS line was only fully assembled at the end of the year 2018. In this year, a few blanks were formed for testing purposes. These tests lasted for several months, up until mid of 2019. During the second half of 2019, the production started in low quantities. This type of manufacturing was a pioneer in Portugal, so the staff had lower experience in the area, making this year a year of learning, without the best mass production. Full production was achieved at the beginning of 2020. There was an increase of 49% of the costs when comparing the year 2019 and 2020. Thus, it is not possible to conclude if there is a tendency for maintenance costs due to a lack of data.

To achieve the objectives of this analysis, extensive data from the company's expenses were shared. The analysis consisted of organizing the given information, splitting it into two main areas, the HS direct line (from the destaker to the exit conveyor belt) and the post-processing area (laser trimming).

Each acquired component and/or service were studied and grouped into sub-categories, according to the machine/process they are a part of. An example, in the HS group the TOX presses, TOX tool heads and tool headsprings were grouped into the TOX press category, because they represent the acquisition of components to fix the press's issues. This Pareto analysis provided insight into which machines/parts of the HS group were most representative of the total money.

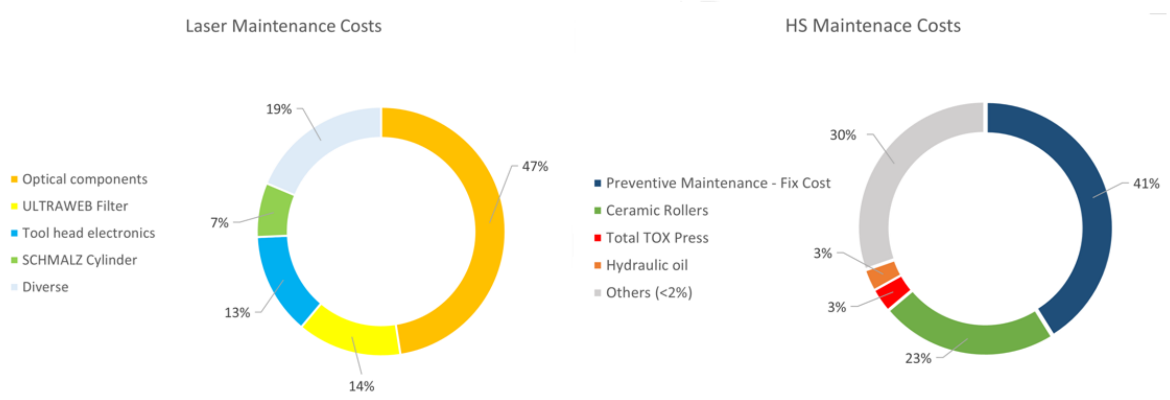


FIGURE 22: MOST IMPACTFUL SPENDING CATEGORIES

The relative costs of the hot stamping line are presented in Figure 22. Regarding HS maintenance costs, the major costs are related to preventive maintenance, performed by the official Loire and Schwartz personal, on the Loire medium press and furnace, respectively. The second biggest cost is the replacement of the ceramic rollers that break when taken out of the furnace, close to one-quarter of the total spendings. This is followed by the costs of components associated with fixing the TOX presses. Lastly, a considerable quantity is spent in specific high-temperature oil, which is used in the Loire medium press for hydraulic movement. The “others” category represents all the costs associated with items that represent 2% or less of the total spendings, that had no relation between them and represented a one-time purchase to improve a piece of equipment.

Focusing on the laser maintenance costs in Figure 22, it is noticeable that the biggest cost is related to optical components in the tool head. This category incorporates components such as dust damaged FPC mirrors, the laser lens, and consumables like polyester swabs, necessary to perform delicate cleaning operations. The second most relevant category is the replacement of ULTRAWEB filters. These filters are used to filter the compressed air system and are changed quite often due to the quantity of dust generated by the process. The third most important category is the electronic components that control various functions of the tool head. Items such as Prima Power signal cables and circuit boards, as well as Hermes circuit boards. The Schmaltz cylinder is part of the fixture that stabilizes the formed blanks cutting the laser trimming process. They are magnetized and grant the proper fixing of the formed blank to prevent misalignments.

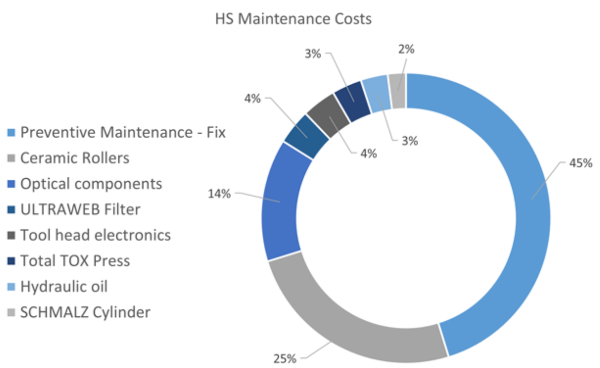


FIGURE 23: RELATIVE HS MAINTENANCE COSTS

Figure 23 shows the relative costs of the various categories forementioned, which represent 73% of the machine maintenance costs. This gives a better perspective on the overall impact of each category in all the maintenance performed in the HS production line. This helps to better understand the problems whose solution will bring the most benefits.

As previously mentioned, the preventive maintenance costs are subcontracted, and at this very moment cannot be reduced due to protocols with the equipment makers. Thus, the priority problems will be i) the longevity of the ceramic roller. and ii) the optical components of the Prima Power® laser's tool head. The furnace's opening seal is deeply connected to the roller longevity, so it is as well relevant to address.

Another relevant factor for the company is the collaborator's safety. Thus, solving any problems that can be hazardous to users is a must. In this case, putting efforts to solve the issues related to the TOX® press. Another reason for acting on the TOX®'s presses is their need for constant maintenance interventions, which is very time-consuming and has a significant impact on the availability of the production line.

3.4 Gestamp's current strategies and studies

Regarding the most impactful problem out of the three selected, the breakage of the ceramic rollers when replaced. Gestamp's approach has been trying to decrease the frequency of the roller's substitution. This reduction means fewer maintenance interventions yearly, therefore fewer rollers are used, reducing costs.

Through trial and error, a significant number of combinations between rollers from different providers has been made. This led them to increase the maintenance period from 4 to 5 weeks. The strategy in use is to treat the ceramic rollers as consumables, as they found a way to make this practice economically viable.

Studies were made within the group (outside Gestamp Aveiro) to viably replace the current boron nitride coated mullite rollers with the usage of NSiC ceramic rollers or even metallic rollers. Whilst the NSiC ceramic rollers have better performance, they did not prove to be economically viable. Currently, they cost about 20 times more than the current mullite rollers (1200€ versus 60€), and only last close to 4 times more (15 weeks versus 4 weeks). This would increase the production costs. Regarding the metallic rollers, experiments were executed with refractory steel. Although it suffered little to no aluminium contamination, the rollers started to warp due to their weight, disrupting the blank's flow.

Focusing now on the Prima Power® lasers, as mentioned before, the main cause of the problem is the metallic dust. Efforts were made to clear more regularly the factory floor, and the laser's filters are changed more frequently than what originally recommended by the equipment producer. There was as well a try to purchase only the directly affected component, which was not possible earlier due to provider constraints. For example, the whole lens assembly was needed to substitute a worn-out lens, instead of purchasing the lens separately (Figure 19).

Lastly, the TOX press. As stated earlier, the main problem was the bending of the too head's shaft. Attempts to reinforce the tool head's shaft have been made to make it stiffer, thus making it able to withstand higher working pressures without bending, as shown in Figure 24.

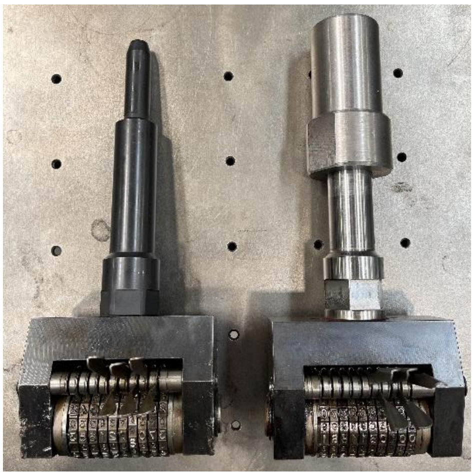


FIGURE 24: STANDARD SHAFT AND REINFORCED SHAFT

This has improved the situation, as it has increased the lifespan of the tool head, although the root of the problem has not been solved. There was as well a reduction of the input-pneumatic pressure of these presses from 5 to 3,5 bar, to reduce their wear.

4 Case study development and analysis

4.1 Summary of the focused problems

The three most relevant problems to solve are related to:

- Replacement of ceramic rollers in the furnace (Figure 16);
- Prevention of the bad closing of the furnace's cover;
- Wear of the laser tool heads' optical components, such as the FPC mirror and lenses (Figure 19);
- TOX® press constant part replacement (Figure 15).

The mullite ceramic rollers are contaminated by the molten aluminium from the blanks due to their porosity, causing deviations and delays in the transportation of the blanks. When roller removal for aluminium cleaning purposes is attempted, most rollers break due to thermal shock. At that moment, the rollers must be replaced with a maximum period of 5 weeks. Attempts were made to achieve the 6 months, but the deviation and delay in the blanks were significant.

Due to a bad closing of the furnace's covers, there was a loss of efficiency of the furnace. To fix it, the furnace had to be turned off which led to the breakage of 24 ceramic rollers.

During the formed blank trimming process, large quantities of metallic dust are released. Despite having measures to prevent damage from dust, the optical components from the laser machine get scratched very often, having big costs associated. This excessive wear results in poor cutting precision and lower efficiency.

Not being one of the costliest categories, the TOX® press presents a safety issue that must be addressed, which is also a very time-consuming fixing. Due to the shape of the press, as well as its working pressures, the press's structure cannot endure the involved forces and the tool head's shaft deviates, wearing other components precociously.

4.2 Possible solutions

Furnace ceramic rollers

As mentioned before, the breakage of ceramic rollers happens when furnace interventions are made. Interventions imply cooling down the rollers to near ambient temperature and then reheating them again. This causes great thermal amplitudes, causing rupture.

The origin of this problem is the aluminium contamination inside the furnace, due to the melting of the blank's coating. Solving this problem (preventing the aluminium contamination) decreases the deviation and delay problems, which results in rollers not having to be swapped so often. The main issue is that the blanks require this coating to not suffer from oxidation inside the furnace and no other viable coating is currently available in the market. Thus, changing the blank coating material is out of the question, having other zinc-based available coatings at an even lower melting temperature than aluminium. Exchanging the ceramic rollers was already tried, with negative results. Other possibilities, yet unexplored, are the adoption of new, recently designed hybrid rollers. These rollers have a ceramic core, and a special metallic cladding made of refractory steel.

Since the aforementioned possibilities are not viable, instead of trying to eliminate the root cause, efforts can be used in reducing its effect. One measure of this affair was already implemented. The use of a special temperature curve along the furnace makes the aluminium contamination melt with the most impact on a certain area of the furnace. Figure 25 shows the various zones of the furnace and its set temperature (below) and its real temperature (above) in Celsius degrees.

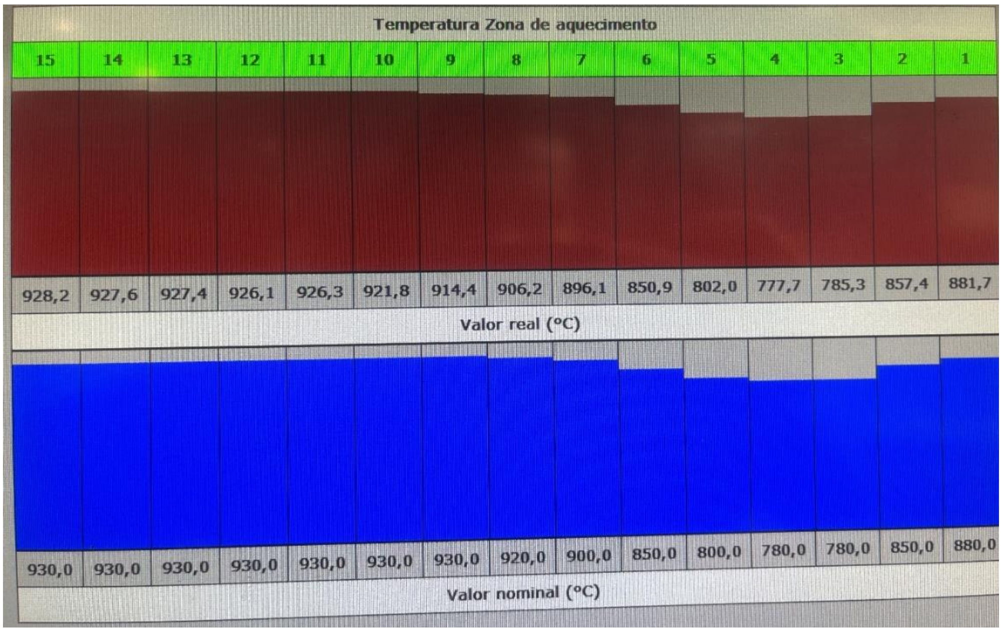


FIGURE 25 FURNACE'S TEMPERATURE CURVE

One other way, not implemented, is that the contamination can be spread is along the furnace's width.

Presently, 6 of the 8 produced references travel aligned with each other, in the same travel axis, centred in the furnace. The furnace is divided into 2 halves and the blank's travel axis at the mid-line of these halves. The remaining 2 references travel with a deviation to the left. Contamination images inside the furnace can be seen in Figure 26.

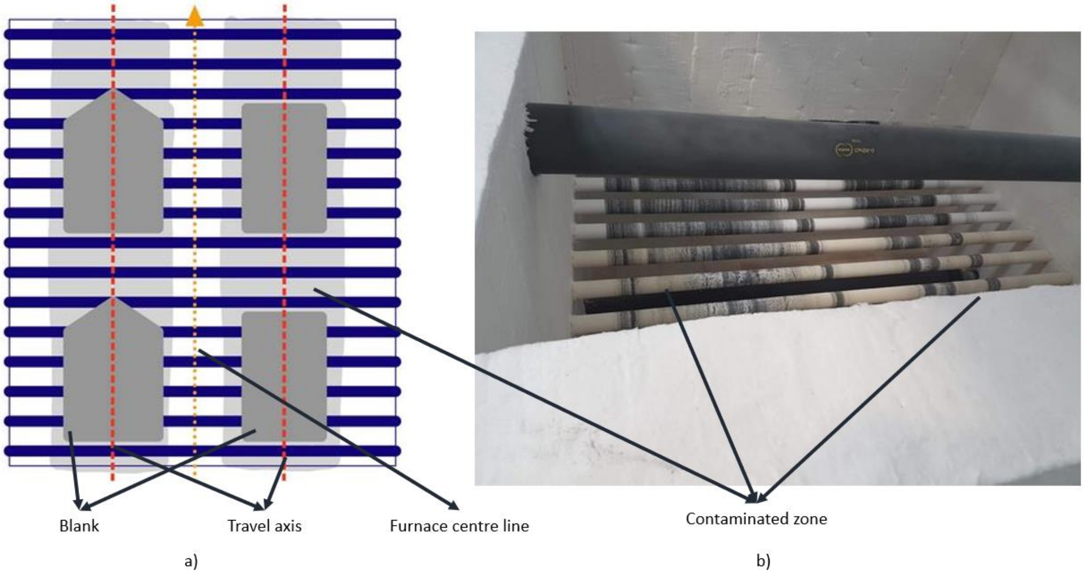


FIGURE 26: FURNACE SCHEMATICS A) BLANK TRAVEL AND B) CONTAMINATED ZONES

To prevent the heavy impact of the contamination in the areas shown in Figure 26 b), the positioning of the blanks can be studied, to increase the area contaminated along the width of the furnace/ length of the rollers. Thus, the encrustations get more spread along the surface and not as deep. As the contaminated area spreads width-wise, aluminium concentrated zones can be decreased, reducing slip. As a result, blank deviation and delay can be further minimised. Consequently, higher period maintenance interventions can be achieved, reducing costs.

Furnace’s cover

Another actuation point can be the improvement of the seal between the various furnace section’s openings. Developing a locking mechanism in these openings results in both a better seal and a safety measure.

This system can be integrated with the rest of the furnace’s informatics system, making it compulsory for the locking system to be activated for the furnace to function. Thus, in a punctual situation where someone forgets to close it, the furnace requires the operator to verify and fully lock the cover and prevent future loss of efficiency and consequent unnecessary interventions and roller breakage.

Another possibility is simply creating a procedure for the opening and closing of the furnace’s cover. To prevent anyone from opening it without consent, the hooks that connect the furnace to the hoist system must be disconnected after having lowered down the covers to their final position.

Prima Power® laser machines

The main problem with the laser machines is the dusty environment they work in, which leads to optical component wear. Upon closer inspection, it was noticed that the aspiration system present inside the machine is not very powerful. Although the use of a more powerful aspiration system can help more effectively remove dust, changes to the machine’s hardware and software are required, which is not possible due to protocols between Gestamp and Prima Power®.

The laser's tool head has an integrated compressed air system whose function is both for cooling and expelling particles that get inside. One of the problems with this particle ejection system is that it accelerates the particles and, although they are ejected from the tool head, they can enter it from other angles. As dust still gets inside the tool head, it is logical that this system isn't enough to prevent metallic dust to enter the lens compartment. This and the fact that the laser needs a hole to leave the tool head makes it impossible to fully seal the equipment.

Another way to collect the remaining metallic dust is required. Through the usage of magnets both on the inside and outside of the tool head. The small magnetic fields generated can prevent the dust leftovers from contacting the lenses and mirrors.

TOX® referencing press

As the main issue with the TOX® press is inherent to its shape and the exceeding force it operates at, there are two possible ways to solve this problem. The most simple and affordable way to prevent exceeding force is to lower its working pressure. Consequently, the lower force would create less bending and consequently less wear. As mentioned previously, there has already been a reduction in the pressure, but lowering it further to the lowest value possible would reduce even more the wear.

Secondly, the changing of the referencing process's machine. To fully solve the problem, there is a need to remove the bending, due to force being made with an offset from the centre of the press. There are more options on the market for referencing machines, some even present in other areas of Gestamp Aveiro. More robust presses can be found in the company, but they lack the necessary space for the blanks to enter the referencing area due to the blank's overall size.

Another way to reference the blanks is a departure from mechanical referencing to laser referencing. As the laser engraving process is contactless, there is no margin for mechanical errors or over force usage.

4.3 Implementation and investigation of the proposed solutions

Spread of the rollers' aluminium contaminated area

To understand what is possible to execute, let us first focus on the overall dimensions of the blanks formed. As mentioned previously, the Loire medium forming press has 2 individual carriages, which means it can produce 2 different components at the same time. Having this, the HS line operates with blank pairs. Both the blank dimensions in millimetres and working pairs are shown in Figure 27.

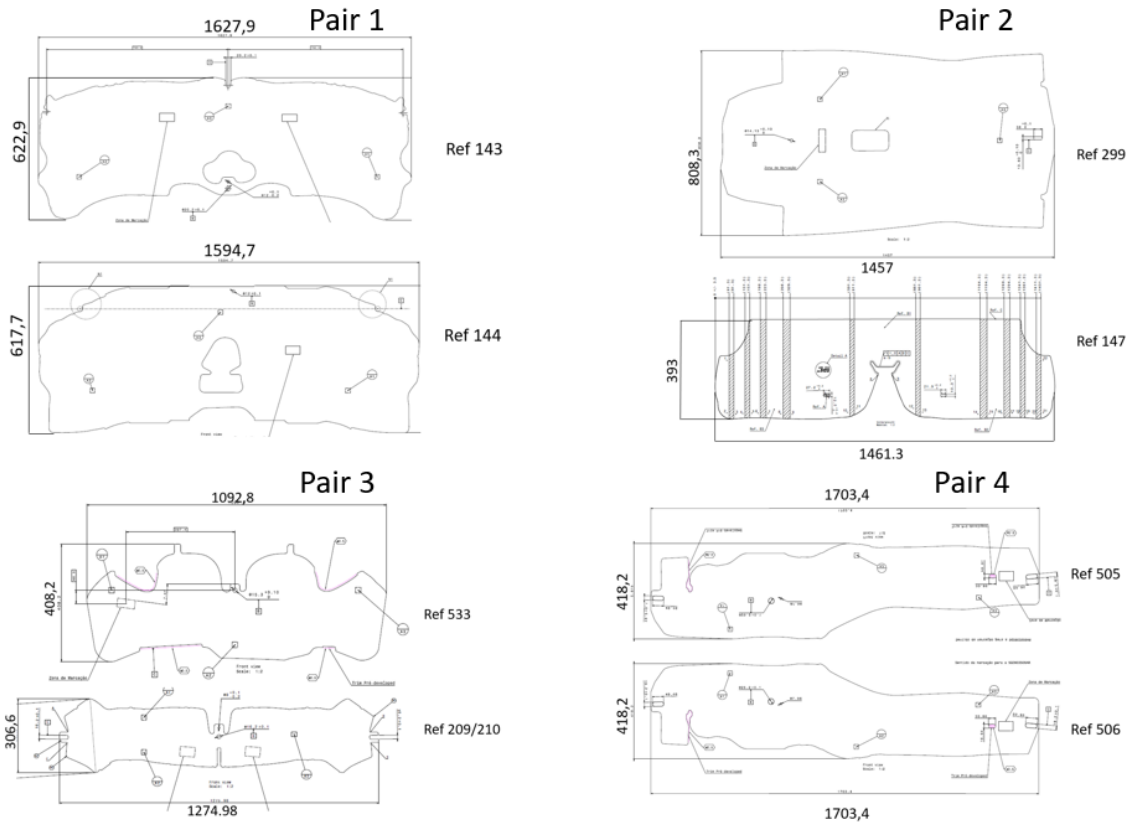


FIGURE 27: WORKING PAIRS AND BLANK DIMENSIONS

Recapping what was previously mentioned, the current strategy has the furnace divided into 2 zones, widthwise. The length of the ceramic rollers is 2060mm, making each zone 1030mm. Due to the centring fingers, in the centring table, the usable distance from each zone is 950mm as shown in Figure 28.

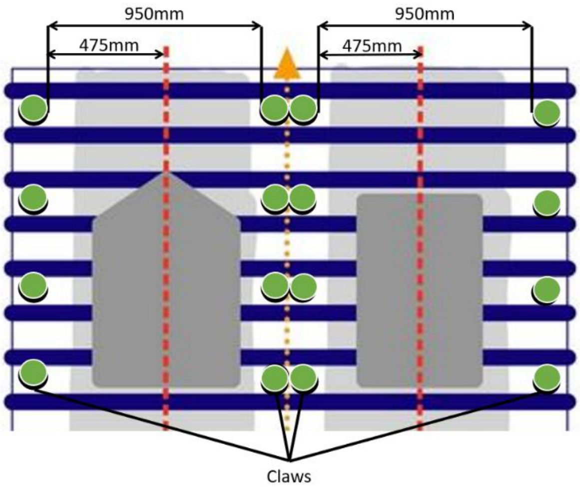


FIGURE 28: CENTRING TABLE CLAWS' AMPLITUDE

In the new strategy, to spread the blanks and consequently the contaminated area, the furnace is divided into 4 zones, according to the width of each blank. An example is demonstrated in Figure 29, regarding pair 1 (references 143 and 144). The origin of each halve of the furnace is considered in the left claw of each halve. The calculations made to find the new travel axis position had in consideration each blanks width. To find the position closer to the right claws, position 1, the travel axis is equal to half of the blank's width. Position 2, which is the position closer to the left claw, is equal to the right claw's position (950 mm) minus half of the width of the blanks. To keep the proper functioning of the HS line, an offset of 50mm was given to each blank. The value of this offset was chosen as it is the lowest offset value that was already in use. As this value is known to work, it was kept. This can be further explained by the following equations 1 and 2, respectively. The new travel axis of each blank are as follows, presented in Table 5.

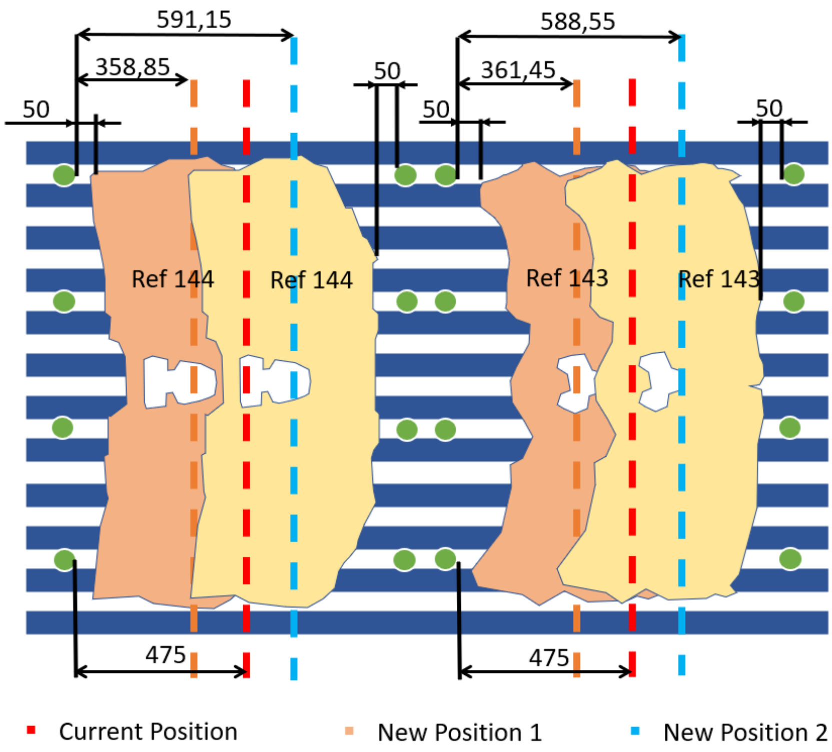


FIGURE 29: NEW TRAVEL AXIS POSITIONS (REF 143 AND 144)

$$P_{1n} = P_{Lc} + (W_{Bn} + 50) \quad (1)$$

Where P_{1n} is the position 1 of the "n" blank being calculated, in mm, P_{Lc} is the position of the left claw (mm) and W_{Bn} is the width of the "n" blank (mm).

$$P_{2n} = P_{Rc} - (W_{Bn} + 50) \quad (2)$$

Where P_{2n} is the position 2 of the "n" blank being calculated, in mm, P_{Rc} is the position of the right claw (mm) and W_{Bn} is the width of the "n" blank (mm).

TABLE 5: NEW POSITIONS FOR THE TRAVEL AXIS (MM)

Pair	Ref	Position in Press	Blank width	Travel Axis Position		Deviation from original axis	
				Variant 1	Variant 2	Variant 1	Variant 2
1	143	Left	622.9	361.5	588.6	-113.6	113.6
	144	Right	617.7	358.9	591.2	-116.2	116.2
2	299	Left	808.3	454.2	495.9	-20.9	20.9
	147	Right	393.0	246.5	703.5	-228.5	228.5
3	209/210	Left	306.6	203.3	746.7	-271.7	271.7
	533	Right	408.2	254.1	695.9	-220.9	220.9
4	506	Left	418.2	259.1	690.9	-215.9	215.9
	505	Right	418.2	259.1	690.9	-215.9	215.9

Another important aspect of this change is whether a reference travels on the right or left side of the furnace. Pairs 1 and 4 both have blanks with very similar widths. Thus, their placement in the furnace right or left side is not relevant. Regarding pairs 2 and 3, both have a big width difference, being that pair 2 has the widest component of the 8 (ref 299) and pair 3 has the narrowest blank (ref 209/210).

To compensate for the extra width represented by ref 299, which consequently means more contamination, ref 209/210 is the best suited to travel on the same side of the furnace as ref 299.

This brings up another constraint, which is the position on the Loire® medium press. Due to the water channels from the cooling system, the tools are not interchangeable. This, paired with the transfer arms that pick up the blanks from the centring table, means that if "tool A" is on the left side of the press, then the correspondent blank must go through the furnace on the left (Figure 30).

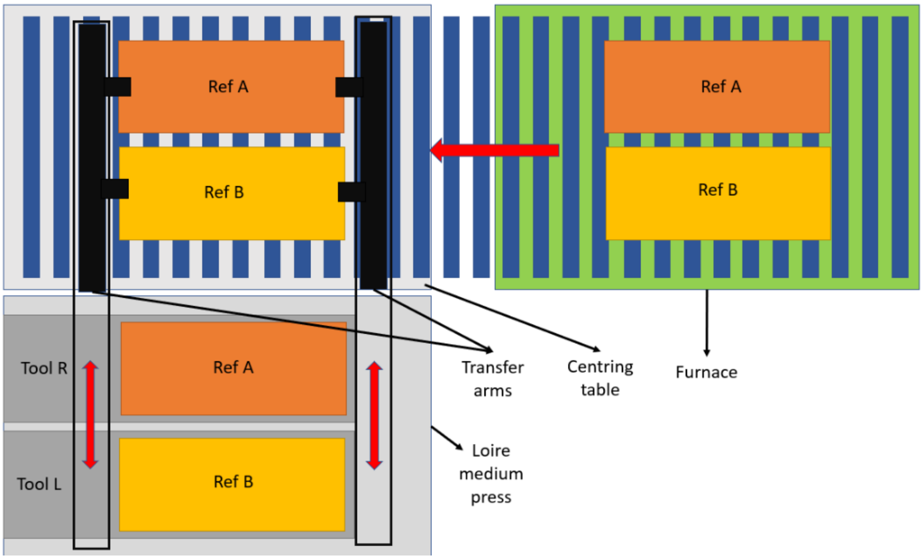


FIGURE 30: SCHEME OF THE TRAVEL AND POSITION IN THE TOOL

To keep alterations' cost low, this positioning was considered, maintaining each blank on their initial travel side, regarding the left or right path inside the furnace. By coincidence, the references 299 and 209/210 are already going through the furnace on the same side, on the left, this being the optimal configuration. The position in the press is as well shown in Figure 30.

To implement these measures, the destaker's robot arms which place the blanks in the new positions are programmed and new stoppers need to be produced. The stoppers are of major importance as a first centring step and to prevent damage to the blank when exiting the furnace. These components are immovable so, to cover all possible combinations, 2 sets of stoppers need to be produced for each blank. This means going from 8 stoppers in fixed positions to 16 stoppers that can be combined, resulting in an increase in programs needed, from 4 to 16. This increases complexity, the margin for error, logistics has twice the cost in stopper production. This is demonstrated in Figure 31 and Figure 32.

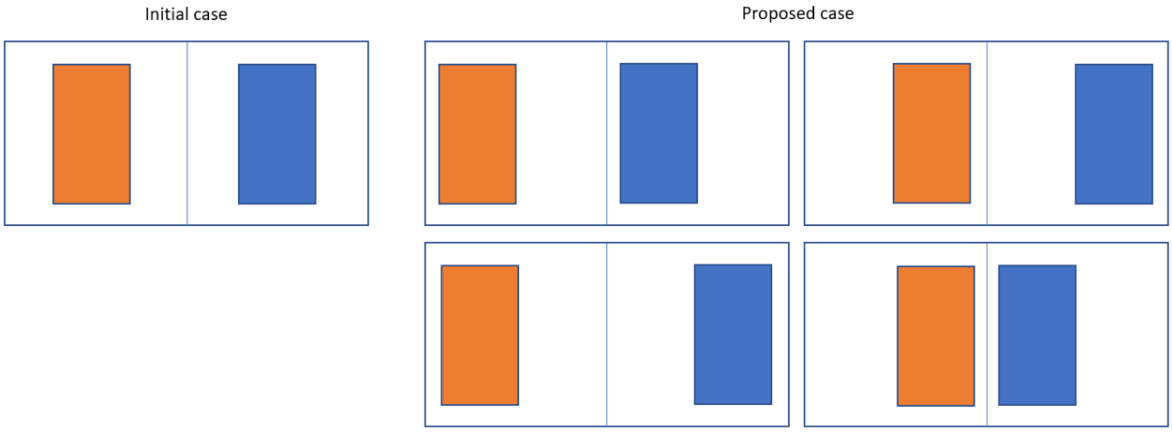


FIGURE 31: POSSIBLE COMBINATIONS IN THE BLANK POSITIONING

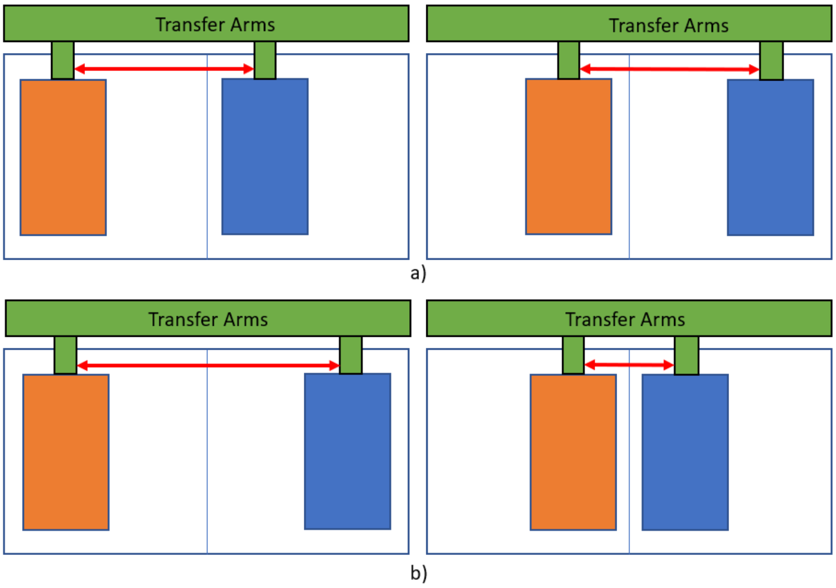


FIGURE 32: POSITIONING OF THE CLAWS IN THE TRANSFER ARMS A) CONSTANT WIDTH AND B) VARIABLE WIDTH

To prevent this increase in complexity, it was considered that both blanks from the same pair were repositioned to the same side. In other words, if blank A's axis is moved to the left, blank B from the same pair is as well repositioned to the left. This decreases the number of needed programs and keeps the distance between the transfer arm's claws constant, as shown in Figure 32 b).

To further reduce the complexity of these changes, each pair has only one variant, it being the left or right one.

Having this in mind, the needed material to implement these changes was producing 8 new stoppers, 4 revamped destaker robot programs, 4 centring table's claw positions and 4 transfer arm's claw new positions. This keeps the complexity of the tool changing very similar to the previous configuration. The chosen configuration is presented in Table 6: Chosen configuration for the blank positioning.

TABLE 6: CHOSEN CONFIGURATION FOR THE BLANK POSITIONING

Pair	Ref	Position in Press	Blank width	Offset	Travel Axis Position	Deviation from original axis
1	143	Left	622.9	right	588.6	113.6
	144	Right	617.7		591.2	116.2
2	299	Left	808.3	Left	454.2	-20.9
	147	Right	393.0		246.5	-228.5
3	209/210	Left	306.6	Left	203.3	-271.7
	533	Right	408.2		254.1	-220.9
4	506	Left	418.2	Right	690.9	215.9
	505	Right	418.2		690.9	215.9

Furnace's cover opening and closing procedure alteration

As this was the easiest and cheapest option, while remaining effective, without evident drawbacks, it was chosen by the company to be implemented.

To implement this procedure change, a formal procedure was developed for the company. This way, operators who performed maintenance inside the furnace were formally obliged to remove the hook from the furnace's cover, granting that its weight was fully resting in its socket on top of the furnace, granting the desired seal.

The developed procedure is presented in topic 5.2 Furnace's cover closing and opening procedure.

Magnetization of the laser tool heads

To achieve the objective of reducing the amount of metallic dust that enters the laser's tool head cavities through magnetization, the magnetized tape was considered due to its ease of application and formability, to fit the contours of the machine. To test its viability, it was decided to realise an experiment in one of the machines.

A technician from Prima Power® was consulted prior to applying the magnets. As the magnets create a magnetic field around the machine's tool head, as well as increased weight, negative consequences were possible to immerge such as imprecise movements due to encoder's interferences, laser beam property alteration and the increase of the overall volume of the tool head. Thus, the usage of lightweight, low-powered magnetic bands was necessary.

The magnets were applied only on the exterior of the tool head. With the laser machine's continuous work, the laser beam is known to deviate. This and the fact that there is very little space inside the tool head, makes the interior application of the magnets risky, possibly resulting in the melting of both the magnetic bands and the tool-head itself.

The placement of the magnetic bands was close to where removable components and moving axis were, them being the locations where less sealing was granted. Thus, these were some of the dust places of entry.

Regarding the horizontal rotation axis, it was possible to place magnetic strips on both sides. In the vertical rotation axis, it was only possible to place one, as there was an assembly mechanism that needed to be available. The magnetic band was as well placed in the exterior of the FPC mirror, which often scratched and in the laser's nozzle.

To ease maintenance interventions, placing the magnetic band over screws was avoided and, in some cases, the magnetic bands were cut to make the screws available without removing the strip.

The application places the magnets were as follows in Figure 33.

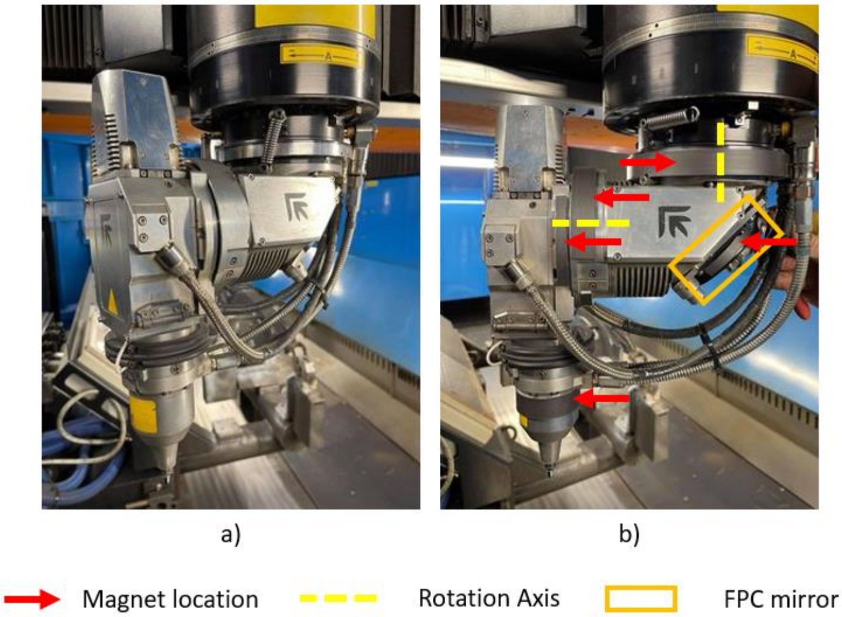


FIGURE 33: MAGNETIC BAND PLACEMENT A) BEFORE AND B) AFTER

One adjustment that had to be made was removing the vertical axis, magnetic band. When an error occurs and the laser tool head hits the formed blank that is being trimmed, an anti-crash system is activated, and the laser tool head pops off. As of performing emergency intervention to correctly re-install the laser tool head in its place, cleaning is needed. While cleaning the interior of that connection zone, the magnet was attracting dust particles, making it impossible to fully remove the dust from that area of the tool head. As this is an emergency procedure, it needs to be performed as fast as possible not to heavily impact the production. As that magnetic stripe was complicating the cleaning process, it was decided to remove it.

Decreasing the working pressure of TOX® presses

To understand the consequences of altering the working pressure of the TOX® referencing presses, several samples, representative of the various blanks were studied. The test consisted of stamping the references at various working pressures, as shown in Figure 34.

FIGURE 34: REFERENCING TEST SAMPLES FROM BY TOX®

Upon a closer look, the tests performed by TOX® did not use the same tool head as the one present in Gestamp Aveiro, so no conclusions were possible to extract. Having this, contact was made with TOX® who claimed when using Gestamp Aveiro's tool head, to perform the same marking, an increase in 10% pressure can be considered. For example, if the desired marking was had with 100 bar with TOX® testing machine, the same result can be achieved at Gestamp Aveiro with 110 bar. Gestamp's TOX® press was being used at a working pressure of about 130 bar. After studying the samples, the production personal claimed that the marking corresponding to 95 bar was sufficient. This left margin for reducing the press's working pressure up to the correspondent of the 95-bar marking from TOX® samples, which is 104.5 bar. To fulfil this improvement, an adjustment of the press's working pressure had to be performed.

To find the new intake pressure, first, the hydraulic multiplication was found, according to the measured values in the input manometer and output pressure switch, as follows in Figure 35.

Press	Intake Pressure	Working pressure	
	bar	bar	
1	3.7	128	
2	3.4	136	
3	3.4	128	Hydraulic
4	3.6	134	Multiplication
Average	3.53	131.5	37.30

FIGURE 35: HYDRAULIC MULTIPLICATION

Having this, to achieve the desired working pressure of 104.5 bar, the necessary intake pressure is 104.5/37.3 = 2.8 bar.

Adoption of a referencing laser system

Members of the Gestamp group were contacted to give insight into the current usage of laser referencing systems. As shown in Figure 36, the currently used equipment is an open-air laser referencing system.

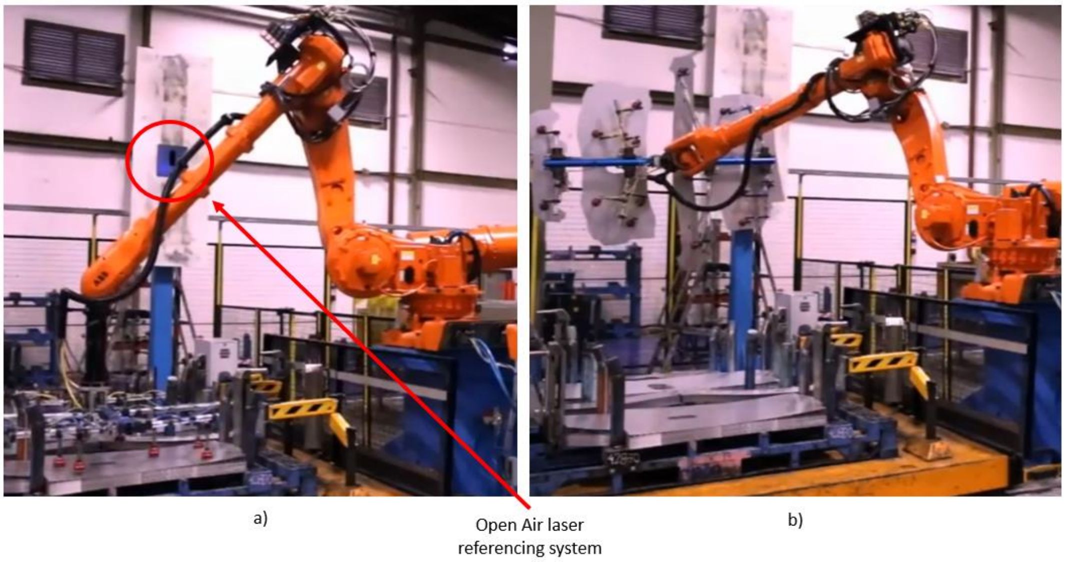


FIGURE 36: LASER REFERENCING SYSTEM IN USE IN GESTAMP BILBAO

After having acquired this information, 2 referencing equipment providers were contacted, MACSA ID® and Laserax®

Regarding Laserax® provided information, similar types of equipment could be attained, ranging from 130k€ to 150k€. These systems had a laser power of 100W and could operate in 2 conditions, engraving or black marking. While engraving removes material in the desired shape, black marking burns the metal's surface, leaving a black taint. Comparing both processes, black marking is faster, but its longevity and endurance to the heat treatment and forming processes are unknown. Despite suppositions from the company that blank marking does not wear off with the heating and forming processes, trials must be executed for a final verdict.

The contact had with MACSA ID® personal granted them an opportunity to visit the factory floor, to give them insight into Gestamp's process. This way they could propose a solution best suited for the situation.

Then, an arrangement was made to provide us with real samples of the markings made by their machines. A batch of 8 blanks was sent to MACSA ID® for testing purposes. This way, it was possible to make real tests on the factory floor. By processing the blanks with the sample markings through the HS line, it was possible to verify if the markings could withstand the temperature variations and forming processes without losing quality.

Once the sample batch was tested by MACSA ID®, a piece of equipment was proposed. With it, the cycle time of the marking was known, as well as a tender of the equipment acquisition cost. Once it arrived at Gestamp, it was processed and analysed. An investment analysis was then made to justify or not the investment.

4.4 Results and discussion

New blank's travel position

Due to the changes in the travel axis of the blanks, there was an inherent change of blank's aluminium stain inside the furnace. In Figure 37 a representation of the blank's contamination overlay is demonstrated before and after the new blank's travel axis changes were applied.

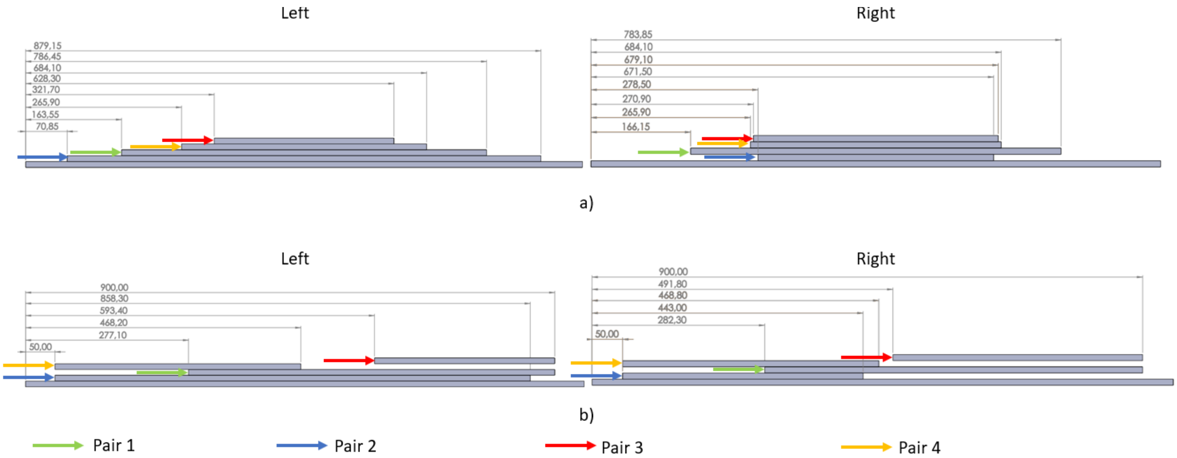


FIGURE 37: REPRESENTATION OF THE BLANK'S CONTAMINATION OVERLAY A) BEFORE INTERVENTION AND B) AFTER INTERVENTION

The following tables compare the use of the ceramic roller's length. Resourcing to these tables, it is possible to analyse the changes that were made and predict how the rollers contamination occurs.

TABLE 7: PREVIOUS ABSOLUTE POSITION OF THE ALUMINIUM CONTAMINATION OVERLAY (MILLIMETRES)

Left - Previous absolute overlay																		
Position (mm)	0.0	70.85	70.85	163.55	163.55	265.9	265.9	321.7	321.7	628.3	628.3	684.1	684.1	786.45	786.45	879.15	879.15	950.0
Overlay (n blanks)	0		1		2		3		4		3		2		1		0	
Right - Previous absolute overlay																		
Position (mm)	0.0	166.15	166.15	265.9	265.9	270.6	270.6	278.5	278.5	671.5	671.5	679.4	679.4	684.1	684.1	783.85	783.85	950
Overlay (n blanks)	0		1		2		3		4		3		2		1		0	

TABLE 8: CURRENT ABSOLUTE POSITION OF THE ALUMINIUM CONTAMINATION OVERLAY (MILLIMETRES)

Left - Current absolute overlay														
Position (mm)	0.0	50	50	277.1	277.1	468.2	468.2	593.4	593.4	858.3	858.3	900	900	950
Overlay (n blanks)	0		2		3		2		3		2		0	
Right - Current absolute overlay														
Position (mm)	0.0	50	50	282.3	282.3	443	443	468.8	468.8	491.8	491.8	900	900	950
Overlay (n blanks)	0		2		3		2		1		2		0	

TABLE 9: PREVIOUS RELATIVE ALUMINIUM CONTAMINATION OVERLAY (%)

Previous relative overlay										
Furnace side	Left					Right				
Overlay (n blanks)	0	1	2	3	4	0	1	2	3	4
Roller Length (%)	15%	20%	22%	12%	32%	35%	21%	1%	2%	41%

TABLE 10: CURRENT RELATIVE ALUMINIUM CONTAMINATION OVERLAY (%)

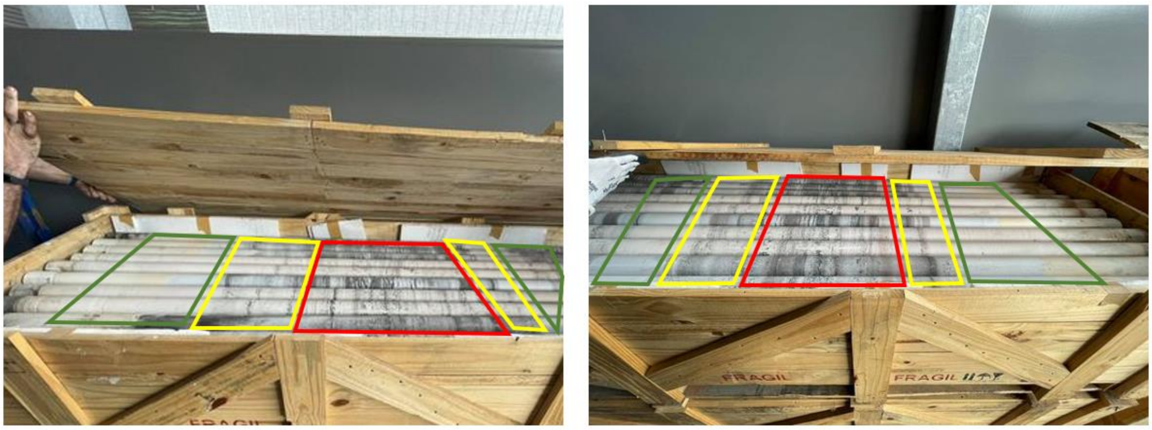
Current relative overlay										
Furnace side	Left					Right				
Overlay (n blanks)	0	1	2	3	4	0	1	2	3	4
Roller Length (%)	11%	0%	41%	48%	0%	11%	2%	70%	17%	0%

Table 7 and Table 8 presents the number of the blank's paths that are coincident for a certain length of the ceramic rollers, in millimetres, before and after the changes made to the blank's travel axis. These tables indicate the placement of the overlay along the rollers.

Table 9 and Table 10 demonstrate the number of blank's paths that overlay in a certain percentage of each roller's length, before and after the changes made to the blank's travel axis. These tables indicate the utilization of each roller.

Concerning the initial state of both sides of the furnace, Table 7 demonstrates that the central area of each side is heavily contaminated since all blanks travel through the same axis in each half of the furnace. Regarding the left side, Table 9 exposes that 15% of the roller's length is unused and 32% of its length is under heavy contamination (4 overlays). On the right side, the waste is even more evident, since 35% of the roller's length is not used and the heavy contamination area is 42% of the total available length.

This is further visible once comparing the calculated results with the old, already used rollers which stored in the facility. This can be seen in Figure 38.



a) b)

FIGURE 38: CERAMIC ROLLER'S CONTAMINATION A) LEFT SIDE B) RIGHT SIDE

Focusing on the proposed changes, Table 8 does not show symmetry along the length of the ceramic rollers, opposingly to the previous travel configuration. The most noticeable factor is that the zones of heavy contamination (4 overlays) have disappeared.

Comparing Table 9 with Table 10, it is possible to state that the blanks are more evenly spread due to the 3 main factors. The first is the elimination of 4 blank overlay areas from 32% to 0% on the left and from 41% to 0% on the right. Secondly, the reduction of the clean zones of the roller or lower contamination areas (0 or 1 blank overlays) from 35% to 11% on the left and from 56% to 11% on the right. Lastly, it is noticeable a major increase of the intermediate contamination zones (2 and 3 blank overlays) from 34% to 89% on the left and from 3% to 87% on the right.

Due to COVID19 restrictions in the company, the staff was not allowed to work overtime, having restrained the opportunity to develop the mechanical components and robot programs to implement the necessary alterations. This, as well as delays in the logistics involved in the purchase of necessary components, made the extraction of experimental quantitative results and irrefutable proof of the effectiveness of the suggested solution impossible.

However, in case of future implementation of these modifications, a good indicator to determine whether the solution is viable or not is the number of interventions made to clean Loire® press's tools before and after the implementation of these measures.

The number of cleaning interventions is correlated to the severity of the roller contamination. If more aluminium is concentrated in the rollers (presence of aluminium blobs in the rollers) there are higher chances of those blobs adhering to the blanks and damaging the tool.

Another qualitative method of verifying the validity of these modifications is the deviation in the blanks when leaving the furnace, as well as the delay between 2 blanks that were dropped in the system at the same time. More delay means bigger contamination in the side of the rollers where the delayed blank is travelling. More deviation means more aluminium blobs in the rollers. Both factors get increasingly more noticeable over the lifecycle of the rollers. If these effects are less noticeable near their current lifetime (5 weeks) and look tolerable for more time (6 or more weeks), this means the alterations had positive results. Even though there is no practical evidence that this increase in lifespan will occur, the theoretical calculations of the contamination spread indicate so.

The resulting savings in roller replacement are shown in Table 11. There, it is possible to verify the lower number of necessary rollers each year. It results in consuming less 160 hollow rollers, saving about 10.000€ per year.

TABLE 11: 5-WEEK MAINTENANCE PLAN VS 6-WEEK MAINTENANCE PLAN COSTS

5 week Maintenance Plan	Nº Rollers	Unitary Cost	Total Cost of each Type
Schwartz massive rollers	60	435 €	26 100 €
Treated Hollow Rollers from Brasil	1014	63 €	63 882 €
		Total Cost:	**89 982 €**
6 week Maintenance Plan	**Nº Rollers**	**Unitary Cost**	**Total Cost of each Type**
Schwartz massive rollers	60	435 €	26 100 €
Treated Hollow Rollers from Brasil	854	63 €	53 802 €
		Total Cost:	**79 902 €**

Furnace's cover closing procedure

Since the implementation of this procedure, no interventions to the furnace were made. The furnace is only opened in events of clog formation, due to roller breakage and consequent blank pile formation inside the furnace, which inhibits the travel of the blanks. Such events did not occur during the development of this dissertation. Other situation where intervention is made inside the furnace is when it has to be cooled down, such as during vacations.

Magnetized laser tool heads

Once the magnetic bands were applied, the laser machines went through their normal working cycle of 1 week, before another cleaning intervention. When intervening in the machine's tool head, images were captured to both laser machines whose tool head had been magnetized and not magnetized, for comparison purposes, as shown in Figure 39.

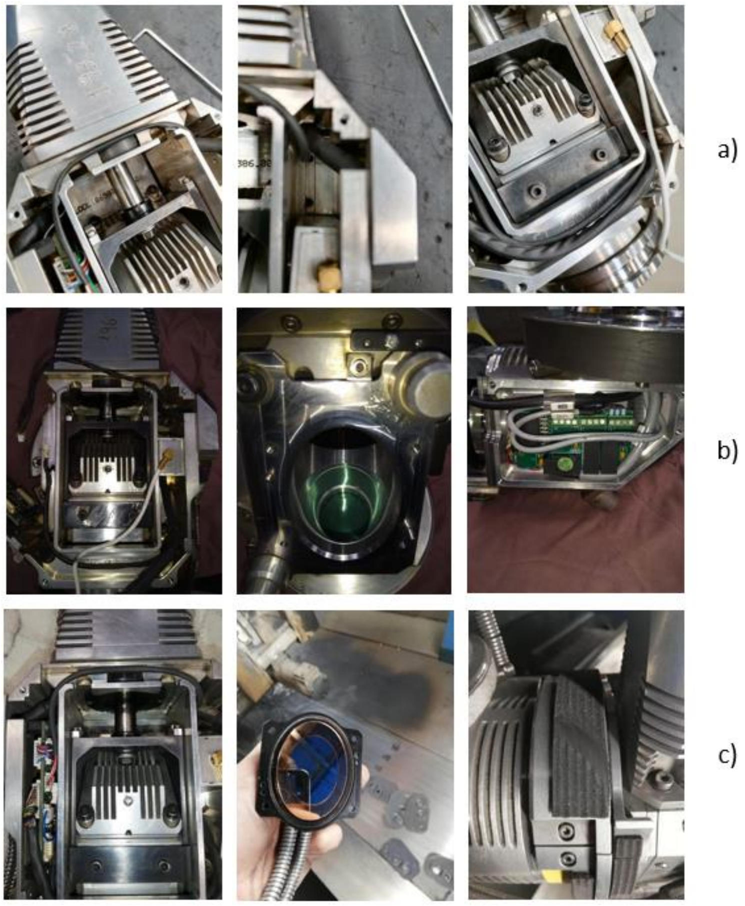


FIGURE 39: COMPARISON BETWEEN AN UNMAGNETIZED TOOL HEAD A) AND 2 MAGNETIZED TOOL HEADS B) AND C)

After going through the normal period in between tool head cleaning maintenance, one week, the first laser's tool head where the magnetic bands were applied was opened and observed. As shown in Figure 39 b) and c), the magnetic bands are visibly very dirty. Despite this, there was not a noticeable improvement in the amount of dust inside the tool head, as seen when comparing the 3 cases in Figure 39.

Despite having caught metallic dust, the amount of dust expelled by the laser cutting process is too much for the superficial area of the magnetic band. As the dust starts pilling up on the surface of the magnets, the force field's intensity starts decreasing, becoming weaker and weaker the more dust the magnet collects. At a certain point, it starts being ineffective and entering the laser's tool head once again.

Despite this method having failed, there is a possibility that an improved vacuuming system will benefit this problem, such as the one proposed. Further commentaries will be made in paragraph 0, regarding the excessive metallic dust on the factory floor.

TOX® working pressure adjustment

Due to technical difficulties, there was no possibility of implementing this measure. To achieve the desired working pressure of 104.5 bar, the input pressure must be 2.8 bar. As a safety feature, the press sends an error message once the input pressure is lower than 3 bar, and the system stops working. To implement the desired measure, an override to this pressure's inferior limit in the press had to be performed. This was not able to be done internally at Gestamp, requiring a TOX® technician. Due to production difficulties, there was no opportunity to stop the line and solicit a TOX® technician to implement this change.

However, as previous actions in reducing the input pressure, and the working pressure as result, have reduced the wear of the press's components, we can assume that further lowering the input pressure results in reducing the frequency at which parts must be replaced due to wear, as fewer forces are involved in the referencing process. Table 12 shows the reduction in maintenance costs since the reduction in intake pressure was made.

TABLE 12: MAINTENANCE COST REDUCTION WITH INTAKE PRESSURE REDUCTION

Pressure	Purchase Value	Used Value	Timeframe	Monthly Used Value	Reduction
bar	€	€	months	€/month	%
5	22 721.00 €	22 721.00 €	15	1 514.73 €	-
3.5	4 535.40 €	2 442.40 €	4	610.60 €	60%

Laser marking

This solution was not implemented. Due to the associated cost of the proposed equipment, it is yet to be analysed internally.

MACSA ID tested the samples with 2 fibre laser machines with 30 W and 50 W of power. Both were processed in the HS line to verify if the references were able to withstand the heating and the forming processes. The results are shown in Figure 40.

a)

b)

FIGURE 40: A) 30W LASER MARKINGS VS B) 50W LASER MARKINGS

Both laser’s (30 W and 50 W) parameters were set to perform the referencing in 1 second. As the 50W was the most powerful, it was expected to leave deeper markings, with more contrast, which is verified by the results in Figure 40. Since some of the markings performed by the 30 W laser were not very visible, the most reliable system to implement is the 50W, which had no visibility problems in the references after the HS process.

Having settled on the equipment, an equipment purchase proposition was sent by MACSA ID regarding the 50 W laser system, which involved the acquisition of 2 of these machines, as well as the required software and training to operate them.

To analyse the investment’s viability, an analysis of the return on investment (ROI) was made. This gives insight into whether the adoption of the laser system is economically viable and if it is a good option for future investment.

In this analysis, all the costs associated with the TOX® press system and the MACSAID® laser system. Regarding the press, as it was already purchased, its initial acquisition cost does not enter the equation. As an estimation of the expected maintenance costs for each, an average of the total spendings per year was made. In addition, the maintenance labour costs were estimated, as well as the required amount of compressed air to operate the presses.

For the laser’s cost analysis, its acquisition price was considered, as it required its purchase. It has no evident maintenance requirements nor consumed resources. The energy required to operate the laser was estimated, as an operating cost.

Since Gestamp has already implemented measures to reduce the wear in TOX® presses, the money spent on their repairing has decreased over time. To have a better understanding of how this decrease impacts the ROI of the laser equipment, this analysis was split into two, one based on the TOX® spendings when working with an intake of 5 bar and another with 3.5 bar. The associated costs of each variant are shown in Table 13.

To calculate the energy cost of the laser engraving system, data from the manufacturers datasheets and catalogues were used (Macsa id, 2021). The total cost (C_T) was calculated with as follows:

$$C_T = E_{ac} * E_y \quad (3)$$

Where E_{ac} is the considered average price of energy and E_y the yearly energy spent.

$$E_y = P * W_T \quad (4)$$

Where P is the power required to operate the machine and W_T is the total working time of both lasers to perform all the markings

$$W_T = \frac{C_y * T_c * N_L * N}{3600} \quad (5)$$

Where T_c is the cycle time of each marking, N_L is the number of alser machines, N is the number of markings each laser makes in one cycle and C_y is the number of cycles per year. To calculate C_y, the number of cycles per minute was measured (3) and it was considered that the machine worked 24h per day, 260 days/year.

$$C_y = 3 * 60 * 24 * 260 = 1123200\ cycles/year \quad (6)$$

The chosen equipment (50 W variant) requires 600 VA of power, which translates to 600 W of power since it is a monophase system.

To calculate the energy spent per year to power the hydro-pneumatic presses, equivalent to the pressurized air consumption, C_T, was calculated as follows:

$$C_T = C_C * N \quad (7)$$

Where $C_C$is the cost per cylinder and N is the number of cylinders.

$$C_C = E_{ac} * E_T \quad (8)$$

Where $E_{ac}$is the considered average price of energy and E_T is the total energy consumed.

$$E_T = N_S * E_S \quad (9)$$

Where E_S is the energy per stroke and $N_S$is the number of stroques, which is equal to C_y, having the same considerations mentioned previously.

$$E_S = F * d \quad (10)$$

Where F is the force of each stroke and d is the course of movement.

$$F = \frac{C_C * V}{1000} \quad (11)$$

Where C_C is the consumption of each cylinder and V is the volume of each cylinder.

The values from the volume and consumption of each cylinder were directly asked from the manufacturer and others are shown in the specification sheets (TOX® PRESSOTECHNIK, 2016) and (PRESSOTECHNIK, 2021).

The considered values and results can be further inspected in the attachments 8.1 and 8.2

TABLE 13: ROI CONSIDERED PARAMETERS

ROI		50W Fiber Laser	Hydro-pneumatic Press (3.5bar)	Hydro-pneumatic Press (5bar)
Fix investment (€)		63639.00	-	-
Yearly Maintenance (€)	Component Cost	-	7327.20	18176.80
	Labor Cost	-	90.00	360.00
Yarly Energy Cosumption (€)	Electricity	114.21	-	-
	Compressed air	-	16.86	16.86

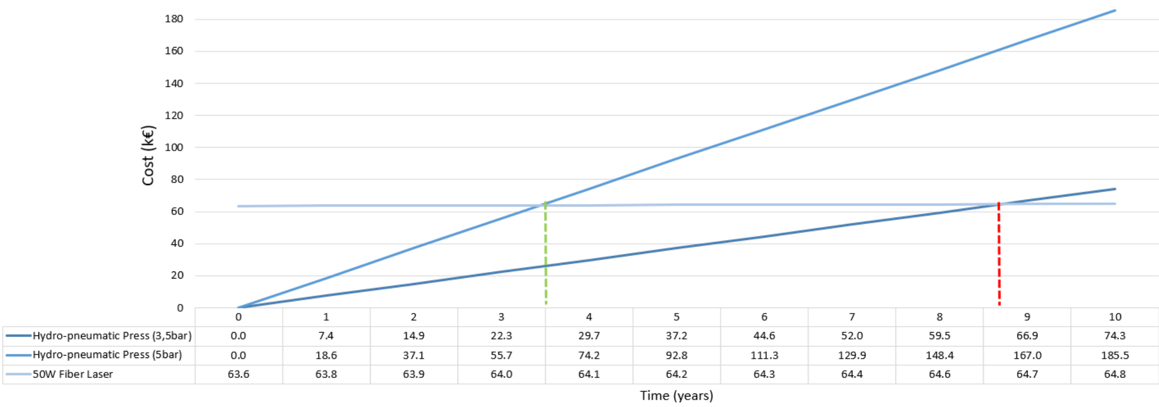


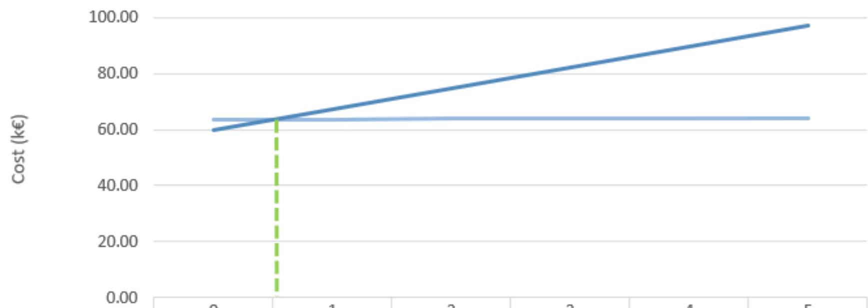
FIGURE 41: ROI ANALYSIS

Figure 41: ROI shows the cost curves of each system, over the years. As demonstrated, the laser system has a high initial cost, but the maintenance and operation costs are minimal. Opposingly, although the hydro-pneumatic system has already been paid for, its maintenance costs are very high. The TOX® 3.5 bar curve intersects the MACSA ID® system in between year 3 and 4, and the 5bar curve intersects between the year 8 and 9. These are the points at which the laser system pays off.

Having in mind that an acceptable time for a return on investment is between 3-5 years. It can conclude that, based on the acquired information, while the laser system was a justifiable alternative if the changes in the working pressure were not possible to execute. After the reduction in working pressure, very easy and uncostly to implement, the payback takes more than twice the time. This would increase even more if, as previously mentioned, if the intake pressure was reduced to 2,8bar, as even less maintenance would be needed.

TABLE 14: ROI PARAMETERS IF PURCHASED NEW

ROI		50W Fiber Laser	Hydro-pneumatic Press (5bar)
Fix investment (€)		63639.00	60000.00
Yearly Maintenance (€)	Component Cost	0.00	7327.20
	Labor Cost	0.00	90.00
Yarly Energy Cosumption (€)	Electricity	114.21	-
	Compressed air	-	16.86



	0	1	2	3	4	5
50W Fiber Laser	63.64	63.75	63.87	63.98	64.10	64.22
Hydro-pneumatic Press (3,5bar)	60.0	67.4	74.9	82.3	89.7	97.2

FIGURE 42: ROI ANALYSIS IF PURCHASED NEW

Interestingly, as shown in Table 14 and Figure 42, if we consider the cost of acquisition of the 4 necessary TOX® presses, even if they came already with an intake pressure of 3.5 bar, after half a year the laser system would be a better investment. Thus, in the case of an implementation of a new assembly line, the laser referencing system is the superior alternative.

Other benefits of the laser system are its flexibility in the message that can be marked in the blanks. While with the press system the company is confined to incremental digits, the laser system provides the ability to mark whatever desired, such as the date and time the piece was produced, providing better traceability.

To replace the mechanical thickness verification of the blanks, an electromagnetic sensor can be added to the robot arms. This can assure that the transportation of one single blank at a time, during the travel of the blank, instead of dedicating one entire step, wasting cycle time.

The proposed machines maintain the current cycle time but, in case the referencing process becomes a bottleneck, twice the laser marking machines can be purchased, reducing the referencing time in half.

5 Preventative maintenance revision

Emphasis was given only to the roller's replacement and the furnace's opening and closure procedure, as they are the only ones that represent major changes. The other implemented solutions present only minor revisions.

5.1 Furnace rollers preventative replacement planning

As mentioned before, at the moment of this research, there is no experimental proof of the effectiveness of blank travel repositioning. However, the theoretical calculations indicate that an improvement is likely. Thus, a new maintenance plan must be made to accommodate the increase in the lifetime of the rollers.

The new plan considers the rollers being able to withstand one extra week. This makes their replacement more cost-efficient. In Figure 43 the previous 5-week maintenance plan is shown, whilst in Figure 44 the updated 6-week maintenance plan is presented. The process to replace the rollers was kept the same, the changes are the time and frequency of the roller's replacement. The horizontal lines represent the different segments of the furnace, with the numerical reference of each roller, and the columns represent the number of the week at which the replacement is executed. Their intersection (light blue) represents the number of rollers that are replaced in a certain zone, at a certain week. The light green represents the weeks when there are vacations. All the roller replacements are made on Sundays.

5 Weeks

ROLLER	WEEK NUMBER																																																			
REFERENCE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
1-10										10																																										
11-20																									10																											
21-30																																											10									
31-40																																																				10
41-50																																																				10
51-60																																																				10
61-70					10															10																		10														
71-80					10															10																		10														
81-120					40					40					40					40					40					40								40					40					40				40
121-160					40					40					40					40					40					40								40					40					40				40
161-170															10															10																		10				
171-180															10															10																		10				
181-190										10																																										
191-200																									10																											
201-210																																											10									
211-220																																																				10
221-230																																																				10
231-240																																																				10
241-250																																																				10
251-260																																																				10
261-274																																																				14

FIGURE 43: 5-WEEK ROLLER PREVENTATIVE REPLACEMENT PLAN

6 Weeks

ROLLER	WEEK NUMBER																																																			
REFERENCE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
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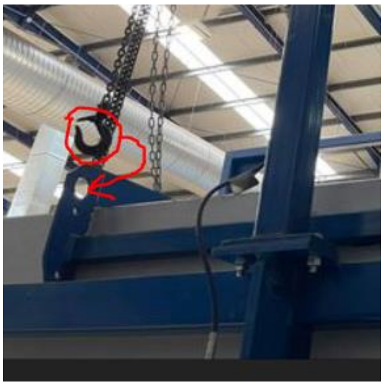
241-250																																																			10	
251-260																																																			10	
261-274																																																			14	

FIGURE 44: UPDATED 6 WEEK ROLLER PREVENTATIVE REPLACEMENT PLAN

5.2 Furnace's cover closing and opening procedure

As previously mentioned, to prevent another bad closing of the furnace's covers, an internal procedure was developed to grant the proper closing of the furnace's cover and desired seal. In it, every step that must be executed is described, as well as all conditions of how actions must be taken. The steps to the proper execution of this interventions are described in Table 15. To be immediately implemented, an official template for the internal procedure was used. It can be seen in the attachments 8.3.

TABLE 15: FURNACE'S COVER OPENING AND CLOSING PROCEDURE

Nº	Description	Visual assistance
1	Turn off the furnace's heating system and wait until it cools down to a temperature inferior to 100°C, so that the furnace's walls don't warp due to heat.	
2	With a ladder, one collaborator must climb to the top of the furnace	
3	Attach all 4 hooks (connected to the crane's chains) in the respective place.	
4	To correctly hoist the furnace's cover, 4 collaborators (on the floor) must synchronously pull the chains from the crane, so that the cover lifts in equilibrium. The cover must be lifted until it is above the safety locking system.	
5	Activate the 4 safety locking bars, present in the crane's support beams.	
6	Lower the cover until it has its weight supported by the safety locking mechanism. The chains must be tensioned so that the safety locking mechanisms do not support all the weight of the cover.	

7	Perform the required intervention inside the furnace only when the furnace's interior is close to ambient temperature (40°C).	
8	After performing the intervention, level the sand present in the furnace's opening, where the cover will rest. This sand is responsible for sealing the heat.	
9	To lower the cover and seal the furnace, the 4 collaborators must synchronously pull the chain of the crane, to lift the cover from the safety locking system.	
10	The 4 safety safety locking bars must be disabled.	
11	Reverse the direction of the crane's moviment system, so as to lower the furnace's cover until it reaches the top of the furnace and penetrates the sand.	
12	Verify with the hands if there are any noticeable gaps between the cover and its groove, to ensure proper sealing (small gaps are allowed, but never superior to 5 millimetres).	
13	Remove the 4 hooks from the cover and leave the chains completely over the furnace, to be out of reach from whomever is on the floor.	
14	Leave the top of the furnace	

6 Conclusions

6.1 Final remarks

Finally, this chapter provides the most significant conclusions achieved in the subjects studied, regarding the effectiveness of each of the presented solutions, which are as follows:

1. Blank repositioning: Although theoretically attractive, these alterations require experimental confirmation to validate the results. The company demonstrated interest in its future implementation, when possible.
2. Furnace open/close procedure: Since the implementation of the procedure, no more accidents have happened. This mistake has occurred only once, thus more time is necessary to prove its effectiveness. Regardless, it is a no-cost measure that holds employees accountable for their mistakes, thus being a promising solution.
3. Magnetized tool heads: Due to the excessive amount of expelled material this measure has proven to be ineffective. Even though it did not work, it allowed us to understand that the aspiration system was inefficient.
4. TOX® press pressure adjustment: Even though it was not implemented, previous studies in the facility have proven that reducing the working pressure of these systems reduces their wear and consequently their maintenance costs. Further reducing the working pressure results in even lower wear.
5. Laser marking: the laser system is not a viable investment if the objective is to substitute the already implemented press system, due to the already implemented maintenance cost reduction measures. However, in the case of implementing a new HS line, it is the preferred alternative, as the acquisition costs are similar, but the maintenance costs are greatly reduced.

6.2 External conditioning factors

During the development of this work, several changes had to be made. Not everything early planned came true and or was accomplished, such as the implementation of the repositioning of the blanks inside the furnace.

The factors that interfered with the good development of this work were as follows:

- Logistics: delayed the shipping and delivery of the samples provided to MACSA ID®
- Unavailability of the workforce: as personal had deadlines and required jobs to prioritize, the staff was not always available to help fulfil some of the proposed solutions.
- Covid restrictions and actions: due to the global pandemic, computer chip shortage, and other sociocultural factors, Gestamp's clients, such as the VW and PSA Group did not order as many components as usual due to other component shortage in their production lines, leading Gestamp to implement layoff alike measures that prevented workers from working over hours, making it impossible to implement the proposed solutions during previously available schedules, such as Saturdays and Sundays.

6.3 Future work

Even though problems are solved, and processes are perfected, there is always more room for improvement. There is always another way to make equipment more robust and a process more reliable.

Regarding the research already developed in the dissertation, continuing the implementation of blank travel repositioning is of great importance to verify its effectiveness. The company has demonstrated interest in this measure and expects to implement it whenever possible.

There are several other problems mentioned in this work whose solutions were not developed. All of them are good situations for a study case once more impactful problems, such as those explored in this work.

Excessive metallic dust on the Prima Power® lasers

One of most interesting situation to study is the excessive metallic on the laser cutting machines, as mentioned in sub-chapter 3.2, regarding excessive metallic dust on the factory floor topic.

During cleaning interventions to the laser cutting machines, one part of the metallic dust is aspirated to the machine's filtering system, while the unaspirated amount is manually vacuumed by a machine operator. To understand the amount of dust that was left unfiltered inside the laser cutting machines, both the manually vacuumed dirt and the automatic aspirated dust were weighted during one cleaning intervention.

a) b) c)

FIGURE 45: A) EMPTY COLLECTION BOX (13.65 KG) B) FULL COLLECTION BOX (20.26 KG) AND C) MANUALLY VACUUMED DUST (1.07 KG)

Not all the dust left inside the machine was able to be manually vacuumed. To give a simplified estimation, it was considered that the unaspirated dust (by the filtration system) was 1.07 kg, which represents about 14% of the total dust (7.68 kg). The quantity of unaspirated dust is bigger than the presented value, as part of has to be cleaned with a cloth, another part is collected by the litter collection system, and another part is expelled to the exterior of the laser machine. Regardless, the amount of unaspirated dust is very significant and should be worked on, to both reduce machine wear and for safety concerns, regarding human resources.

The filters were verified to be from a reliable brand (the one recommended by Prima Power®) and are regularly replaced, according to manufacturer specifications.

There are 2 evident problems related to the machine. The first is the positioning of the vents inside the machine as shown in Figure 46.

a) b)

FIGURE 46: LASER MACHINE'S VENT POSITIONING

The biggest vent is positioned above the tool head (Figure 46 b)). This means that the particles are being pulled towards the tool head, increasing the risk of entering its components and causing wear to the lenses and electric circuits, being one of its major problems, as previously mentioned.

The second problem is the poor sealing of the machine's insides. As the fixture responsible for fixing the formed blanks rotates (to remove the already cut part from the machine and insert a new one to be cut), it generates an airflow, responsible for removing particles from the inside of the machine, contaminating the exterior, the factory floor.

To better understand the aforementioned issues, an airflow simulation study of the laser machine should be considered, as the equipment may not be the best suited for this application. This would allow to understand where deadspots (places where dust builds up) are and what causes them. Another possible solution can be the acquisition of another aspiration module, as the machines allow the application of 2 of them. To understand the viability of this solution, a study should be performed to understand the necessary airflow required to remove the ongoing volume of particles for each machine. Knowing the weight of particles emitted by the laser cutting would allow as well to calculate the weight of particles that leave the machine and contaminate the factory floor.

As important as it is, maintenance is not the only cost a factor has. Many other aspects of the facility can and should be perfected, as they represent major costs as well. As shown in Figure 21, the energy represented more than one-third of the total costs of 2020. This makes energy consumption a very interesting opportunity to reduce costs as well.

There are various ways of reducing energy consumption costs, such as reusing "wasted" energy from the ongoing processes and implementing ways of producing energy in-house through sustainable and renewable sources.

Solar panel adoption viability

One way of taking advantage of Gestamp's factory massive footprint would be the installation of solar panels. The rooftops of all its warehouses and factories have a superficial area north of $25km^2$ and have good solar incidence.

These conditions are worth considering, as a significant amount of renewable energy could be produced, lowering their dependence on the grid and lowering energy costs.

A detailed study is required to understand whether such an investment could have a desirable payback time and how much the savings would be over time.

Co-generation of energy

Another possible way of decreasing the energy consumption is to covert or recover part of the wasted energy in certain processes, such as the heating process in the Hot Stamping furnace. This led us to think of solutions involving co-generation.

A lot of energy is wasted in the heating process because escape gasses at high temperatures, resultant from the combustion of the natural gas, must be released. One of the ways this energy can be employed is to heat water, to later be consumed in sanitary matters. Already implemented in Gestamp Aveiro, heated water, from heat removal in industrial processes, is used in the painting facility. This hot water, mixed with degreasers, is used to clean the produced parts before being painted.

Furthermore, this energy can be converted into electricity for example, to power other low power applications through the application of a vapour turbine and a generator.

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8 Attachments

8.1 MACSA ID® power consumption table

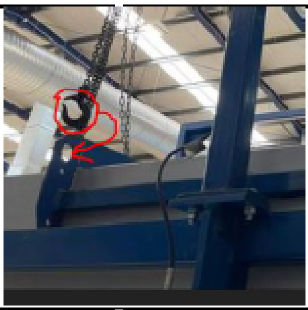
Power (P)	Cycle Time (Tc)	Number of Lasers (NL)	Number of Markings per Laser (N)	Cicles per Year (Cy)	Working Time (WT)	Yearly Energy Spent (Ey)	Average Energy Price (Eac)	Total Cost (Ct)
VA	s	n	n	n (3x/min, 24h/day, 260days/year)	h/year	kWh/year	€/kWh	€/year
600.00	1.00	2	2	1123200.00	1248.00	748.80	0.15	114.21

8.2 TOX® PRESSOTECHNIK press consumption table

Volume (V)	Consumption (Cc)	Force (F)	Course (d)	Evergy per Stroke (Es)	Energy per Stroke (Es)	Strokes Number (Ns)	Total Energy Consumed (Et)	Energy Average Cost (Eac)	Cost per Cylinder (Cc)	Number Cylinders (N)	Total Cost (Ct)
L	N/L	kN	mm	J/n	kWh/n	n	kWh	€/kWh	€	n	€/year
402.12	7.00	2.81	32.00	90.08	2.5E-05	1123200	28.11	0.15	4.22	4	16.86

8.3 Furnace opening and closing internal procedure

Gestamp Aveiro	PROCEDIMENTO TÉCNICO DE MANUTENÇÃO		Cod.: GEN_PNE_001
DEPARTAMENTO DE MANUTENÇÃO	Designação:	Abertura e Fecho das Tampas do Forno	Rev(0) 2021/04/05

N.º	Descrição	Ajuda visual
1	Desligar o sistema de aquecimento do forno e deixar que o forno atinja uma temperatura inferior a 100°C.	
2	Com o auxilio de um escadote, 1 colaborador deve subir para o topo do forno.	
3	Prender os 4 ganchos (presentes nas correntes do guindaste na tampa), no respetivo local.	
4	Para içar de forma correta a tapa do forno, quatro colaboradores (no chão de fábrica) devem puxar a corrente do guindaste de forma sincronizada, para que a tampa suba de uma forma equilibrada. A tampa deve subir até ficar numa posição acima do mecanismo de repouso da tampa.	
5	Acionar os 4 mecanismos de segurança presentes nas barras de suporte dos guindastes.	

Gestamp Gestamp Aveiro	PROCEDIMENTO TÉCNICO DE MANUTENÇÃO		Cod.: GEN_PNE_001
DEPARTAMENTO DE MANUTENÇÃO	Designação:	Abertura e Fecho das Tampas do Forno	Rev(0) 2021/04/05

N.º	Descrição	Ajuda visual
6	Descer a tampa até que esta fique com o seu peso suportado pelo mecanismo de segurança previamente mensionado. As correntes devem ficar sob tensão, de modo a que os mecanismos de segurança não fiquem a suportar a totalidade do peso da tampa.	
7	Realizar a intervenção dentro do forno necessária apenas quando o interior do forno se encontrar perto da temperatura ambiente (inferior a 30℃)	
8	Após a intervenção desejada, nivelar a areia que se encontra em redor da abertura do forno, onde a tampa irá pousar.	
9	Para baixar a tampa e selar o forno, os 4 colaboradores devem, sincronizadamente, puxar a corrente da guindaste de modo a elevar a posição da tampa do forno.	
10	Desativar os 4 mecanismos de segurança que se encontravam a impedir que a tampa do forno descesse.	

N.º	Descrição	Ajuda visual
11	Puxando a corrente no sentido inverso, fazer descer a tampa do forno sincronizadamente até que esteja totalmente apoiada na estrutura do forno, na areia.	
12	Um dos colaboradores deve subir ao topo do forno para, com a mão, verifiacar se existe vedação entre a tampa e o seu local de encaixe, nos 4 cantos da tampa (uma pequena folga é admitida)	
13	Remover os 4 ganchos dos locais de encaixe na tampa e deixar as correntes totalmente em cima da tampa do forno, de modo a que estejam fora de alcance de quem estiver no chão.	
14	Descer do topo do forno	
15		