KAUNAS UNIVERSITY OF TECHNOLOGY
MECHANICAL ENGINEERING AND DESIGN FACULTY

DANAS MERKELIS

ANALYSIS ON POSSIBILITY TO REDUCE SCRAP IN PLASTIC CHROME PLATING PROCESS

Master's Degree Final Project

Supervisor
Assoc. prof. dr. Regita Bendikienė

KAUNAS, 2017

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Industrial Engineering and Management (621H77003)

Supervisor
Assoc. prof. dr. Regita Bendikienė
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Reviewer
Assoc. prof. dr. Antanas Čiuplys
2017.06.02

Project made by
Danas Merkelis
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(Faculty)

Danas Merkelis

(Student's name, surname)

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(Title and code of study programme)

"Analysis on possibility to reduce scrap in plastic chrome plating process"

DECLARATION OF ACADEMIC INTEGRITY

2 June 20 17

Kaunas

I confirm that the final project of mine, **Danas Merkelis**, on the subject “ANALYSIS ON POSSIBILITY TO REDUCE SCRAP IN PLASTIC CHROME PLATING PROCESS” is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarized from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this thesis.

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Production engineering
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MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme INDUSTRIAL ENGINEERING AND MANAGEMENT

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Analysis on possibility to reduce scrap in plastic chrome plating process

Approved by the Dean Order No.V25-11-8, 21 April 2017

2. Aim of the project

The main aim of the master thesis is to analyse how does the product FOT specification changes depending on the positioning and orientation on the chroming bar as well as how does that respectively influences the laser engraving operation quality for the end product. The conclusions of the analysis performed will answer the problem statement question further the recommendation on how to reduce scrap by 30% quickly and without investing into new equipment will follow

3. Structure of the project

Literature overview including injection moulding process, injection moulds, chrome-plating of plastics and process, layer thicknesses and rack construction design. Methodology of company and data gathered, the product and problem.
Experimental part of analysis conducted: set-up and part racking, results of stability, process variation visualization, metallization thickness, and effects for laser engraving quality.
Implementation part: evaluation of scenarios, implementation and calculations
Conclusions and further recommendations for the company.

4. Requirements and conditions

Master thesis is prepared following the guidelines for preparing Master's Final Degree project, which is approved by Kaunas University of Technology

5. This task assignment is an integral part of the final project

6. Project submission deadline: 2017 June 2nd.

Student	Danas Merkelis (*Name, Surname of the Student*)	(*Signature, date*)
Supervisor	Assoc. prof. dr. Regita Bendikienė (*Position, Name, Surname*)	(*Signature, date*)

Danas Merkelis. Analysis on possibility to reduce scrap in plastic chrome plating process / supervisor Assoc. prof. dr. Regita Bendikienė; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Research field and area: Technological Sciences, Production Engineering

Keywords: *production, chrome-plating, injection moulding, laser engraving*

Kaunas, 2017. 44 p.

SUMMARY

The master thesis conducted is the investigation of the root cause of the high scrap rate of product FOT in laser engraving department. Product FOT splits into two versions after chrome-plating operation where one of the versions continue to laser engraving department, where the other is sold directly to the customer. High scrap rate occur at laser engraving department where the laser marking quality varies on parts from the same batch when laser parameters remain constant.

An analysis done focusing on chrome-plating process variation throughout positioning of parts on the processing bar: the position on the rack as well as the orientation. One processing bar – 140pcs of parts were numbered and measured before and after the chrome-plating operation to find out how does this affect the product specifications. Furthermore, the positioning on the processing bar was noted, as well as two sub-groups were done. One sub-group was hanged orientating the marking surface outside the processing bar, while the second sub-group vice versa.

Chroming process instability was noticed due to unstable current spread throughout the processing bar: part specification change amplitude was equal to the change of nine to ten times. Meaning that the difference of change of part weight or high from its nominal after the injection moulding operation to secondary after chrome-plating operation may vary nine to ten times on parts from the same batch. Additional analysis of coating thickness for the laser engraving area was done for five parts from first sub-group and five parts from second sub-group. Parts were selected including several parts that changed the most and several that changed the little. This resulted a conclusion that coating thickness of parts from the same batch varies from nine to ten times. These ten samples were laser engraved to see how does it affect the marking quality – parts with thicker coating layer were better in quality, while parts with thinner layer were scraped.

Since the tendency of parts with thicker and thinner coating layer is visualised and noticed and the Company XXX wants to reduce the scrap rate without investments – the handling operation were introduced and tested. Parts are split into thin and thick layered straight after the chroming cycle is over. Parts with thicker layer continues to laser engraving operation, while the parts with thin coating layer are send directly to the customer. This change does not require an investment, but only administrational internal work. The part cost price does only increase by 0,1 €/pcs, while the scrap rate is reduced by 33%.

However, this suggestion is considered as short-term solution, which does not solve the main root cause of the high scrap rate. Therefore, final recommendation for the Company XXX would be to invest into new racking system, which would require the designing of the racking system, as well as test runs, adjustments and similar analysis of the product change.

Merkelis Danas. Broko kiekio sumažinimo galimybių plastiko chromavimo procese analizė. Magistro baigiamasis projektas / vadovas doc. dr. Regita Bendikienė; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Mokslo kryptis ir sritis: Technologijos mokslai, gamybos inžinerija

Reikšminiai žodžiai: *production, chrome-plating, injection moulding, laser engraving.*

Kaunas, 2017. 44 p.

SANTRAUKA

Magistro baigiamasis darbas analizuoja pagrindinę produkto FOT broko atsiradimo priežastį lazerinio graviravimo operacijoje. Galimi du FOT produkto tiekimo variantai: vienas tiekimas iš karto po chromavimo operacijos, kitas po graviravimo. Gana didelis brokuotos produkcijos kiekis gaunamas lazerinio graviravimo skyriuje graviruojant to pačios chromavimo partijos detales, nepaisant to kad proceso parametrai yra tokie patys.

Analizė atlikta sutelkiant dėmesį į proceso variaciją chromavimo operacijoje: atsižvelgiant į detalių poziciją ant chromavimo baro, taipogi pačią detalės orientaciją. Analizuojamas kiekis 140vnt FOT detalių, arba vienas chromavimo baras. Visos detalės buvo sužymėtos ir pamatuotos įskaitant jų aukštį ir svorį prieš ir po chromavimo operacijos. Tai leido matyti kaip keitėsi detalių specifikacija ir kokia tendencija priklausomai nuo vietos ir detalės orientavimo.

Analizės rezultatai: pastebėtas proceso nestabilumas dėl netolygaus srovės pasiskirstymo per visą chromavimo barą. Detalių specifikacijos pasikeitimo amplitudė svyravo nuo devynių iki dešimt kartų. Kitaip tariant, detalių aukščio ar svorio pasikeitimo skirtumas nuo nominalaus po injekcinio liejimo iki po chromavimo, tarp mažiausio ir didžiausio pasikeitimo svyravo nuo devynių iki dešimt kartų toje pačioje partijoje. Papildomai, buvo pamatuotas padengimo sluoksnio storis. Dešimt labiausiai pasikeitūsių detalių iš dviejų skirtingų orientavimų grupių buvo pasirinktos paviršiaus padengimo storio matavimui. Kelios matuojamos detalės buvo mažiausiai pakeitusios tiek svorį, tiek aukštį, kitos daugiausiai. Padengimo sluoksnio storio skirtumas tarp detalių iš tos pačios chromavimo partijos lygus dešimt kartų. Visos pasirinktų dešimt detalių buvo graviruojamos su standartiniais lazerio parametrais. To pasekoje, pastebėta, jog detalės su storesniu padengimo sluoksniu buvo geresnės kokybės, kai tuo tarpu detalės su plonesnių padengimo sluoksnių – prastesnės.

Storesnio ir plonesnio padengimo išsidėstymo tendencija aiškiai matoma po analizės – chromavimo baro kraštuose detalės pasidengia storiau. Įmonei XXX pasiūlytas broko sumažinimo planas, nereikalaujantis investicijų, taipogi greitai įvykdomas. Detalės skirstomos į dvi grupes iš karto po chromavimo operacijos. Storesnį sluoksnį turinčios detalės – graviruojamos, o plonesnį sluoksnį turinčios detalės siunčiamos tiesiogiai klientui. Pasiūlymo investicija – administracinis vidinis darbas, kuris detalės savikainą padidina tik 0,1 €/vnt, kai tuo tarpu broko kiekį sumažina 33%.

Galutinės rekomendacijos pataria naudoti šį pasiūlymą ir išvengti didelio broko kiekio, taipogi sutaupyti 1408 € per metus – neišmetant detalių. Tačiau galutinė rekomendacija įmonei XXX yra investuoti į naują chromavimo kabinimo sistemą ir jos dizainą, įskaitant papildomus testus, skaičiavimus bei panašias analizes.

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INTRODUCTION

This Master thesis is an investigation of production and root cause for the high scrap rate of product called FOT at the Company XXX, located in Kaunas. Company is mostly recognised for their know-how in the plastic injection moulding industry. Due to growing markets and competitiveness additional operations such as chrome-plating and laser engraving are performed within the Company. These additional operations were implemented on a quick notice therefore no thorough analysis were done when performed. Thus at this point caused relatively high scrap rates for the end product.

Product FOT is selected for this thesis as same versions from injection moulding department follows the chrome-plating path, when after that it splits into two versions: either laser engraved or shipping to a customer with no further operations applied. High scrap rate after laser engraving operation is a key problem and figure for this master thesis. Relation is found between chrome-plating operation and laser engraving. Instability of both processes force to consider why this appears. Instability in product quality appear in laser engraving when laser parameters are the same every single cycle, however, parts from the same chroming batch tend to vary between good marking and marking with a scrap. Most common scrap is divided into two big groups: part quality and marking quality. An assumption is that layer thickness of different metals after chroming varies on parts, which influences the layer thickness on parts, therefore it affects the laser engraving quality. While chroming process is mostly standard: including standard timing, bath chemical concentration and temperatures, the handling and racking position differs from part to part. Therefore the investigation on how does the part position and orientation on the chroming bar affects the layer thickness of Cr, Cu and Ni will be done. In addition, how does this affect the laser engraving process through product quality perspective.

The analysis followed in this master thesis will find the root cause which affects the appearance of high scrap rate in the laser engraving department when the process parameters of both processes remains the same. Master thesis conclusion will suggest a way to decrease the total scrap rate by 30 per cent from its initial level at the beginning of the master thesis without long lead time and minimal investments required. **The main problem statement**:

How to reduce the scrap rate of product FOT in the laser engraving department by 30% without investing into an expensive equipment and in short lead time?

To answer and solve the main problem question, the following sub-questions will be investigated and answered during this master thesis:

1. What are the relations and differences between part positioning and orientation on the chrome-plating processing bar and specification of the part before and after chrome-plating process?
2. How much the layer thickness of the coating does differ on parts from the same batch and are there any tendencies?

3. How does the coating layer thickness on laser engraving area influence the marking quality of the end product?

Therefore, from the problem statement it can be concluded that **the main aim** of the master thesis is to analyse how does the product FOT specification changes depending on the positioning and orientation on the chroming bar as well as how does that respectively influences the laser engraving operation quality for the end product. The conclusions of the analysis performed will answer the problem statement question further the recommendation on how to reduce scrap by 30% quickly and without investing into new equipment will follow.

The main tasks of master thesis are:

1. Analyse the change of product FOT specification before and after chrome-plating.
2. Study the chroming coating layer thickness dependability from the position on the processing bar as well as products' orientation.
3. Investigate the chroming coating layer thickness impact to the product quality after laser engraving operation.
4. Improve the scrap rate of an end product by 30% in short notice and without investing into new equipment, as well as measure the improvement made and emphasise it.

Fair delimitation points are set-up for this master thesis in order not to go too deep into the investigation and only focus on the main problem statement and objectives of this master thesis.

The chroming operation itself will not be deeply investigated since it is set as a standard chemical operation and must be investigated together with chemical engineers. Handling and racking will be the focus concern at chrome-plating department. No distrust points in terms of injection moulding or laser engraving will be made: laser engraving process parameters are standard and it is assumed that due to companies' know-how within injection moulding the parts tested has no influence for any non-standard chrome-plating results. No big investments are suggested at current point since the agile improvement is needed for the already running production at the moment of master thesis conducted.

1 LITERATURE OVERVIEW

1.1 THE INJECTION MOULDING PROCESS

Injection moulding is an automated process that works in cycles shown in Figure 1.1 - 1.3. Plastic material in a form of granulate is loaded into plasticising area and melted into low density form. Plasticising area usually composed of screw piston which rotates about its axis and slides along it [2]. Rotating screw is pushing melted material toward the gate of the mould. As the injection valve is closed at that very moment material gets pressure up in front. After the given doze of material is reached the valve opens and material is injected into a mould with the high pressure [1]. When the form is filled, high pressure is formed inside. Press must be closed and pressed with enough force to make the mould stay in the same position, so that the plastic would not leak out of the mould area. The connection between the mould bushing and injection nozzle is kept all the injection moulding cycle. Plastic cools down and hardens thus it chances its volume by shrinking. The resulted reduction in volume must be compensated by continuously pressing the plastic into the mould. This is done until the plastic solidifies completely. While the plastic part is cooled by the exhaust temperature the injection moulding machine is preparing for the next cycle. When the work piece reaches the normal temperature so it retains its original shape without the help of moulds, the press opens and ejectors throws the part from the mould. Mould is closed again and the cycle is repeated.

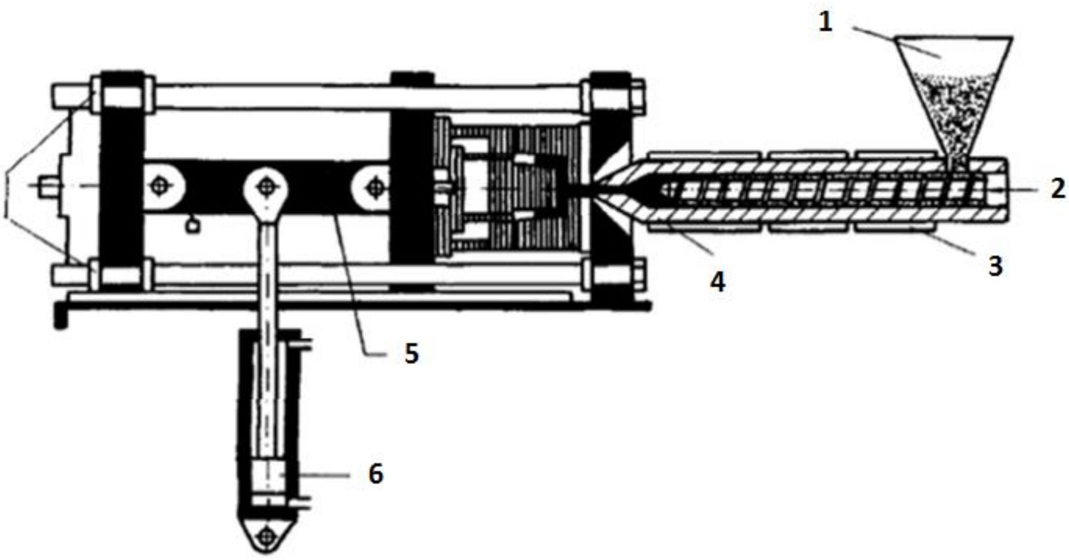

Figure 1.1 First step Injection (1- hoper / feeding bunker; 2- plasticising area; 3-heating element; 4- nozzle; 5- clamping mechanism; 6- cylinder)

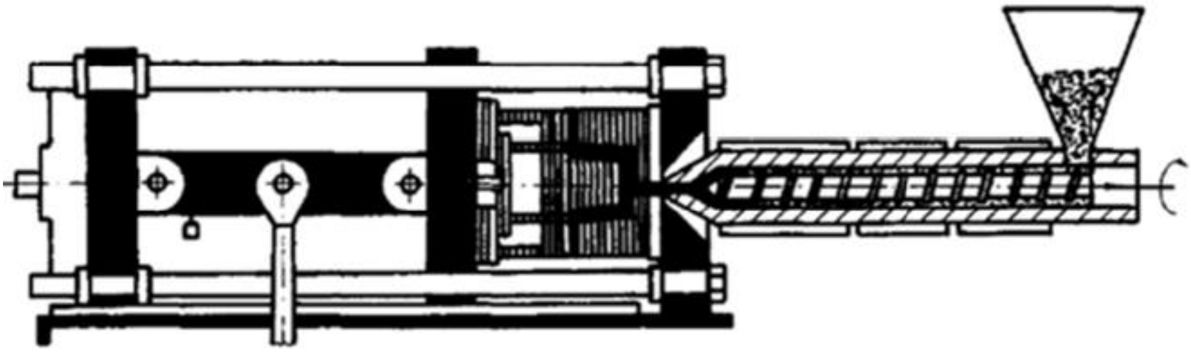

Figure 1.2 Second step - Holding

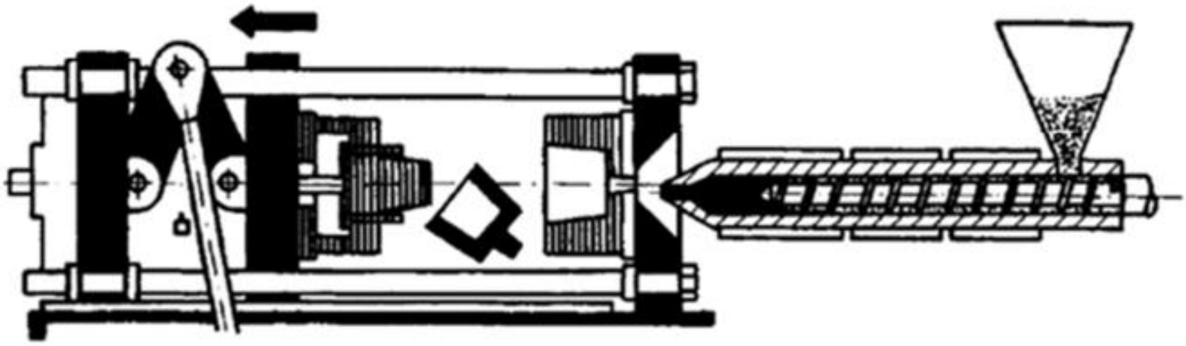

Figure 1.3 Third step - Ejection

1.2 STRUCTURE OF INJECTION MOULD

The production of plastic parts by injection moulding is not possible without the injection mould. Injection mould is designed and manufactured individually for each case; in other words, it is unique. The main functions that the injection mould does are distribution of the plastic, forming, cooling and ejecting. All of this should be included and calculated within the designing stage of the mould. If not, the final part would lack of quality. The most common moulds are classified by the way the mould is holding the part: 1) without holding; 2) with inner holding; 3) with outer holding; 4) with both ways of holding. It should also be classified into hot runner moulds and cold runner moulds.

Figure 1.4 specifies one of the simplest moulds: cold runner mould without holding. The main components that are shows are:

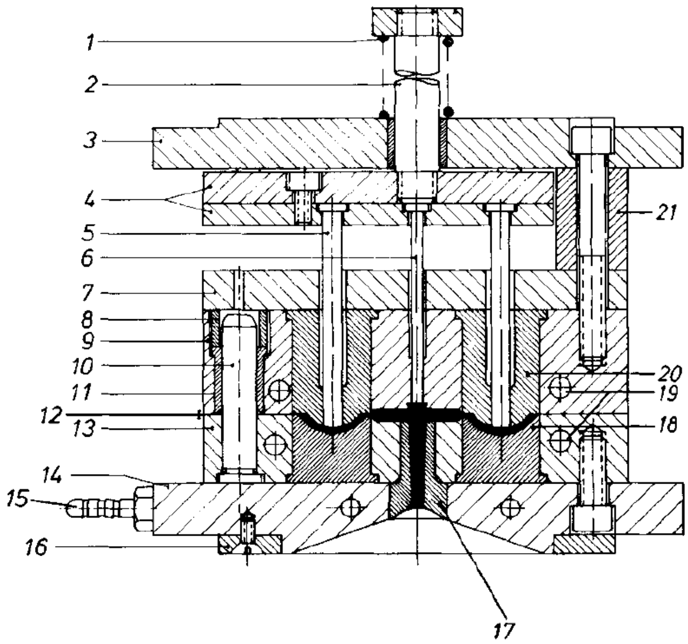

Figure 1.4 Scheme of the injection moulding mould [3] 1 – return spring; 2 – ejection pin; 3 – moving mounting flange; 4 – ejection brick; 5 – ejector; 6 – gate pusher; 7 – back-up plate; 8 – bearing sleeve; 9 – moving plate of moulding inserts; 10 – centre axis; 11 – centre sleeve; 12 – split line; 13 – motionless plate of mould inserts; 14 – immobile flange; 15 – cooling line connection; 16 – centre ring; 17 – gate sleeve; 18 – immobile insert; 19 – cooling channel; 20 – moving insert; 21 – beam.

The injection moulding process from the mould perspective begins when plastic is injected into the gate sleeve (17). It travels through the channels across the motionless (13) and moving (9) plates to the cavity. The cavity is between moving (20) and immobilise (18) insert. In these the plastic is pressed with the holding pressure and cooled down through the cooling channels (19). When the plastic is solid in the shape wanted, the mould opens through the split line (12) and are pushed out by ejectors (5). Ejectors are assembled in a brick (4) which is driven by the drive shaft as well as it relates to the pushing system of the injection moulding machine. After ejection, the mould is closed for another injection cycle. During that the mould is aligned in a help of centre axis (10) and centre sleeve (11).

There are two types of plastic distribution methods within the mould. It is distribution of plastic in hot runner moulds and distribution of plastic in cold runner mould. As the master thesis, will investigate the chrome-plating process only the hot runner mould will be overviewed. Hot runner moulds are mostly used for parts that has high requirements in terms of surface as it leaves no residual of plastic on part.

In the hot runner mould the melted plastic is distributed through the hot channels (4). Due to the fact, the plastic stays at the same temperature from the injection nozzle (6) to it reaches the moulding part (5). The moulding channels are manufactured in the block (1), which is always heated with heaters (2). It is worth mentioning that there could be internal or external heaters.

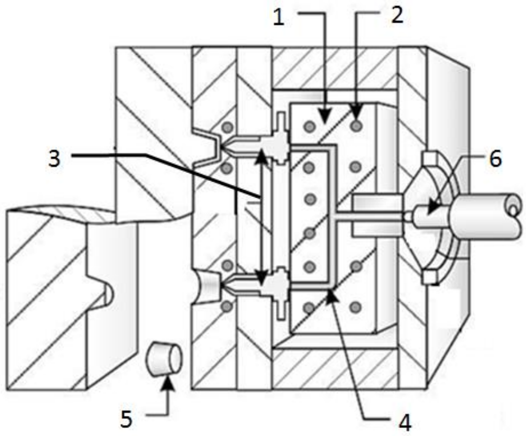

Figure 1.5 Hot runner mould [4]

Using this distribution method of plastic, the cost price of the part decreases as no residuals of plastic are left during the manufacturing cycle. Additionally, no post-processing operation are needed as e.g. cutting of the intake. Since the temperature is even throughout the whole system less pressure is needed to fill the mould. This type of moulds is more expensive than traditional moulds. It is because distribution plate needs to have clean channels for the plastic distribution, which are heated as well as jets. To maintain a constant temperature within the system, expensive temperature control system is needed

1.3 CHROME-PLATING ON PLASTICS

The plating on materials that are non-conductive has been ongoing for many years. Since technologies advanced in chemical processing techniques plating on plastics began on commercial level in 1960 [5]. Chrome-plating on plastics is usually done for decorative purposes, more rarely for functional needs. It is mostly used within automotive, electronics or plumbing appliance industries. Plastics have become more competitive within the market of chrome-plated items due to its light weight and possibilities of design, as well as, significantly lower manufacturing costs [6].

Plating could be divided into two sub-groups of electro less plating and electroplating [6].

Electro less plating is an autocatalytic method where the reduction of metallic ions is accomplished through the oxidation of chemical compounds that are present [7]. Where the Electroplating is, a chemical process depositing a metal on plastics. The principle of working is to electrically conduct metal atoms of nickel, copper and chrome off anodes which are placed in the plating baths and then on the parts itself [8]. After the current is applied the plastic part performs as cathode and metal ions from the bath sinks on the parts [8].

Most of the plated plastics are used for decorative purposes. However, some of the plated plastics are used within engineering field – mostly electronic products. For this application, plated plastic materials are now used in the industries of aerospace, automotive, electronics and some mechanical sectors as well as for daily products [9].

The surface properties of plastic are a dependable on the plastic physical and chemical properties itself. Additionally, the way it is produced and processed. Plastics are usually divided into simple and complex. Often plastic contains from several different monomers which consist macromolecules [10]. In chrome-plating process one property of plastic is important: hydrophilicity and hydrophobicity. Most of the plastics are hydrophobic materials, in simple words the humidity would not stay on plastic. When this type of materials degreased they do not become hydrophilic. This does belong on properties of the polymer molecules and polar groups [10]. When plastics are process many particles remain on the surface as alkanes, plasticizers and other residuals as dust or dirt. These impurities decrease a chance of good chrome-plating process if they are not removed before the processing [10].

Very important characteristics of the plastic surface to metal coating is surface roughness, which is main cause between good and bad coating. Adhesion between the plastic and metal coating is best explained by press-stud theory. According to this theory the metal particles basically lock on to the microporous and cavities on plastic part when they are etched. For example, ABS plastic is good for chroming procedure due to its surface after etching [10].

Acrylonitrile-butadiene-styrene (ABS) is one of the most important synthetic engineering resins, due to excellent properties on impact and chemical resistance. It has a good surface roughness for press-stud theory to work. It is easily fabricated and stable in the size of the finished product. ABS is widely utilized within automotive and electric products [11]. ABS is most usually plated plastic due to relatively good stability dimension-wise and toughness. Though application of this material is rather narrow due to non-conducting and lack of stiffness [12].

1.4 CHROME-PLATING PROCESS

Chrome-plating process is covering plastic with different metal layers by the process of electroplating. Different layers of copper, nickel and chrome are covering the plastic depending on the need and use of an item electroplated. For the purpose of ease, it can be divided into two stages as chemical pre-treatment or preparation stage and electrolytic treatment stage. In order to obtain adequate adhesion of the metal layers, the polymer surface must be modified in the pre-treatment stage by etching in a bath using sulfochromic solution. Chrome is normally applied over copper and nickel in very thin coating – 1.2 μm, where copper and nickel accordingly – 5 μm and 7.6 μm [13, 14].

The preparation stage includes degreasing, etching, neutralizing and activation [10], where after that electroplating starts including acceleration and electro less plating stages. Each stage is separated with rinsing with hot or cold water to clean the residuals.

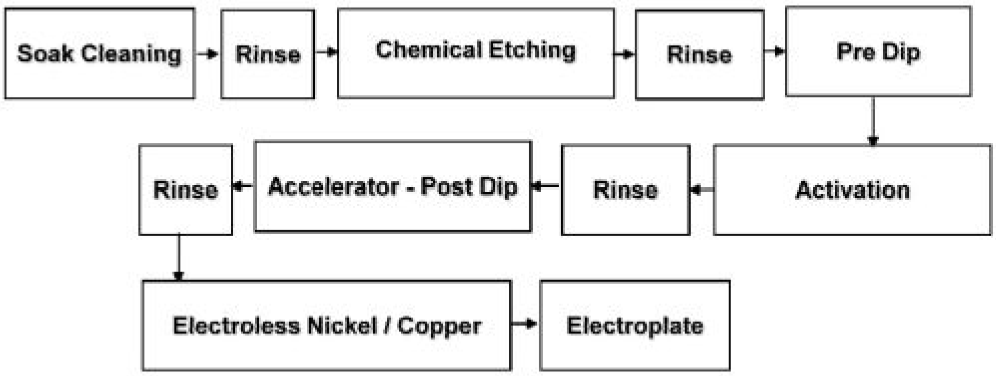

Figure 1.6 Typical process for plating ABS [15]

The degreasing stage is needed for the etching to be performed evenly throughout all surface of the part. The degreasing is usually done with organic solvents or leachates. The organic solvents wash organic pollution and it is usually selected according to the material – so that it would not destroy it [10]. Leachates are used for other kind of fatty residuals.

The etching stage is the base of the whole electroplating process, which has most influence to the success. By etching the surface of the plastic is changed and micro holes with complex structures are created. These complex holes are the reason why metal particles stick to the plastic surface. Etching in a way is similar to the metal corrosion [10]. In other words butadiene is selectively etched out from the surface of the plastic leaving microscopic holes that are used as bonding for the activation when the electro less is started. Different acids are used within etching process but mostly chromic and sulfuric acids, which are operated within 50-65 °C [15].

Neutralisation is a step to basically rinse the parts after etching by removing the excess etchant from the parts and racks. The activation is the last step before the chemical process to be appeared. This stage is really important since the chemical metallisation by means of metal ions reduction and reduction oxidation can only take place in the surface having catalytic properties [10]. In general, this activation is done by seeding the surface or surface holes after etching with a catalytically active metal, usually palladium and tin salts. The parts are then plated with nickel and copper [15].

Electro less plating purpose is to make the part electrically conductive to the final stage of the electroplating. The cooper and nickel is covered using the dipping process over the activated palladium layer. Later chromium can be easily electroplated on the surface of the part.

Layer thicknesses

The selection of the process and layer thickness is the main consideration when it comes to producing an electroplated part. The cost for the process varies a lot depending on the demand of the customer. The layer thicknesses of different metals might vary as well as the process cycle time, which highly affects the cost of the product. It mostly depends on product specification and customer demands: if the product is purely cosmetic and there is no fluctuation in terms on humidity or temperature the electroplating composition and thickness can be minimal. On the other hand, if the product will be used in high humidity or temperature changing environment, the process must differ [16]. Bright acid electroplated copper is used as a base for the nickel chromium plating since the ABS plastic possess a higher coefficient of expansion that the nickel chromium coatings. Copper can level the porosity of the surface after etching, which is perfect for chromium: as it is impossible to deposit thin decorative coating of chromium without the porosity. These three metal layers works perfectly works together. In simple words the copper makes the part smooth, chromium makes it decorative, while nickel works as corrosion protection [16].

As mentioned, depending on the product specification there are different requirement thicknesses for different materials on parts.

Table 1.1 Material thickness requirements [16]

Material / Part requirements	**Mild part requirements**	**Moderate part requirements**
Bright Acid Copper	15 µm	15 µm
Bright Nickel	7 µm	15 µm
Chromium	0.125 µm	0.25 µm

1.5 ELECTROPLATING TECHNIQUES

There are different electroplating techniques that are used within the industry. Depending on part size, complexity, later use and quantities required different electroplating techniques could be selected that fits the needs.

Mass plating is very often used for mass production where parts are kept in barrels that are self-circulating and tumbling until metallisation appears. It is quite popular within economics of scale as fits perfect for high quantities and large parts that does not require delicacy. It is because scratches appear while plating. Therefore, it is more popular plating nuts, bolts and other small objects.

Continuous plating is mostly used for plating wires, tubes and other objects as coated objects are moved continuously through plating flow. Material and energy is saved within this process as well as within Line plating, where parts to be coated are moved in production line, as it also saves time and number of chemicals used.

Rack plating is mostly used for delicate parts as parts are hung on racks which are dipped into baths. The process is more complicated compares to for instance mass plating, however, more delicate parts can be produced. It is also known as batch plating.

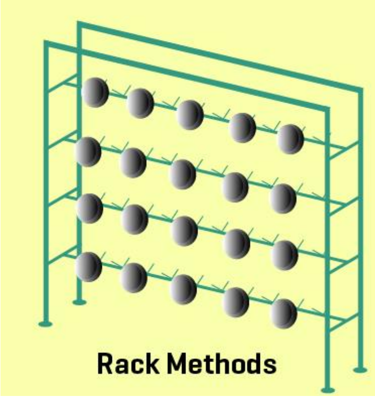

Figure 1.7 Rack or Batch plating method

Rack construction

Plated plastics offer designed freedom of choice on how the part design should look. With these modern times and more complex plastic parts the plastic rack design consideration have become a crucial point, which mostly influences the part quality. The proper design, construction and maintenance of the plating rack directly influences the quality of the coating [16].

Rack splines are the parts that carry the main current throughout the rack. It can be single or multiple depending on part construction and complexity. Copper is the most common for spline construction although alternative materials with superior conductivity might be used. Improper material selection or insufficient cross sectional area can cause less current deliveries to parts than needed. Additionally, burn off the thin electro less deposit due to excessive heat build-up, and burning or blistering of the rack coating which all can cause skip plating [16].

The rack construction consists of several parts including plating rack hooks, rack cross bars and rack contact tips. All of them have their function and must be done in a proper way. The rack hooks, which make immediate contact with the cathode bar needs to be constructed as continuation of the spline to permit maximum conductivity. Spline and rack hooks should be constructed using cooper or cooper alloys. The cross bar serves with several purposes including giving a strength to the rack as well as serve the current from the splines to the contacts. Rack contact tips is holding the part in place and provides electrical contact to the part. It needs to be calculated so the contact tip would keep the part steady, however, not too much tension must be placed as it might cause the deformation of the part in the plating process. Mostly stainless steel is used as a contact material due to the use of corrosive solutions in the pre-plate system and the use of nitric acid bearing rack stripping. The length of the contact usually kept as minimum as possible to be able to have the flexibility and good electrical conductivity [16].

A specific individual rack must be used for every part, otherwise it might result in trade-offs in quantity, performance or productivity decrease. Prototype racks are usually tested before normal racks are produced for serial production. Attention to the part placement on the racks must be given. It should be done to optimise the distribution of the material thicknesses and visual quality. The positioning on the rack must be balanced so that the current would spread out equally. Spreading out the parts in the efficient way is the key: low current density parts should be placed toward anodes etc. Parts should also be racked to keep the shelf roughness on the bottom as well as minimise drainage due to risk of pollution of baths in a carryover principle. Current flow should be balanced throughout all the parts, otherwise the material will not be even. There are several methods to use if the current is not balanced throughout the rack. One of the alternatives is current robber (conductive members with cathodic charge), which draws the plate from the workpiece. Another alternative is placing non-conductive member close to the part [16].

Due to several reasons the quantity of contacts required for plastics parts is greater than requirements for metal parts. First, stainless steel has a very limited current carrying capacity. Additionally, limited pressure can be applied to plastic, therefore it needs to be divided as well as limited current carrying capacity is within thin electro less. The design of the contacts must be thoroughly overviewed as there are several tips that needs to be done. The contact of the part must be within medium to high current density area and the contact tip must be produced out of stainless steel or titanium. The contacts cannot lose tension during the serial production so it must be flexible in a stiff matter, but it cannot contact the significant area of the part. The contact should not be placed on high quality surfaces meaning that it must usually be designed to be contacting the area which is not seen – as there is possibility of miss-plating or discoloration [16].

Not only thoughtful design for the racks are needed, but good care and storage after every use. The electroplate build-up on the contacts can appear therefore it should be removed after each cycle to insure clean contact to every part. It is usually done using nitric acid based strippers. The coating of the rack must be checked as well otherwise all the acids will deteriorate the interior of the rack. It must be stored in a proper way and not stacking those together [16].

2 METHODOLOGY

2.1 THE COMPANY AND DATA

The Company which is analysed is a worldwide organisation with facilities spread around the world. The thesis analyses the manufacturing site located in Kaunas. The Company is an injection moulding manufacturing Company that produces injection moulding parts and components to different production sectors including: light vehicles, heavy vehicles, medical, industrial and furniture. The Company master most techniques and materials within the polymer segment and perform assembly of components.

Internal data about products such as output production numbers, scrap rates, operation types and cycle times collected internally at the Company. These data will be looked upon as highly reliable, and possible questions will be discussed directly with the person in charge of that area of the Company e.g. Production and Quality. All external data needed will be obtained through relevant literature in the faculty' library etc. Internet sources will be used for investigations, though data from open sources will be validated in the best possible way, to minimise bias naturally associated with public webpages.

2.2 THE PRODUCT

The product used for master thesis analysis is called FOT, which has high scrap rate within its operational path. To produce FOT several operational steps used: injection moulding, chrome-plating and laser engraving. The product is assembled at customer therefore it should meet all required specifications including dimensional specification and appearance specification. The FOT is used as one of the bath mixer components for the final assembly [19]. The customer of the FOT is operating in the competitive high class environment, meaning that appearance requirement for the FOT is demanding: no scratches, water marks or any other surface damage. Only minor surface imperfections are allowed according to the customer requirements. Dimensional requirements are set on drawing which is the property of the customer and cannot be published or used externally. Therefore only the key values are used. The most crucial ones are for the customer is the diameter of the part and the height. These are controlled within production to check the process stability. Weight is also a key to be controlled to avoid process instability. FOT diameter must be within the specified tolerances since another plastic cover is assembled together and pushed inside. Another important dimension is the height. The whole unit needs to be assembled together it is important for the FOT to be within the tolerances [19]. Main specifications from the drawing:

1. Material: ABS
2. Weight: 24 grams
3. Height: 52.5 ± 0.1 mm

Laser engraving is used for one version of the part to mark the power key on it, which also needs to be precise and aligned with the hole on the part. Marking intensity and sign was approved by the customer therefore it must be kept roughly the same throughout the production. Laser engraving on the marking area Figure 2.1 is also specified within the drawing – positioning and size-wise. Therefore, it is also crucial to keep that in mind during serial production. Marking sign is shown below, the laser engraving intensity is visually approved therefore is judged as the master sample.

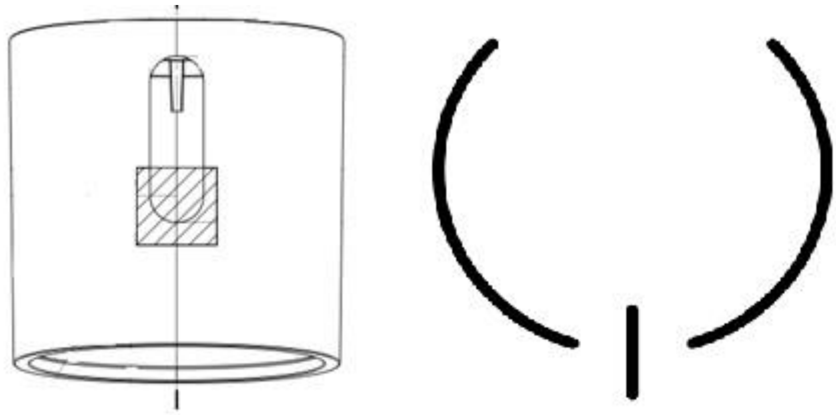

Figure 2.1 FOT marking location

Common understanding to follow the part through production flow is needed. Product FOT needs to recognise at every production stage therefore further will be presented with a letter after the name. This will help to follow the production path. Letter A will indicate the injection moulding phase. Meaning that FOT-A is a part after injection moulding operation, FOT-B part after chrome-plating, FOT-C is the part after laser engraving. This indication will be used within the master thesis. There are two final products: either FOT-B, or FOT-C that are sold to the customer.

Process flow is the movement and transformation of raw materials and components into finished products, which is delivered to the customers by different means. The goods flow downstream, while the information and payments going upstream. In some cases, the flow can be flexible meaning that goods can flow upstream and information can flow downstream.

Current and standard process flow chart illustrates the supply chain of the Company as well as main operations divided into flow. A thorough process flow chart is made including all handling and other operations as detailed as possible.

Process flow chart can be found in Appendix 1 – Process Flow Chart. Figure 2.2 indicates the symbol and functions, which are performed during the process flow: before and after main operations. The indication of products can be found to follow the process path for FOT-B and FOT-C separately.

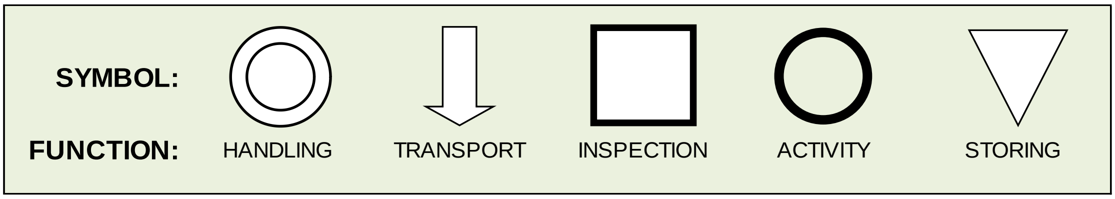

Figure 2.2 Process Flow Chart symbols

Fischerscope XRAY XDL 220 used in this master thesis for measuring coating thickness layer in decorative coating used within FOT part. The chromium, nickel and copper thickness measurements were done on ABS plastic. The machine is used for non-destructive thickness measurements and analysis of thin coatings. It is usually used for quality check as well as solution analysis. It is used for process control and quality assurance to inspect the thin coating of chromium-plating and other solution analysis of electroplating. The equipment is shown in Figure 2.3 below.

Figure 2.3 Fisherscope XRAY XDL 220

The measuring area may vary depending on the needs – smallest is Ø0,2 mm, while the standard is Ø0,3 x 0,05 mm. A standard measuring area were used within the master thesis [20].

The further operation of laser engraving is done using Technifor Lasertop 2000 which is used within serial production of the production of FOT-C. It has been used for the master thesis laser engraving analysis on different surfaces of the part. The laser and its main parts are shown in Figure 2.4.

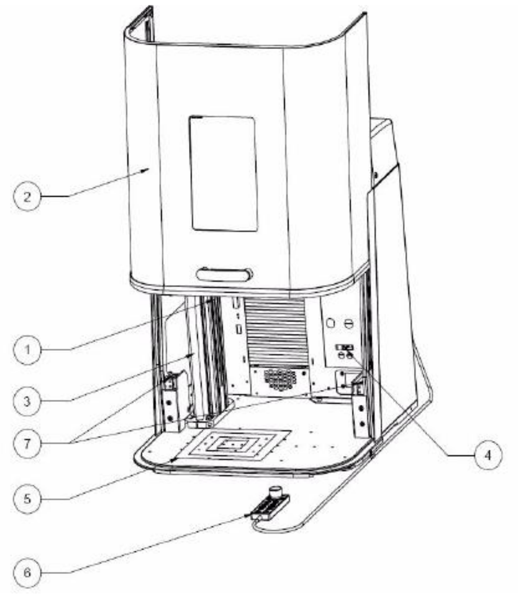

Figure 2.4 Technifor laser 1-marking head; 2-door; 3-motorized z-axis; 4-numerical counter 5-marking area; 6-remote control; 7-door locking latch [21]

The laser is user friendly as it is simple to use. The laser beam wave of the specified laser is 1064 nm, the power differs from 10 to 20 W as well as the frequency of the laser beam varies from 20 to 100 kHz. The laser can work in the working environment which is 15-35 °C. The humidity level should not extend 80%. As it seems the laser is quite flexible with its specification. The operating area of the laser is a square of 240 mm – parts this big can be laser engraved with a laser at the Company XXX [21].

The programing and adjusting the laser beam and operate the program is user friendly. The screen in Figure represents the marking surface corresponding to the laser machine. This will permit the user to add any data wished to execute in marking. The graphic zone display the marking surface for the marking head. Linear or circular texts and logos can be marked in an accurate way. The view of the zone is the exact representation of the marking as it is executed [22].

2.3 PROBLEM DESCRIPTION

Different operation to produce FOT-B and FOT-C are linked together, which creates a thorough process flow. The correlation of scrap is found due to unstable processes within production. The scrap type of FOT-C and a relationship with FOT-B is the fundamentals of the analysis.

Quite big scrap rates appear after chrome-plating and laser engraving operations, which have caused financial loses to the Company. The values are considered as highly reliable as given by the Company XXX, which have been following the serial production of the year 2016. Table 2.1 below provides the scrap values within different products for period of 1 year. More thorough information can be found in Appendix 2 - Scrap.

Table 2.1 Scrap rates for all versions of FOT in 2016

P/N	OK [pcs]	NOK [pcs]	TOTAL [pcs]	Scrap [%]
FOT-A	52.690	590	53.280	1,1
FOT-B	46.410	4.580	50.990	9,0
FOT-C	8.760	2.652	11.412	23,2

Scrap data provided by the Company XXX is divided per product. Due to this, differences can be analysed. Easy to conclude that scrap rate percentage is too high for the serial production and ended up in quite huge financial loss in 2016 – Appendix 2 - Scrap. However, there is no exact data of what type of scrap were the most common etc. Therefore, rough assumptions will be made further. Company's know-how within injection moulding field can be easily reflected through the number of scrap percentage in the FOT-A product. High numbers of scrap percentage appear for FOT-B and FOT-C products. The focus area for this master thesis is the FOT-C products due to its highest percentage and process linkage.

Laser engraving related scrap usually appear within the engraved surface of the part. The biggest issue with FOT-C product is that the engraved surface is not smooth, it has cracks on the marking as well as the rough surface around the marking. FOT-C most common scrap is shown in Figure 2.5 and Figure 2.6 below.

Figure 2.5 Laser engraving crack scrap on FOT-C

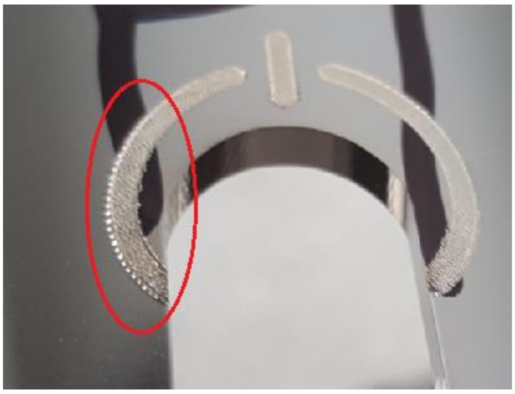

Figure 2.6 Laser engraving rough surface scrap on FOT-C

The scrap appears on parts with no certain stability or trend. The scrap is not batched up. The laser equipment settings are constant; therefore, it can be assumed that laser work is stable. The operator related failures on part positioning is minimised to minimum as fixture is used – Figure 2.7

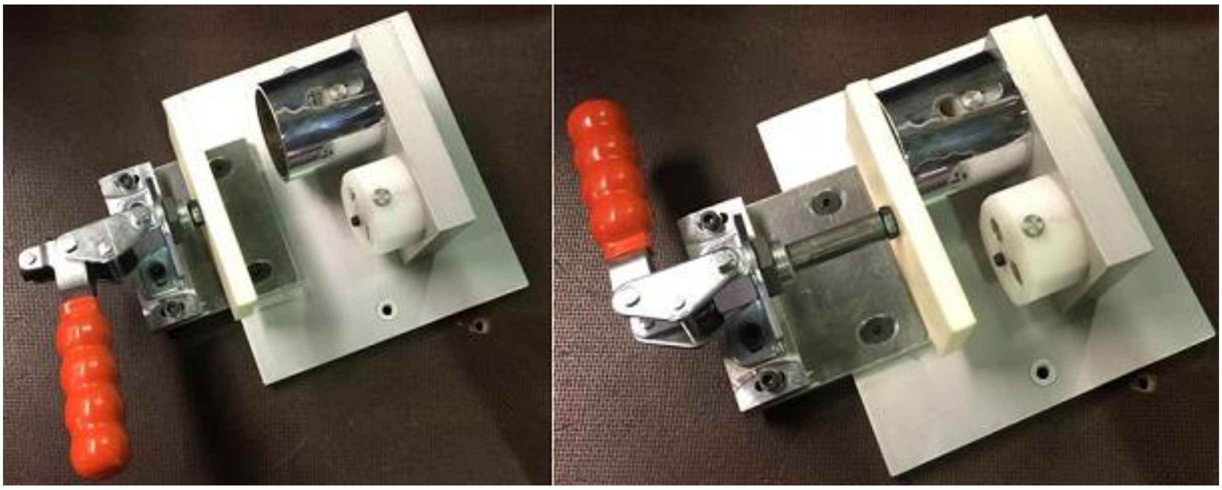

Figure 2.7 Laser engraving fixture

Fixture is designed and produce to minimise the risk of placing the part not accurate: having different angle etc., which could cause having laser parameters not according to the needs.

All in all, the quality of laser engraving does differ on FOT-B parts that are from the same racking bar or batch, which is the relation between two different operations. There is an instability in quality of laser engraving when laser parameters and part positioning does remain the same every single cycle, however, parts from the same chroming batch tend to vary between good marking and marking with described scrap. An assumption for the master thesis is that layer thickness of different metals after chroming varies, which affects the quality of laser engraving. Since chroming process is standard for the whole processing bar: standard timing, bath chemical concentration and temperatures, the handling and racking position differs from part to part.

In conclusions, the report will concentrate on analysis of how the metallisation layer thickness differs from part to part on the same chroming bar depending on their position. As well as, how does these thicknesses affect the laser engraving – whether there are tendency of scrap appearance depending on layer thickness of certain metal. In addition, parts usually placed on racks with no assumptions direction-wise therefore the effect of the direction is checked. Operations itself are considered as standard and professional within the Company XXX therefore will not be investigated further, as this would require different engineering knowledge and timing.

3 EXPERIMENTAL PART

Main analysis will be done to investigate the distribution of chemical materials through one batch or chroming bar and how will this affect other operation – marking with laser engraving. After scrap review the process instability is seen therefore this will be analysed further.

Further this should conclude whether the chroming layer thickness differ on parts from the same bar, what is difference and how does it affect the laser engraving quality. Positioning will also be a key finding – whether there is a difference for quality of laser engraving on how to hang parts on the rack.

3.1 SET-UP AND PART RACKING

One chroming bar of the FOT-B was chosen to be analysed for this thesis, which is 140 pcs in total. Parts FOT-A are not analysed as it is according to specifications: it was produced according all internal standards and procedures. ABS material humidity was as needed, dimensions were followed and approved, and surface was approved during serial production. Random parts were selected meaning that no cavities were considered. The tool of FOT has 4 cavities, which may vary dimension and weight wise, however, the key within analysis is the difference from part to part during the operation change.

FOT-A parts were marked by cutting in the number on the part: this is done to indicate and follow the parts on the chroming bar. To follow the change every part was weighted and measured with calibrated and certificated equipment. Calibration certificate for calliper Appendix 3 – Calibration 0478, certificate for scales Appendix 4 – Calibration Scales. Part height was chosen as a measure to follow throughout the analysis since this measure is convenient to measure. As injection moulding process is quite stable as well as the height is tool bound dimension – random place for height measure was selected. FOT-A were measured through a split line of the mould with the calliper 0478 shown in Figure 3.1. Dimension 52,5 ± 0,1 mm was measured. The way of measuring shown in Figure 3.2

Figure 3.1 Calliper

Figure 3.2 Height measure

The way of measuring is followed on FOT-A and FOT-B after the chroming process. Therefore, all parts were measured identical by one operator to minimize the risk of instability. The results of weight and height were stable and within the specified tolerances Appendix 7 – Measurements and Analysis.

The bar of 140 pcs has several racks on both sides, which allows to hand 70 pcs of parts per side Figure 3.3. Racks do align one to another in a step way to be able to fit more FOT parts on the bar and make a process more productive.

Figure 3.3 Chroming bar with racks

The rack has a 4 contact legs that touches the part to keep a good current within the procedure Figure 3.4. Four contact legs are used due to process stability, meaning that the current is divided equally as well as stability of the part.

Figure 3.4 Rack part contacts

Parts were hanged on the racks along the bar in a sequence: started with part 1 and ended up with part 140. The bar has racks on it that allows to hand parts on both sides – 70 pcs per side. To see whether there is a difference in positioning the part itself, parts were hanged identically. Parts from 1 to 70 were hanged in one side – the hole on the part hanging outside the bar Figure 3.5, while the parts from 71 to 140 were hanged in the other side of the bar – the hole on the part hanging inside the bar Figure 3.6.

Figure 3.5 Parts 1-70 (hole outside)

Figure 3.6 Parts 71-140 (hole inside)

If to simplify the hanging positions of the FOT in the sequence it can be seen as a grid view. As mentioned before rack goes in steps making the parts to overlap in every line. The simplified view of sequence and positioning of the parts are shown in Table 3.1 below. The other side is identical, but starting from part 71 instead of part 1

Table 3.1 Positioning of parts on the chroming bar

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		53		54		55		56		57		58		59		60
61		62		63		64		65		66		67		68		69		70	

All the parts were hanged by one operator in the same way trying to keep the racking legs in a good contact with the part Figure 3.7. Therefore, process variation in terms of operator is minimised. Standard chroming operation have been performed throughout the re-search.

Figure 3.7 Close look to positioning

Measuring system analysis (MSA) was done to check how suitable is the measuring equipment is by quantifying its accuracy. It does determine the amount of variation within results of measure by the measuring equipment use to perform the action. In this thesis, it is done to analyse whether the results of the height measure before and after the chroming operation is valid to be used for further conclusions. This is an objective method to assess the validity of the calliper used for this analysis to minimize the factor of process variation through actual measuring variation itself [24].

Three operators measured same numbered parts – 10 pcs. In this case the height was measured at the same position where the dimension is used for analysis – dimension 52,5 mm. One part was faulted to see whether the measuring method can find the failure. Same parts were measured 3 times by each operator. Part measure results of the MSA can be find Appendix 5 – MSA Measure while the thorough results in Appendix 6 – MSA Results specifies the accuracy of the measuring technique used for part height analysis. Figure 3.8 simplifies the results by showing the consistency within repeatability of measure results for different operators and concludes the results percentage wise.

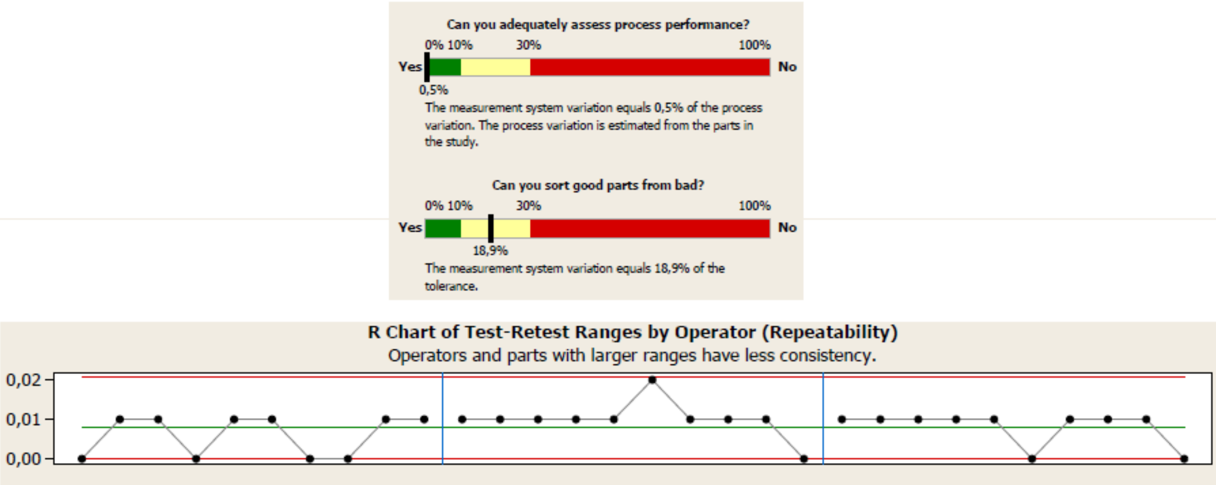

Figure 3.1 MSA for height results

It can be overviewed that there is lack of consistency in repeatability of results especially within Operator 1 and 3. Operator 2 have been consistent within his results. A variation has a range of 0,01 mm as maximum in cases of measure 4 or measure 6. All in all, simplified conclusions are provided showing that this measuring technique can assess process performance, however, it could be improved in relation to sorting good parts from bad parts. Yet this appear because FOT-A nominal measured value is close to the minimal tolerance edge and having variation may cause not finding the scrap part. Summing up in this case of the analysis measuring technique selected can provide trustful results as repeatability of measure is only 16,12% of the tolerance range. Considering the minimum and maximum values of height change after chroming process it does withstand the accuracy.

3.2 RESULTS FOR STABILITY

Both parts FOT-A and FOT-B were measured in the same matter using the same devices, therefore some process stability analysis can be done in to find out the stability of the processes. Thorough dimensional results for every part can be found in Appendix 7 – Measurements and Analysis. Parts divided into two groups: 1-70 and 71-140, to follow the results of the chroming bar. Therefore, FOT-A parts should not have any difference between these two groups. It is important to mention that parts have been taken randomly therefore the process stability is not as accurate as it should. However, the difference between FOT-A and FOT-B is valid.

The mean and minimal as well as maximal values are the key within this analysis, as it gives the best overview of the process change and variation. Results for both FOT-A and FOT-B are shown accordingly in Table 3.2 and Table 3.3.

Table 3.2 FOT-A overall values

	Weight average	Height average	Weight MIN	Weight MAX	Height MIN	Height MAX
Part 1-70	19,24	52,44	19,17	19,35	52,40	52,48
Part 71-140	19,24	52,44	19,17	19,34	52,40	52,48

Table 3.3 FOT-B overall values

	Weight average	Height average	Weight MIN	Weight MAX	Height MIN	Height MAX
Part 1-70	21,75	52,52	21,00	22,61	52,49	52,58
Part 71-140	21,87	52,53	21,17	22,79	52,50	52,60

Looking at both tables gives an overview of the overall values for parts before and after chrome-plating. There is no difference of FOT-A parts if taking two groups into account. The difference appears in FOT-B where it seems that the group of parts 71-140 is bigger and heavier than parts in the first group. There is no variation between the groups which can conclude that the positioning on the rack does have an influence on the processing of the parts. This can be easily seen in table where the differences between minimal and maximal values between two sub-groups are considered. There is not variation, as it should, in the FOT-A parts, where difference between sub-groups of FOT-B is significant. Sub-group of parts placed with the hole inside is bigger – these can be found in Table 3.4.

Table 3.4 Differences between part groups

	Difference of weight average	Difference of height average	Difference of weight MIN	Difference of weight MAX	Difference of height MIN	Difference of height MAX
FOT-A	0,01	0,00	0,00	0,01	0,00	0,00
FOT-B	0,12	0,007	0,17	0,18	0,01	0,02

Differences between sub-groups are important, especially in the case of FOT-B, since it is necessary to see the process change concerning the positioning of the part. However, the amplitude of the diversity between minimal and maximal value between parts are the key to process stability in this case. These differences are specified in Table 3.5.

Table 3.5 Differences between minimal and maximal values

Parts and Subgroups	Difference of weight MIN-MAX [gram]	Difference of height MIN-MAX [mm]
FOT-A (1-70)	0,18	0,08
FOT-A (71-140)	0,17	0,08
FOT-B (1-70)	1,61	0,09
FOT-B (71-140)	1,62	0,10

What can be concluded from a table is that the difference between minimal and maximal values for FOT-A and FOT-B are similar in height perspective, where it differs a lot in weight perspective. It can be seen that the amplitude between minimal and maximal weight value of the injection moulded part is low – 0,18 grams, considering different cavities are measured. Where the difference between chrome-plated parts grows by 9 times in size. The amplitude between FOT-B parts are stable within sub-groups, but is quite high which could conclude that the process stability in terms of amount of chemicals on the part may vary depending on position of the bar.

Difference in height remains close to the same, which can also be influenced by the measuring technique. However, it must be analysed in a way of the change variation and not the parts itself

FOT parts were chrome-plated according to the standard parameters as it is used for serial production. The overall result was that 4 parts were not chrome-plated due to a bad contact with the rack: 3 parts (1; 75; 136) were not chrome-plated; 1 part was missing (140). It might have appeared due to hanging failure – handling operator failure. However, all the parts without exception were measured again in the same way as mentioned in previous sub-chapter. Full results can be found in Appendix 7 – Measurements and Analysis. Overall change results are shown in Table 3.6 below.

Table 3.6 Main characteristics of a change

Part / Characteristics	**Weight average**	**Height average**	**Weight MIN**	**Weight MAX**	**Height MIN**	**Height MAX**
Part 1-70	2,52	0,087	1,81	3,42	0,03	0,15
Part 71-140	2,62	0,098	1,85	3,57	0,05	0,18

Main characteristics of the changes are presented. Weight average is the average change of the weight of the FOT that occurred taking all the parts into account. The average weight change is higher on the parts that were positioned with the hole inside the bar. Weight changes 2,5-2,6 grams on average, meaning that much of additional chemicals are added on the part after chrome-plating operation.

Height average is the average change in height from initial FOT-A sample to FOT-B sample. 0,08-0,1 mm on average is the growth of the material on top of the FOT surface. Parts that did change more in weight were higher accordingly.

MIN and MAX values are also presented in the table which represents the minimum and maximum changes that occurred on parts after the chrome-plating process. Part height have become bigger by 0,18 mm maximally, which is close to the tolerance width given on the customer drawing specification. However, if to consider difference between minimal and maximum values it can be concluded that the tolerance width and variation of the chrome-plating is wide.

For a better overview of the stability of both processes the capability studies were done to get a broader picture. All 140pcs of parts were taken randomly out of the injection moulding batch, meaning that no attention paid to which cavity is taken. The tool used to produce FOT has 4 cavities – instability within cavities might appear as they are mechanically produced one by one and it is never identical due to instability of mould producing process. Therefore, it is not accurate to keep track on height – part weight has been followed, which varies less throughout different cavities due to stable shot weight per process cycle. Since every single part was measured before and after the chrome-plating it is possible to check the stability of these both processes in terms of weight change fluctuation. The process capability studies are commonly used within Sig Sixma quality methodology as statistical measurements. The Cpk refers to process capability where the Cpk number is an index which basically measured how close the process is to the specification limits by considering the normal variability of the process. There are certain Cpk values that is preferred to be followed per customer standards. No certain Cpk value is required by the customer in the master thesis case therefore the higher is the value the less likely is that the item would be out of tolerance range within the process [23].

Parts have been weighted before and after the chrome-plating process to follow the process – more thorough results for both weight and height are presented in Appendix 8 – CPK Analysis. The weight tolerances have been selected randomly: 1 gram of tolerance for injection moulding process and 2 grams of weight tolerance for chrome-plating process.

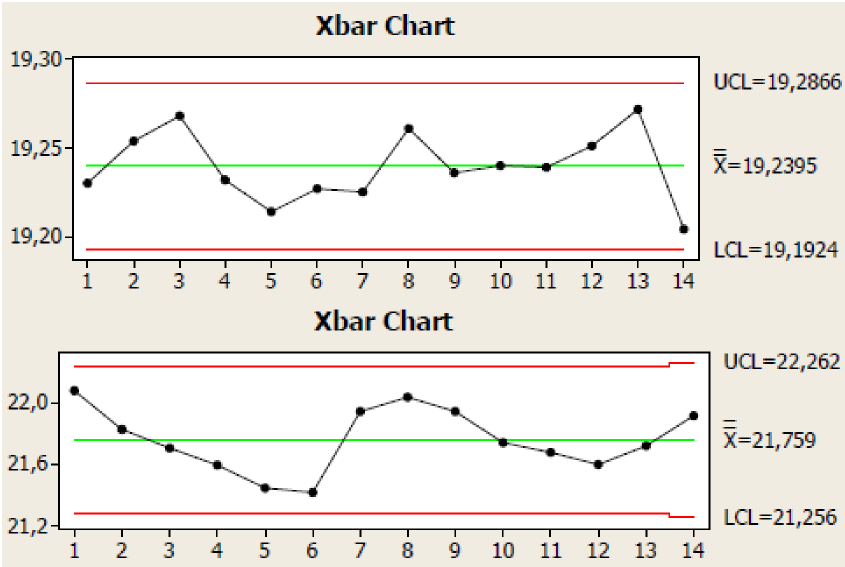

Figure 3.8 Sample mean results of capability check 1- Injection Moulding; 2- Chrome-plating

If Figure 3.8 with two Xbar charts should be evaluated the average results of the part itself gone up after the chrome-plating process, which is normal. However, the difference between upper and lower value amplitude have increased by 10 times, which shows that the process variation field is broader after the chrome-plating operation.

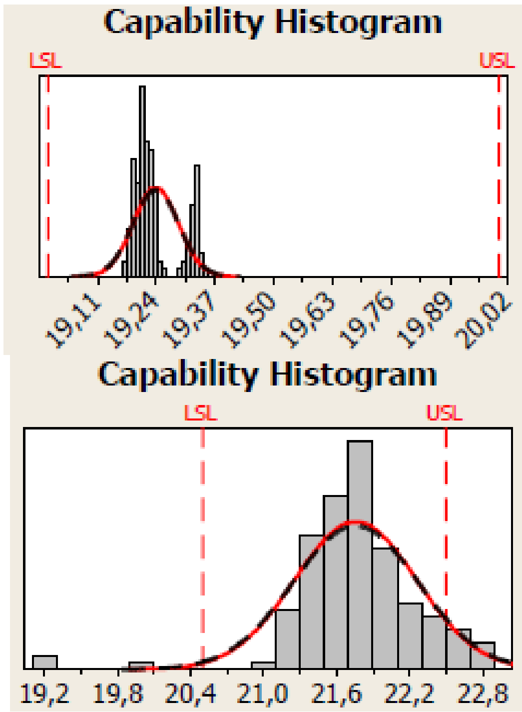

Figure 3.9 Capability Histogram 1- Injection Moulding; 2- Chrome-plating

If capability histograms to be compared Figure 3.9 the distribution of the injection moulded weight is more stable that is concentrated at the lower end of the tolerance. The spread narrow and no risk seen for parts to be out of tolerance range. When chrome-plated parts are considered the spread of the values is broad and some values are out of specification limits.

Within	
StDev	0,04970
Cp	3,35
Cpk	1,61
PPM	0,72

Within	
StDev	0,5029
Cp	0,66
Cpk	0,49
PPM	76403,13

Figure 3.10 The overall Cpk values for weight Left – Injection moulding; Right – Chrome-plating

All in all, the process capability or the process stability of weight is more accurate within injection moulding process as the parts are within the tolerance range distributed in a narrow section. The distribution of chrome-plated samples' weight is spread out throughout and out the tolerance range. Injection moulding operation in this case has more stability – Figure 3.10.

3.3 PROCESS VARIATION VISUALISATION

Measuring results show differences and process variation. It does show that parts fluctuate within the same batch in terms of dimensional height and weight. The visualisation of the part change on the part will help to determine whether there is any tendency on the positioning of the part with the results of the fluctuation. In Figures 3.11 and 3.12 below process variation findings are visualised: first and second sub-groups accordingly.

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		53		54		55		56		57		58		59		60
61		62		63		64		65		66		67		68		69		70	

Figure 3.11 Parts 1-70 (hole outside)

	71		72		73		74		75		76		77		78		79		80
81		82		83		84		85		86		87		88		89		90	
	91		92		93		94		95		96		97		98		99		100
101		102		103		104		105		106		107		108		109		110	
	111		112		113		114		115		116		117		118		119		120
121		122		123		124		125		126		127		128		129		130	
	131		132		133		134		135		136		137		138		139		140

Figure 3.12 Parts 71-140 (hole inside)

Squares with part number is coloured in group depending on the change it had from stage of FOT-A until FOT-B. The indications are explained in Table 3.4 below. All squares that are not coloured refers to results in between – considered as normal for chrome-plating process.

Table 3.4 Meanings of visualisation of variation in chroming bar

Identification	Explained meaning
1	Only red coloured parts are parts that were not successfully chromed - scraped. Including 1; 75; 136
2	Over 3 grams of weight change from initial part
3	Under 2,30 grams of weight change from initial part
4	Over or equal to 0,14mm in change of height
5	Under or equal to 0,05mm in change of height (0,06mm for second bar since it did fluctuate more)
6	Over 3 grams of weight change and Over 0,14mm in change of height
7	Under 2,30 grams of weight change and Under 0,05mm in change of height
Bolded margins	There are 10 pcs of bolded margins – selected for laser engraving test as most critical parts

The obvious visual tendency can be seen within two analysed bars Figure 3.11-3.12. If to analyse first sub-group of parts it can be concluded that a top layer is heavier, which show that more metals would appear on parts after the chrome-plating operation. Both sub-groups tend to have heavier and higher parts within the frame of the bar, while all with a smaller change in size tend to group in the centre of the bar.

Parts in bolded squares were selected for further analysis. 10 pcs – 5 pcs from each sub-group were selected to check the layer thickness within the area of laser engraving. Different type of parts was chosen to have different results. Parts chosen are listed in Table 3.5

Table 3.5 Parts chosen for metal thickness and laser engraving analysis

Sub-group 1-70	Sub-group 71-140
4 – over 3 grams / over 0,14 mm	80 - over 3 grams / over 0,14 mm
21 – over 0,14 mm	90 - over 3 grams / over 0,14 mm
36 – under 2,30 grams / under 0,05 mm	119 - under 2,30 grams / under 0,06 mm
45 – under 0,05 mm	124 - under 2,30 grams / under 0,06 mm
61 – over 3 grams / over 0,14 mm	138 - over 3 grams / over 0,14 mm

3.4 METALLISATION THICKNESS

As the variation through different racking position is noticed in process variation visualisation, ten most critical parts have been chosen to be measured for different layer thicknesses of the coating. Ten parts from both subgroups, five each, have been selected. Coating thickness including: chrome layer, nickel layer and copper layer is measured for parts chosen. Two sub-groups are chosen due to different positioning on the rack part-wise. The layer thickness is measured in one point, this point is within the area of laser engraving position shown in Figure 3.13

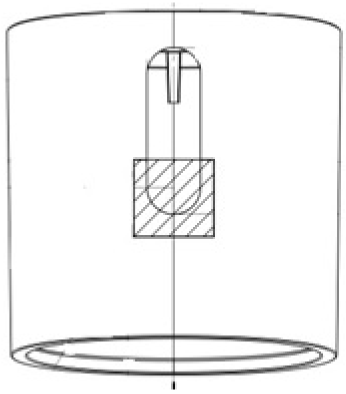

Figure 3.13 Area of measured layer thickness

Results are presented in table below. Original test results generated by Fischerscope XRAY XDL 220 can be reviewed in Appendix 9 – Coating Thickness Results.

Table 3.6 Thickness test results

Part	Chrome µm	Nickel µm	Copper µm
1 (36)	0,286	11,1	17,3
2 (45)	0,098	13,1	13,7
3 (61)	0,110	16,3	15,0
4 (21)	0,245	16,0	14,8
5 (4)	0,252	17,3	18,6
6 (138)	0,064	6,37	9,93
7 (124)	0,001	3,31	0,459
8 (119)	0,002	2,70	0,641
9 (80)	0,035	9,54	6,50
10 (90)	0,060	9,32	7,02

Coating thicknesses are presented in Table 3.6 and it do vary in an enormous amount from part to part with no accurate tendency. The marginal differences can be seen within some part groups.

Results can be compared with given average thickness standard for mild and moderate part requirements in Table 1.1 [16].

According to the standard results within the quality of parts are dependable on chromium thickness layer as well as nickel – these metals shall be thicker to provide a higher quality and gloss surface. The chromium should be within 0.125-0.25 μm, Nickel should be within 7-15 μm, while copper should be approximate 15 μm [16]. If chromium layer is considered only part numbers 1(61), 4(21) and 5(4) are within the required thickness layer, where the thickness layer of nickel is higher for two of these part numbers. Copper is within the range only for part number 4(21). Brief conclusion could be made that only one part out of ten is within the tolerance range of standard chrome-plating thickness layer results. Parts 6-10 have a thin layer of chromium, where layer thicknesses of nickel and copper are too low as well compared to a standard provided. Parts 1-5 are way closer to standard results, which could mean that a positioning of the part itself on the rack do have an influence on thickness layer.

The coating layer thickness was measured in one areal point only, which does not reflect the actual accurate layer thickness throughout the whole part. However, since this area is a main concern in this master thesis, a data is taken as valid. There is a tendency of difference within different parts. Meaning that there are differences between parts that were heavier and higher from the parts that were lighter and lower. To simplify the overview of an overall metal thickness within area a sum of all thicknesses added for a better judgement. Sorted total summed up coating thicknesses are specified in Table 3.7.

Table 3.7 Sorted total coating thicknesses

Part	**Chrome μm**	**Nickel μm**	**Copper μm**	**Total thickness μm**
5 (4)	0,252	17,3	18,6	36,15
3 (61)	0,11	16,3	15	31,41
4 (21)	0,245	16	14,8	31,05
1 (36)	0,286	11,1	17,3	28,69
2 (45)	0,098	13,1	13,7	26,90
10 (90)	0,06	9,32	7,02	16,40
6 (138)	0,064	6,37	9,93	16,36
9 (80)	0,035	9,54	6,5	16,08
7 (124)	0,001	3,31	0,459	3,77
8 (119)	0,002	2,7	0,641	3,34

From results in Table 3.7 it can be judged that parts from second sub-groups which were oriented with the marking surface inside the racking bar, is having a thinner layer of coating in that position. For instance, even though part 36 was lighter and lower than part 80 it still has thicker coating layer in the laser engraving area. However, the tendency of heavier and higher parts within the same sub-groups having thicker coating, remains.

3.5 EFFECT IN LASER ENGRAVING

Parts that were measured in layer thickness from two sub-groups were laser engraved according to the standard operation, which is used in serial production. Standard laser parameters were used. As the layer thickness of different parts chosen from process variation visualisation chart were measured, it is time to see how it affects the laser engraving process.

The test started from part 1(36) and ended with part 10 (90). The test run was done according to internal procedures as accurate as a serial production run. Same fixture was used as well as the same laser process parameters, to keep the parts in the same production environment as normal. Mounting motion on the laser engraving fixture shown in Figure 3.14 below.

Figure 3.14 Placing FOT-B on fixture: step 1; step 2

Seven parts out of ten were according to customer needs, meaning no differences from master samples appeared on laser engraved marking. Parts according to the standard from the test run is shown in Figure 3.15, all the results can be found in Appendix 10 – Laser Results.

Figure 3.15 Engraved parts according to the customer standard

Three parts out of ten were scrapped. None of the scrapped parts were cracked: two of them had rough surface around the marking, while one of the parts was having a slight crack. Since this was a full run test where all the items were accurately checked the third part is scraped. It might have not been during the serial production, as scrap is not too big. However, it is still appearing. The rough surface around appeared on parts 124 and 119, while the minor crack appeared on part 80. Results of all the parts can be found in Appendix 10 – Laser Results, while the scraped parts are shown in Figure 3.16.

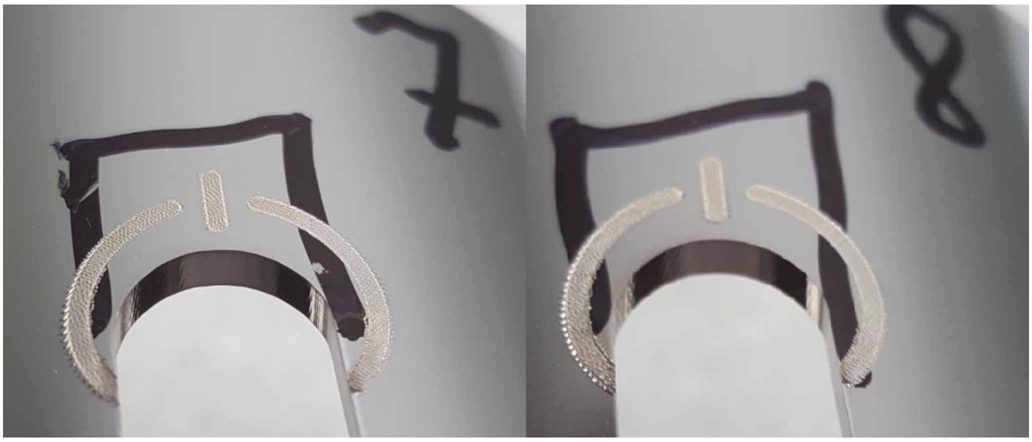

Figure 3.16 Engraved and scraped parts

According to the laser engraving results it can be seen that high scrap rate do appear on the second sub-group of the parts, meaning that the positioning of the part itself on the rack do have an influence. The scrap appeared on parts that had lower coating thickness on the laser engraving area. The scrap did appear on parts, which had the lowest coating thickness and the slight crack appeared on part 9(80), which were third from the bottom if to take total thickness into account. These three parts had the lowest chromium thickness of all the parts tested. As well as it had the lowest thicker of the copper layer throughout the parts.

All in all, it does seem that the laser engraving issue and scrap appears on parts which are not thick enough after the coating operation – the ABS plastic reacts to the heat of laser.

3.6 RE-SEARCH CONCLUSIONS

The re-search done went through every operational step of FOT production cycle to analyse the reason of scrap appearance at FOT-C – laser engraving stage. After the chrome-plating operation, the FOT versions split up to where some parts are sent straight to the customer, while the other sub-group is sent the laser engraving stage where the scrap occur. The process instability including layer thickness variation in chrome-plating operational stage was in question and analysed.

After various analysis, the conclusions summed up. These results are taken as valid since the measurement system analysis concluded that measuring equipment is applicable to measure the required values to give rigorous results. As parts were taken randomly excluding the cavity variation in injection moulding the variation in this operational stage increased. However, it is still not as high as variation of different results after the chrome-plating operation. The change in height and weight after the chrome-plating had no tendency and fluctuated in high scale. The amplitude between minimal and maximal values measured increased in 9 times after the coating was applied, which on other hand increased the process instability. The weight of the part increased by around 2,5 grams meaning that much of the coating material was added on the parts as a mean. The height of the parts increased by roughly 0,1 mm, which is the tolerance range given by the customer. The process capability results showed that chrome-plating process is unstable if the weight is a concern.

The racking visualisation section helped to see the tendency of the process variation that appeared throughout the analysis. It is clearly visible that the current is not divided equally throughout the chroming bar, which influences the process variation [16]. Parts do get a thicker coating layer around the process bar: including the top and bottom layers as well as the sides. All the thinner and lighter parts do appear in the chroming bar centre. As the process variation appears on part dimensional change including weight and height it does appear in coating layer thickness. The layer thickness differs 10 times from the thickest to the thinnest which is close to the difference of an amplitude of the values measured between minimal and maximal. The analysis of two sub-groups did gave a result as well, which showed that positioning of the part itself does matter as the thicker material layer appear on the parts that do look outside, meaning that the layer thickness is spreading through the part but the thicker side is farther.

As there is such a big variation in all the measures mentioned above there is a variation in the laser engraving. The tendency of overviewed scrap appears on parts that has thinner layer thickness. This could mean that the ABS plastic itself starts to react to the laser beam heat and frequency generated.

To sum up, there is a big variation of process and the chrome-plating surface quality does depend on the positioning of the part on the processing bar, as well as it depends on how the part is positioned itself. This however affects how the layer thickness of different coating materials are spread out on the part, which finally affects the laser marking quality. These three variables are linked to each other and has an influence on the final quality of FOT-C product.

4 IMPLEMENTATION / SUGGESTION

4.1 OBJECTIVES AND SUGGESTIONS

Re-search conclusions have shown that a big process fluctuation appear in chrome-plating operation. Main issue that process variation through the processing bar influences the coating thickness on parts included in the same batch. In addition, the positioning of the part itself does influence the coating layer around the pat. These variable are linked together, which causes bad product FOT-C quality after laser engraving operation, since thin coating layer thickness influences the burns around the marking, as well as cracking.

The main objective of the master thesis is to reduce the scrap rate by 30% for FOT-C product without investment into an expensive equipment, therefore recommendations made should reflect on it. Results of the re-search made to see the process fluctuation within the same processing bar including the visualisation of the changes on the bar is vital within the master thesis. The conclusions made is crucial for the suggested improvements and scenarios, therefore main findings of the re-search is listed below:

1. The difference between minimal and maximal values – process amplitude, within chrome-plated parts are 9-10 times its size. Including minimal and maximal weight, height and coating thickness, while it is close to zero within injection moulded parts.
2. Thicker, higher and heavier parts appear around the processing bar, while parts in the centre of the processing bar tends to change less. This is clearly seen in process variation visualisation Figure 3.11-3.12.
3. The orientation of the part itself does matter as coating thickness tend to be smaller in the side of the part, which is oriented inside of the processing bar.
4. Parts with a thinner coating layer does tend to have scrap in the laser engraving operation, which might be due to high laser beam temperature and ABS plastic reaction.

These main findings do help to come up with solutions to maintain the lower scrap level within the process at Company XXX. Several scenarios are highlighted and explained below, which could be helpful for the Company.

Scenario 1

The most logical solution would require re-design racking system, which would lead to utilizing and centralising the current throughout the whole bar. Additionally, the maintenance of the racking systems needs to be updated and checked.

The racking system used within the Company is produced using aluminium alloy which is lighter and can be thinner. However, the insufficient cross sectional area have caused less than anticipated current delivered to parts as well as some burn off of the thin electro less deposit, which is due to heat up build. Burning and blistering is seen on the racking system used within the Company, which also causes skip of the plating. All in all, the re-design using copper alloy may be thoughtful since it has almost double of conductivity values than aluminium [16]. Other solutions to increase the level of stability throughout the racking system might be considered such as current shielding, which is a way to reduce plate build-up on high current density areas. Non-conductive member is placed closed to the part next to the shortest path, to increase the length of the path current must travel to get to the part. If these are divided in the right way – the current might be even out [16]. As an alternative for current shielding the auxiliary anodes are used. However, it is mostly used when the part design is complicated and it is impossible to obtain the desired thickness in the recessed area. It is placed next to the recessed area and works as a secondary anode, which completes the recessed area additionally after the min power source is applied [16].

All in all, these solutions would require either rebuild the racking system, or do as many test runs and calculations, as it will start working. Since the Company XXX is not willing to invest this year this solution is not applicable in this case and at this current moment. Additionally, this would require further investigation on what are the cause and distribution of current throughout the processing bar.

Scenario 2

As there are two final parts FOT-B and FOT-C, which reaches the customer the process variation can be handled to avoid the high scrap rate in the laser engraving department. Due to analysis done and main findings reached the scrap could be avoided by sorting. The process flow needs to be reviewed and some administration work is needed to implement this change into production. The process flow would add a sorting of parts after the chrome-plating operation where according to process variation visualisation done Figure 3.11-3.12 and results retrieved the parts would be packed into separated boxes. This would create a flow where only parts with thicker coating layer would proceed to the laser engraving department, the other parts would be sent directly to the customer. A simplified process flow current and suggested shown in Figure 4.1 below. It helps to understand the idea behind the suggested scenario.

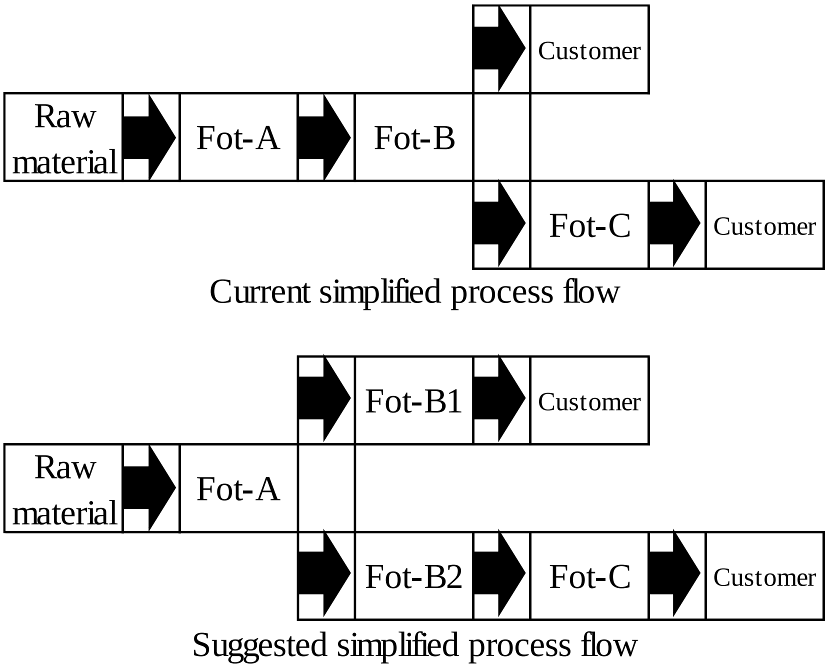

Figure 4.1 Simplified process flow of suggested scenario 2

The suggested process flow will not disturb the normal process flow of the handling and packing operations. The packing is done manually even so therefore no additional disturbance should occur within the packing. There will be more handling of the boxes, more inventory space etc. However, the part is not considered as high runner so the implementation should not create inconveniences within the normal operations.

Scenario 3

Scenario 3 suggested is similar to scenario 2 described above. The improvement would include additional sorting. The Company is producing different parts that are known as knobs or FOTs', which are very similar in design. Due to similarity same processing racks are used within productions. Only the described FOT continues to laser engraving department, as other similar parts would be sent directly to the customer, or would continue to assembly department. The scenario would suggest to mix the parts on the same processing bar, meaning that according to process variation visualisation table the parts would be mixed and stacked accordingly. This would however increase the risk of mixing the parts together. Additionally, it would be harder to make a production plans.

General Observations

As the re-search showed the positioning of the part on the processing rack has an influence on the thickness level in certain areas it needs to be controlled. The work instruction, which is used within production needs to be updated accordingly. This should be done to make sure that FOT-B parts are hanged only in certain position direction-wise, which would mean that it must be hanged with the laser engraving surface outside the rack. As the re-search showed this location would have a thicker thickness layer of the coating. In addition to this the maintenance of the processing rack system needs to be done more often in order to avoid current leaks. The maintenance needed more often to make sure that contacts are cleaned and ready to be used for serial production.

Several scenarios have been suggested and overviewed for the Company XXX to go and implement. There are several advantages and disadvantages within each scenario.

Scenario 1 is the best solution engineering-wise that would be oriented towards the root cause of the problem. This would lead to re-design of the whole processing bar, additional analysis and investigation to prepare the best balanced racks however, this would require a large investment. The whole new racks would need to be produced and adjusted. Since the Company is not willing to invest into the re-designing of racks and additional analysis it could not be implemented at the current moment.

The second and third scenarios are similar, which would lead to additional handling for the production site. This would not solve the issue entirely, however, this could lead to decreasing of the scrap rate at the current moment. At this point scenario 2 is better as it does not increase the risk of mixing the goods throughout the process, as well as, the planning department would not be overloaded to mix the production plans. Especially, since the production plans can be forecasted as different moment, which would increase the size of the inventory radically.

Scenario 2 is most convenient in this case as the investment would be low and internal, while the part cost price would not increase as much. The second scenario would be implemented to check the progress. Comments within general observations should also be implemented within production, as it would increase the process stability with no investment.

4.2 IMPLEMENTATION

Scenario 2 to be implemented and tried within production to check the results within the idea of reducing the scrap level in the laser engraving department for FOT-C without investments made at the Company XXX. Scenario 2 refer to the Figure 4.1 that explains the idea behind and the process flow that is implemented.

The goal is to reduce the scrap rate for the FOT-C product at the end by implementing handling operation. FOT-B is split to FOT-B1 and FOT-B2 where FOT-B1 is going directly to the customer, and FOT-B1 is separated and sent to laser engraving department. Data from process variation visualisation table is used for selection of certain parts. Handling operation separating two different FOT-B part numbers is handled in the production area by the same operator. The investment behind the idea is the internal administration work to arrange information needed for the serial production. The production run of two processing bars – 280 pcs overviewed for the conclusions. Results from year 2016 is used as valid data for calculations.

As the Company XXX is focused towards no investments for the production the investment selected is the use of the internal administrative resources. The investment needed is divided into several operations that is performed within the specified timing frame:

1. The creation of additional part numbers and the ERP system setup – 2 hours
2. Preparation of work instructions needed – 6 hours
3. The mentoring and informing production, all three shifts – 8 hours
4. Additional timing for planning and logistics department, however, this is added to the cost price of the part.

An overall investment for implementation of this scenario were 16 working hours of the person in charge administration-wise. If this to be expressed to monetary value: the assumption is that the person in charge cost 1726 €/month for a Company. Working hours per month are 168 hours on average. Simple calculations done in Equation 4.1-4.2.

$$Cost\ per\ hour = 1726\ € \div 168\ hours = 10{,}27\ €$$

Equation 4.1 Administration cost per hour

$$Investment = 10{,}27\ € \times 16\ hours = 164{,}38\ €$$

Equation 4.2 Investment needed

The quantity of parts applicable for laser engraving are assumed according to the experimental re-search done and process variation visualisation Figure 3.11-3.12. However, parts used for laser engraving shall be separated according to the customer needs, in order not to keep to many parts on stock. The annual need or the annually produced amount in 2016 for FOT-B was 50,990 pcs, while the need for FOT-C was 11,412 pcs. This equals to a 4,46 times less need for FOT-C. It is assumed that this trend would be followed in 2018 too. If to keep the need in account $1/4^{th}$ of the processing bar must be kept as FOT-B2 or parts that will be further processed. This would sum-up to 35 pieces per processing bar. If to take the processing variation visualisation table as the reference, it would be suggestable to pick-up parts for further processing from the frame of the whole processing bar Figure 4.2.

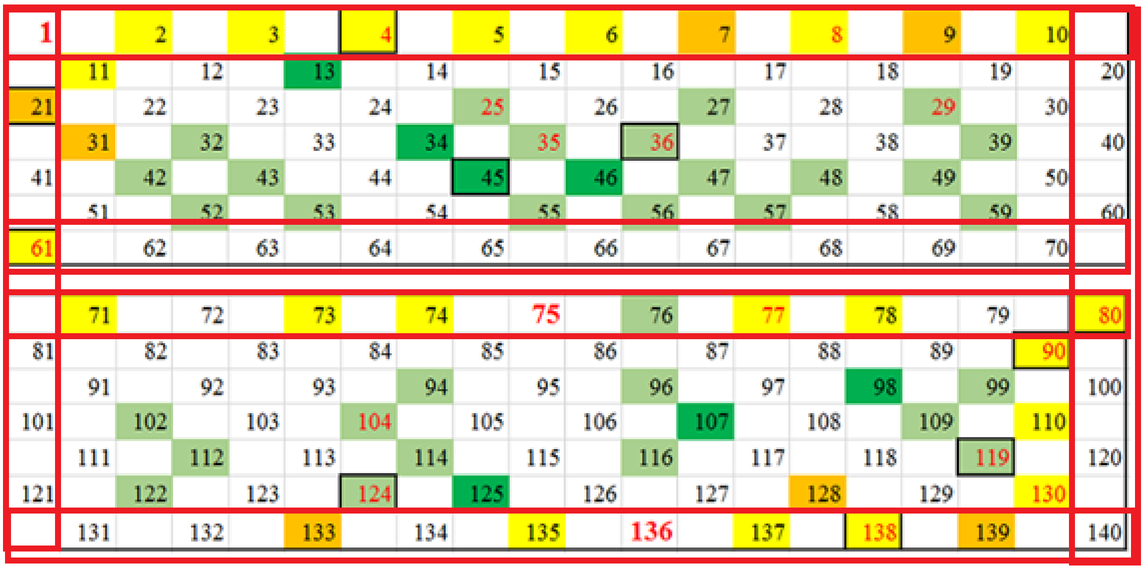

Figure 4.1 Suggested areas for FOT-B2 to be picked

The areas marked in red are the most convenient material to be continued as FOT-C in the further stage. As 35 pieces is the need from the processing bar the areas selected are: 1-10; 61-70; 71-80; as well as sides 21-61; 20-60 ending up with 36 pieces selected throughout the processing rack. The figure specifies that there are more selectable parts from one processing bar – including the second line 11-20 and 81-90, if the ramp up of the stock would be needed. Totally 60 to 70 pcs are suitable for further processing if there is a demand, which is convenient as the processing bar can be split up by half. This should be noted into the work instruction and explained to employees involved, otherwise too much handling and overproduction could occur. On the other hand the production would be flexible in a way of the need, however, the planning need to know that 70 pcs is the maximum that can be produced of FOT-B2 from one processing bar.

The handling operation is the main influencer in this case, however, since it is an operator based operation and every part must be placed to the box the operation time is not increased by margins. FOT-B2 parts would be taken-off first to the separate box including separate labels, secondly the FOT-B1 parts follow, in order not to mix. Two boxes needs to be packed instead of one, meaning that 30sec packing-wise is increased. Additionally, the handling time have gone up for approximately 80sec from 420sec for one processing bar, to 500sec for the processing bar. The operator cost for the Company XXX is around 622,38 €. Operator' cost per hour are referred in Equation 4.3.

$$Cost\ per\ hour = 622{,}38\ € \div 168\ days = 3{,}70\ €$$

Equation 4.3 Operator cost per hour

Having all the inputs the output is found – the cost price amount per part to be increased affecting the decrease of the margin for the Company XXX. Calculations below in Equation 4.4-4.5.

$$Operational\ time\ increase\ per\ part = (500\ \text{sec} - 420\text{sec} + 30sec) \div 140\ parts = 0{,}78\ sec$$

Equation 4.4 Operational time increase per part

$$Price\ increase\ per\ part = \frac{3{,}70\ €}{3600\ sec} \times 0{,}78sec = 0{,}0009\ €$$

Equation 4.5 Price increase per part

To sum up the calculations it can be concluded that the price increase is really minor, adding a percentage needed for the planning department, warehouse and other related activities the price increase can be rounded up to 0,01 € per part. Taking the product cost from Appendix 2 - Scrap the final cost price of the FOT-B2 would be 0,45 €/pcs, while the price for FOT-C would be 0,777 €/pcs.

Test production for scenario 2 for two processing racks performed for the timing valuation as well as the end results for FOT-C. The full run test production performed as a regular no ramp-up production therefore 38pcs from processing bar packed separately as FOT-B2 samples: grouped 1-10; 61-70; 71-80; as well as sides 21-61; 20-60 – 76 pcs in total. These samples processed in laser engraving department emerging 6pcs of scrap – or 7,8%.

Projecting that forecasted annual demand for FOT-C in 2018 is 12,000pcs the money perspective calculations can be made. Scrap rates for both scenarios in quantity and value in Table 4.1. The Company save 1408 € annually by the implementation of scenario 2.

Table 4.1 Scrap quantity and value current and projected

	PCS	Value
Current scrap 23,2%	2784,0	2.135,33 €
Scenario 2 scrap 7,8%	936,0	727,27 €

By implementing scenario 2 into the production the decrease of scrap for FOT-C is vital – decreased close to 3 times. If the investment must be taken into account, the cost could be added to the scrap value as negative, which would give 891,65 € to sum up with. However, the investment payback time can be calculated dividing the scrap into even values throughout the year – Table 4.2.

Table 4.2 Daily scrap difference current vs scenario 2

Work days annual	252	Scrap daily
Current annual scrap	2.135,33 €	8,47 €
Scenario 2 annual scrap	727,27 €	2,89 €
Difference		5,59 €

There are 252 work days annually on average. The current and scenario 2 annual scrap values are divided by days, to find out daily scrap value in both cases. From this perspective the difference or saving up can be seen if the scenario 2 is implemented within the production. The investment payback period can be calculated in days, by dividing the investment by the difference of the scrap value, which is in this case – 29 days.

Summing up the implementation of the scenario 2 the results are positive for the Company XXX. As the investment is low and internal the scenario is suitable for the Company to implement. Additionally, the results are seen shortly. The significant decrease of the scrap rate is seen after implementation, as well as the cost price of the part does not increase that much, due to the fact that parts are needed to be handled anyhow. If to take the investment into account it is payed back money wise in 29 work days. The scrap percentage dropped from 23,2% to 7,8%, which is roughly 3 times. The annual scrap value saved is 1408 €, which is significant taking into account that only handling is adjusted throughout the process flow.

CONCLUSION

Master thesis was conducted as production investigation of product FOT at a Company XXX, located in Kaunas. The investigation was done analysing high scrap rate of products from the same batch, and constant laser engraving parameters. The re-search is performed analysing product specification change and process variation in chrome-plating department: how does racking position and orientation affects the chrome-plating coating layer thickness, and how this affects the laser engraving quality at the end of process flow. The analysis supports the concept of decreasing the scrap rate by 30% on running production - by providing not costly and quick solution. The following findings have been halted:

1. Process variation amplitude of minimal and maximal value of weight and height before and after chrome-plating process differs 9 times from its initial value. Coating layer thickness differs 10 times of parts from the same batch.
2. Tendency of chroming coating layer thickness to its position on the processing bar is definite – parts, which are positioned around or in the sides of processing bar do get a thickest coating layer compared to parts that are in the centre of the processing bar. The orientation of the part itself does influence the coating layer on the surface – thicker coating layer appears on surfaces outside the processing bar.
3. Parts that are chrome-plated with a thinner coating layer thickness do tend to be scraped in the laser engraving operation.
4. Due to low investment and minimal timing required additional handling is proposed and implemented, where FOT-B parts are packed as two different part numbers depending on the coating layer thickness.
    - 4.1 Scrap percentage dropped by 33,6% - from 23,2% to 7,8%
    - 4.2 Only internal administrative investment of 164,38 € is needed
    - 4.3 No additional handling required therefore a cost price for part only increased by 0,01 € per part.
    - 4.4 The annual savings of parts not wasted are 1408 €

FINAL RECOMMENDATION

Master thesis conducted showed the process instability in chrome-plating department. The root cause of the process instability which appears is the false design of the processing racks that results uneven partition of current through every part. The scenario with no big investment needed works for FOT part by minimising the scrap rate in the laser engraving department by 33,6%, which is a quick and non-costly solution. However, it is a short-term solution which can be implemented quickly but that does not solve the root problem of the chrome-plating process.

Process instability may cause additional scrap for other part numbers that are produced using the same processing racks. Re-design of the racking system and further analysis of the results is needed to solve the main issue with the process instability. There are several option from either total re-design including thorough or trying to level up the current by adding current shielding or auxiliary anodes.

All in all, the process of the chrome-plating is unstable causing issues in the laser engraving department. This might further result other scrap within the production, therefore a long-term solution of rack re-design is needed for the Company XXX, while the recommended short-term solution is in use.

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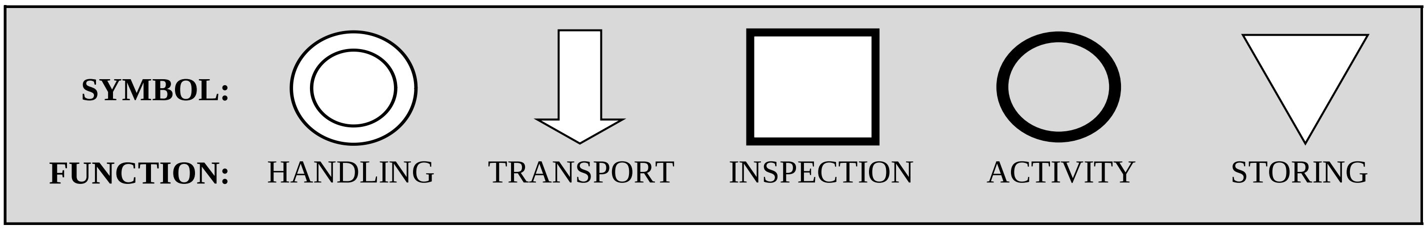
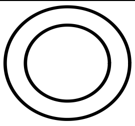
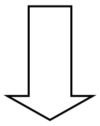
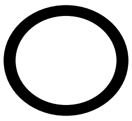
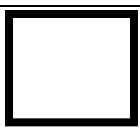
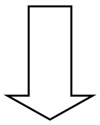
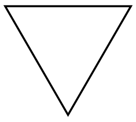
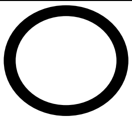
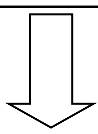
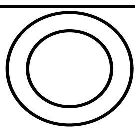
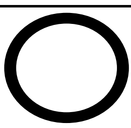
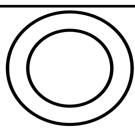
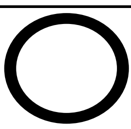
LIST OF APPENDICES

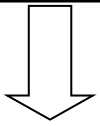
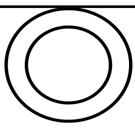
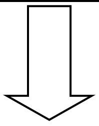
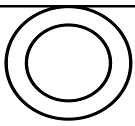
Appendix 1 - Process Flow Chart



Nr.	SYMBOL	Description of process step	Part Number
HANDLING OF INCOMING GOODS			
100		Unloading incoming material	Raw material
101		Transport	
102		Goods office	
103		Inspection of incoming material	
104		Transport to warehouse	
105		Storing	
INJECTION MOULDING			
200		Order raw materials from warehouse	
201		Transport to production area	
202		Filling a drier with raw material	
203		Material drying	
204		Charging suction station with dry material	
205		Injection moulding	

206		Eject part from tool	
207		Robot gripping the part	
208		Robot putting the part on the conveyor belt	
209		Conveyor belt transport and cooling of part	
210		Inspection	
211		Packing	Fot-A
212		Transport to warehouse	
213		Storing	
Chrome Plating			
300		Order Fot-A from warehouse	
301		Transport to production area	
302		Placing parts on racks	
303		Chrome plating	
304		Removing parts from racks	
305		Packing	Fot-B
306		Transport to warehouse	
307		Storing	
Laser Printing / Engraving			

Only valid for Fot-C			
400		Order Fot-B from warehouse	Fot-C
401		Transport to production area	
402		Placing parts on engraving fixture	
403		Laser engraving	
404		Removing parts from fixture	
405		Packing	
406		Transport to warehouse	
407		Storing	

DELIVERY			
500		Transport from warehouse for delivery	Fot-B and Fot-C
501		Final packing and strapping	
502		Transport for loading	
503		Loading for delivery	

Appendix 2 - Scrap

P/N	OK, [pcs]	NOK [pcs]	Total [pcs]	Total cost [EUR]	Scrap cost [EUR]	Scrap [%]	Operation
FOT-A	52.690	590	53.280	60	60	1,11	Injection moulding
FOT-B	46.410	4.580	50.990	2.015	2.015	8,98	Chrome-plating
FOT-C	8.760	2.652	11.412	2.034	2.034	23,24	Laser engraving
TOTAL	**107.860**	**7.822**	**115.682**	**4.109**	**4.109**	**6,76**	**Process flow**

1. Main data from Company XXX

P/N	OK [pcs]	NOK [pcs]	TOTAL [pcs]	Scrap [%]
Fot-A	52.690	590	53.280	1,1
Fot-B	46.410	4.580	50.990	9,0
Fot-C	8.760	2.652	11.412	23,2

2. Simplified table

Appendix 3 – Calibration 0478

KALIBRAVIMO SERTIFIKATAS
Slankmatis , 150 mm

Id nr: 0478 Gamintojas: Mitutoyo Corp Tipas: Skaitmeninis

Rezultatas

Nom.matmuo mm	Toerancija. mm	Nukrypimas mm
Išoriniai matavimai		
10,3	±0,05	0,00
22,8	±0,05	-0,01
50,0	±0,05	0,00
100,0	±0,06	0,01
150,0	±0,06	-0,01

Rodmenys

Nom.matmuo	Tolerancija	Nukrypimas
mm	mm	mm
Vidinis matavimas		
30,002	±0,05	-0,03
39,991	±0,05	-0,04
Gylio matavimas		
20,0	±0,05	-0,02

Max paralelinis matavimas

Tolerancija mm	Nukrypimas mm
0,02	-0,01

Pastaba:
Kalibravimo įrengimai:
Plokštelės 8089
Plokštė 7508
Žiedas 1190
Laikiklis su spaustuvais

Kalibravimo data: 2017.04.10 Kalibravo:

Appendix 4 – Calibration Scales

VALSTYBĖS ĮMONĖ
KAUNO METROLOGIJOS
CENTRAS

Paskirtosios įstaigos spaudas,
nurodantis pavadinimą, adresą, telefoną
(spaudas dedamas išrašius sertifikatą)

LMI
LIETUVOS METROLOGIJOS
INSPEKCIJA

PATIKROS SERTIFIKATAS

Nr. 0044176

Data	2015 m. rugsėjo 15 d.
Puslapių skaičius	1
MP pavadinimas, tipas, Nr., matavimo ribos, tikslumas	Elektroninės laboratorinės svarstyklės *Kern* PLJ 3500-2NM, Nr. WL 110018, Min 0,5 g, Max 3500 g, e=0,1 g, d=0,01 g (II)
MP savininko pavadinimas, įmonės kodas arba adresas	
Patikros metodo žymuo	BPM 8871101-08:2013
Naudotos etaloninės MP pavadinimas, tipas, Nr.	Etaloniniai svarsčiai: MGO-2-1110 Nr. 36; GO-2-1110 Nr. 24; KGO-2-20 Nr. 194
Patikros protokolo registracijos Nr., data	Nr. M1-H-565-1, 2015 m. rugsėjo 15 d.
Matavimo priemonė patikrinta (laboratorijos pavadinimas)	Mechaninių matavimų sektorius
Išvada	MP tinkama.
Patikros sertifikatas galioja iki	2017 m. rugsėjo 14 d. (data)

A. V.

Metrologas (pareigų pavadinimas) — (parašas) — Sektoriaus viršininkas Algirdas Baltanauskas (vardas ir pavardė)

Laboratorijos vadovas (pareigų pavadinimas) — (parašas) — Sektoriaus viršininkas Algirdas Baltanauskas (vardas ir pavardė)

Appendix 5 - MSA Measure

First cycle

Part	Operator A	Operator B	Operator C
1	52,46	52,47	52,46
2	52,43	52,43	52,42
3	52,45	52,44	52,44
4	48,35	48,34	48,35
5	52,44	52,44	52,45
6	52,44	52,43	52,43
7	52,45	52,46	52,46
8	52,45	52,44	52,45
9	52,45	52,46	52,45
10	52,44	52,46	52,44

Second cycle

Part	Operator A	Operator B	Operator C
1	52,46	52,46	52,47
2	52,43	52,42	52,42
3	52,44	52,44	52,45
4	48,35	48,35	48,35
5	52,44	52,45	52,44
6	52,44	52,45	52,43
7	52,45	52,45	52,46
8	52,45	52,45	52,45
9	52,46	52,45	52,46
10	52,45	52,46	52,44

Third cycle

Part	Operator A	Operator B	Operator C
1	52,46	52,46	52,46
2	52,42	52,43	52,43
3	52,45	52,45	52,44
4	48,35	48,34	48,34
5	52,45	52,44	52,45
6	52,43	52,45	52,43
7	52,45	52,45	52,45
8	52,45	52,44	52,44
9	52,45	52,46	52,45
10	52,45	52,46	52,44

Appendix 6 - MSA Results

Gage R&R Study for Height
Summary Report

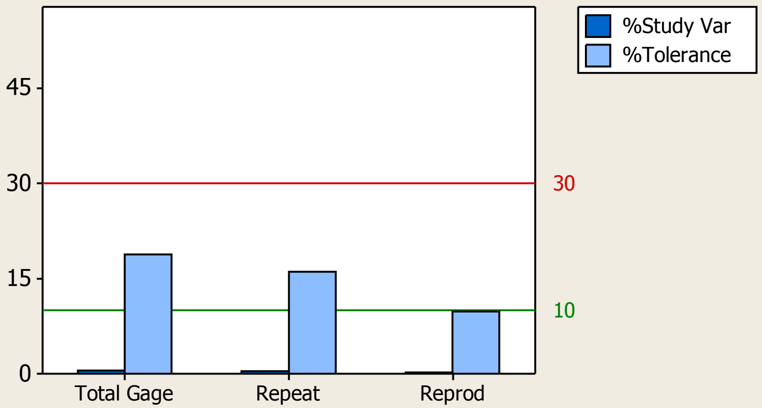
Can you adequately assess process performance?

The measurement system variation equals 0,5% of the process variation. The process variation is estimated from the parts in the study.

Can you sort good parts from bad?

The measurement system variation equals 18,9% of the tolerance.

Variation by Source



Study Information

Number of parts in study	10
Number of operators in study	3
Number of replicates	3

(Replicates: Number of times each operator measured each part)

Comments

General rules used to determine the capability of the system:
- <10%: acceptable
- 10% - 30%: marginal
- >30%: unacceptable

Examine the bar chart showing the sources of variation. If the total gage variation is unacceptable, look at repeatability and reproducibility to guide improvements:

-- Test-Retest component (Repeatability): The variation that occurs when the same person measures the same item multiple times. This equals 85,5% of the measurement variation and is 0,4% of the total variation in the process.

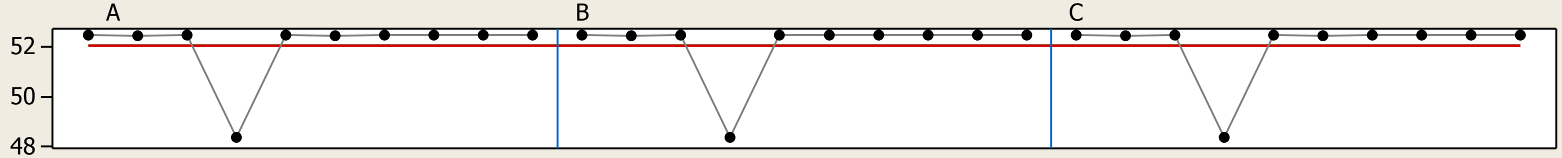
-- Operator and Operator by Part components (Reproducibility): The variation that occurs when different people measure the same item. This equals 51,8% of the measurement variation and is 0,3% of the total variation in the process.

Appendix 6 - MSA Results

Gage R&R Study for Height
Variation Report

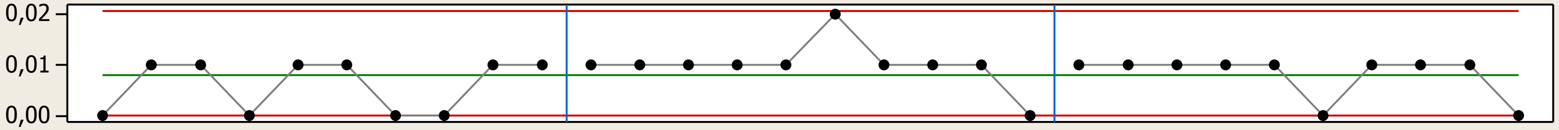
Xbar Chart of Part Averages by Operator

At least 50% should be outside the limits. (actual: 100,0%)



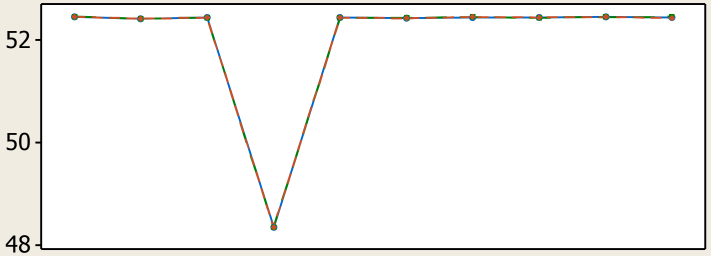
R Chart of Test-Retest Ranges by Operator (Repeatability)

Operators and parts with larger ranges have less consistency.



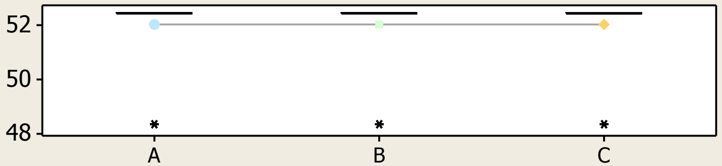
Reproducibility — Operator by Part Interaction

Look for abnormal points or patterns.



Reproducibility — Operator Main Effects

Look for operators with higher or lower averages.



Variation by Source

Source	StDev	%Study Variation	%Tolerance
Total Gage	0,006	0,48	18,86
Repeatability	0,005	0,41	16,12
Reproducibility	0,003	0,25	9,78
Operator	0,000	0,00	0,00
Operator by Part	0,003	0,25	9,78
Part-to-Part	1,296	100,00	3889,36
Study Variation	1,296	100,00	3889,40

Tolerance (upper spec - lower spec): 0,2

Appendix 7 - Measurements and Analysis

Injection Moulding Department

52,5 +/- 0,1

Part number	Part Weight	DIM C1	Out?
Part 1	19,18	52,46	
Part 2	19,21	52,42	
Part 3	19,17	52,43	
Part 4	19,20	52,40	
Part 5	19,23	52,43	
Part 6	19,19	52,46	
Part 7	19,24	52,41	
Part 8	19,22	52,41	
Part 9	19,33	52,41	
Part 10	19,33	52,48	
Part 11	19,21	52,44	
Part 12	19,32	52,45	
Part 13	19,22	52,45	
Part 14	19,23	52,42	
Part 15	19,31	52,48	
Part 16	19,22	52,41	
Part 17	19,32	52,45	
Part 18	19,20	52,46	
Part 19	19,18	52,43	
Part 20	19,33	52,45	
Part 21	19,33	52,43	
Part 22	19,25	52,44	
Part 23	19,31	52,44	
Part 24	19,23	52,45	
Part 25	19,23	52,45	
Part 26	19,24	52,45	
Part 27	19,26	52,44	
Part 28	19,35	52,43	
Part 29	19,24	52,46	
Part 30	19,24	52,46	
Part 31	19,22	52,42	
Part 32	19,33	52,46	
Part 33	19,22	52,42	
Part 34	19,23	52,46	
Part 35	19,33	52,47	
Part 36	19,19	52,46	
Part 37	19,19	52,44	
Part 38	19,18	52,48	
Part 39	19,20	52,45	
Part 40	19,23	52,43	
Part 41	19,21	52,43	
Part 42	19,22	52,45	
Part 43	19,33	52,43	
Part 44	19,18	52,48	
Part 45	19,19	52,47	
Part 46	19,19	52,44	
Part 47	19,21	52,44	
Part 48	19,21	52,45	
Part 49	19,19	52,43	
Part 50	19,21	52,41	
Part 51	19,21	52,44	
Part 52	19,19	52,46	
Part 53	19,19	52,44	
Part 54	19,21	52,45	
Part 55	19,21	52,44	
Part 56	19,33	52,44	
Part 57	19,23	52,43	
Part 58	19,22	52,43	
Part 59	19,29	52,44	
Part 60	19,19	52,42	
Part 61	19,22	52,43	
Part 62	19,20	52,41	
Part 63	19,21	52,42	
Part 64	19,19	52,43	
Part 65	19,19	52,44	
Part 66	19,20	52,44	
Part 67	19,30	52,45	
Part 68	19,20	52,45	
Part 69	19,20	52,45	
Part 70	19,34	52,46	

Injection Moulding Department

52,5 +/- 0,1

Part number	Part Weight	DIM C1	Out?
Part 71	19,34	52,44	
Part 72	19,23	52,45	
Part 73	19,33	52,44	
Part 74	19,21	52,45	
Part 75	19,21	52,45	
Part 76	19,22	52,42	
Part 77	19,33	52,42	
Part 78	19,32	52,45	
Part 79	19,20	52,45	
Part 80	19,22	52,44	
Part 81	19,22	52,44	
Part 82	19,22	52,41	
Part 83	19,22	52,46	
Part 84	19,24	52,44	
Part 85	19,21	52,42	
Part 86	19,24	52,45	
Part 87	19,23	52,46	
Part 88	19,33	52,44	
Part 89	19,23	52,44	
Part 90	19,22	52,45	
Part 91	19,25	52,46	
Part 92	19,33	52,44	
Part 93	19,24	52,45	
Part 94	19,22	52,43	
Part 95	19,18	52,44	
Part 96	19,21	52,45	
Part 97	19,21	52,45	
Part 98	19,31	52,47	
Part 99	19,22	52,46	
Part 100	19,23	52,42	
Part 101	19,21	52,44	
Part 102	19,21	52,42	
Part 103	19,21	52,44	
Part 104	19,21	52,44	
Part 105	19,31	52,44	
Part 106	19,20	52,43	
Part 107	19,21	52,46	
Part 108	19,32	52,45	
Part 109	19,32	52,44	
Part 110	19,19	52,47	
Part 111	19,23	52,42	
Part 112	19,23	52,41	
Part 113	19,32	52,44	
Part 114	19,21	52,41	
Part 115	19,24	52,42	
Part 116	19,20	52,40	
Part 117	19,19	52,43	
Part 118	19,32	52,45	
Part 119	19,24	52,44	
Part 120	19,33	52,46	
Part 121	19,30	52,46	
Part 122	19,33	52,44	
Part 123	19,32	52,44	
Part 124	19,34	52,44	
Part 125	19,19	52,48	
Part 126	19,24	52,43	
Part 127	19,22	52,43	
Part 128	19,23	52,40	
Part 129	19,32	52,43	
Part 130	19,23	52,43	
Part 131	19,21	52,41	
Part 132	19,18	52,40	
Part 133	19,19	52,40	
Part 134	19,20	52,43	
Part 135	19,23	52,44	
Part 136	19,21	52,44	
Part 137	19,17	52,41	
Part 138	19,20	52,41	
Part 139	19,21	52,41	
Part 140	19,24	52,42	

Appendix 7 - Measurements and Analysis

Post-chroming - 1st sub-group Front

52,5 +/- 0,1

Part number	Part Weight	DIM C1	Out?
Part 1			
Part 2	22,56	52,55	
Part 3	22,54	52,55	
Part 4	22,55	52,54	
Part 5	22,32	52,55	
Part 6	22,61	52,57	
Part 7	22,13	52,55	
Part 8	22,31	52,55	
Part 9	22,08	52,55	
Part 10	22,44	52,56	
Part 11	22,22	52,56	
Part 12	21,73	52,52	
Part 13	21,80	52,50	
Part 14	21,72	52,52	
Part 15	21,80	52,54	
Part 16	21,80	52,54	
Part 17	21,80	52,52	
Part 18	21,79	52,53	
Part 19	21,50	52,50	
Part 20	22,11	52,53	
Part 21	22,28	52,58	
Part 22	21,71	52,54	
Part 23	21,85	52,54	
Part 24	21,83	52,53	
Part 25	21,53	52,50	
Part 26	21,64	52,51	
Part 27	21,38	52,53	
Part 28	21,77	52,55	
Part 29	21,38	52,49	
Part 30	21,69	52,54	
Part 31	21,79	52,56	
Part 32	21,58	52,53	
Part 33	21,62	52,50	
Part 34	21,72	52,50	
Part 35	21,55	52,50	
Part 36	21,25	52,50	
Part 37	21,58	52,50	
Part 38	21,55	52,54	
Part 39	21,49	52,51	
Part 40	21,83	52,55	
Part 41	21,85	52,54	
Part 42	21,40	52,54	
Part 43	21,52	52,53	
Part 44	21,51	52,52	
Part 45	21,16	52,50	
Part 46	21,51	52,51	
Part 47	21,30	52,51	
Part 48	21,45	52,51	
Part 49	21,25	52,51	
Part 50	21,52	52,50	
Part 51	21,48	52,50	
Part 52	21,00	52,55	
Part 53	21,49	52,51	
Part 54	21,60	52,53	
Part 55	21,15	52,51	
Part 56	21,23	52,51	
Part 57	21,41	52,52	
Part 58	21,57	52,55	
Part 59	21,49	52,53	
Part 60	21,76	52,52	
Part 61	22,34	52,57	
Part 62	21,98	52,53	
Part 63	22,11	52,55	
Part 64	22,11	52,51	
Part 65	21,99	52,51	
Part 66	21,75	52,52	
Part 67	21,97	52,53	
Part 68	21,76	52,52	
Part 69	21,56	52,53	
Part 70	21,84	52,53	

Post-chroming - 2nd sub-group Back

52,5 +/- 0,1

Part number	Part Weight	DIM C1	Out?
Part 71	22,53	52,57	
Part 72	22,07	52,57	
Part 73	22,44	52,57	
Part 74	22,47	52,58	
Part 75			
Part 76	21,25	52,55	
Part 77	22,75	52,60	x
Part 78	22,79	52,57	
Part 79	22,03	52,53	
Part 80	22,79	52,58	
Part 81	21,77	52,55	
Part 82	21,72	52,53	
Part 83	21,73	52,54	
Part 84	21,61	52,54	
Part 85	22,05	52,54	
Part 86	21,71	52,52	
Part 87	22,00	52,54	
Part 88	22,23	52,55	
Part 89	21,88	52,54	
Part 90	22,73	52,60	x
Part 91	22,02	52,53	
Part 92	21,81	52,53	
Part 93	21,73	52,54	
Part 94	21,42	52,51	
Part 95	21,84	52,52	
Part 96	21,44	52,52	
Part 97	21,99	52,53	
Part 98	22,02	52,53	
Part 99	21,30	52,53	
Part 100	21,83	52,53	
Part 101	21,58	52,53	
Part 102	21,48	52,52	
Part 103	21,60	52,51	
Part 104	21,39	52,50	
Part 105	21,86	52,52	
Part 106	21,55	52,50	
Part 107	21,75	52,51	
Part 108	22,07	52,53	
Part 109	21,17	52,52	
Part 110	22,32	52,57	
Part 111	21,78	52,53	
Part 112	21,26	52,51	
Part 113	21,75	52,56	
Part 114	21,39	52,51	
Part 115	21,78	52,52	
Part 116	21,49	52,50	
Part 117	21,61	52,50	
Part 118	22,04	52,53	
Part 119	21,21	52,50	
Part 120	21,69	52,53	
Part 121	21,53	52,52	
Part 122	21,46	52,52	
Part 123	21,63	52,53	
Part 124	21,41	52,50	
Part 125	22,08	52,53	
Part 126	21,65	52,52	
Part 127	21,70	52,55	
Part 128	21,41	52,54	
Part 129	22,08	52,51	
Part 130	22,23	52,57	
Part 131	22,07	52,51	
Part 132	21,61	52,52	
Part 133	21,93	52,54	
Part 134	21,98	52,54	
Part 135	22,49	52,56	
Part 136			
Part 137	22,29	52,52	
Part 138	22,64	52,56	
Part 139	22,19	52,55	
Part 140			

Appendix 7 - Measurements and Analysis

Injection moulding

	Weight average	Height average	Weight MIN	Weight MAX	Height MIN	Height MAX
Part 1-70	19,24	52,44	19,17	19,35	52,40	52,48
Part 71-140	19,24	52,44	19,17	19,34	52,40	52,48

Difference between MIN and MAX values within the process

	Difference of weight average	Difference of height average	Difference of weight MIN	Difference of weight MAX	Difference of height MIN	Difference of height MAX
FOT-A	0,01	0,00	0,00	0,01	0,00	0,00
FOT-B	0,12	0,007	0,17	0,18	0,01	0,02

Amplitude between Max and Min

Parts and Subgroups	Difference of weight MIN-MAX [gram]	Difference of height MIN-MAX [mm]
FOT-A (1-70)	0,18	0,08
FOT-A (71-140)	0,17	0,08
FOT-B (1-70)	1,61	0,09
FOT-B (71-140)	1,62	0,10

Chrome plating

	Weight average	Height average	Weight MIN	Weight MAX	Height MAX
Part 1-70	21,75	52,528	21,00	22,61	52,58
Part 71-140	21,87	52,535	21,17	22,79	52,60

Appendix 7 - Measurements and Analysis

Part number	Difference in weight	Difference in height
Part 1		
Part2	3,35	0,13
Part 3	3,37	0,12
Part 4	3,35	0,14
Part 5	3,09	0,12
Part 6	3,42	0,11
Part 7	2,89	0,14
Part 8	3,09	0,14
Part 9	2,75	0,14
Part 10	3,11	0,08
Part 11	3,01	0,12
Part 12	2,41	0,07
Part 13	2,58	0,05
Part 14	2,49	0,10
Part 15	2,49	0,06
Part 16	2,58	0,13
Part 17	2,48	0,07
Part 18	2,59	0,07
Part 19	2,32	0,07
Part 20	2,78	0,08
Part 21	2,95	0,15
Part 22	2,46	0,10
Part 23	2,54	0,10
Part 24	2,60	0,08
Part 25	2,30	0,05
Part 26	2,40	0,06
Part 27	2,12	0,09
Part 28	2,42	0,12
Part 29	2,14	0,03
Part 30	2,45	0,08
Part 31	2,57	0,14
Part 32	2,25	0,07
Part 33	2,40	0,08
Part 34	2,49	0,04
Part 35	2,22	0,03
Part 36	2,06	0,04
Part 37	2,39	0,06
Part 38	2,37	0,06
Part 39	2,29	0,06
Part 40	2,60	0,12
Part 41	2,64	0,11
Part 42	2,18	0,09
Part 43	2,19	0,10
Part 44	2,33	0,04
Part 45	1,97	0,03
Part 46	2,32	0,07
Part 47	2,09	0,07
Part 48	2,24	0,06
Part 49	2,06	0,08
Part 50	2,31	0,09
Part 51	2,27	0,06
Part 52	1,81	0,09
Part 53	2,30	0,07
Part 54	2,39	0,08
Part 55	1,94	0,07
Part 56	1,90	0,07
Part 57	2,18	0,09
Part 58	2,35	0,12
Part 59	2,20	0,09
Part 60	2,57	0,10
Part 61	3,12	0,14
Part 62	2,78	0,12
Part 63	2,90	0,13
Part 64	2,92	0,08
Part 65	2,80	0,07
Part 66	2,55	0,08
Part 67	2,67	0,08
Part 68	2,56	0,07
Part 69	2,36	0,08
Part 70	2,50	0,07

Part number	Difference in weight	Difference in height
Part 71	3,19	0,13
Part 72	2,84	0,12
Part 73	3,11	0,13
Part 74	3,26	0,13
Part 75		
Part 76	2,03	0,13
Part 77	3,42	0,18
Part 78	3,47	0,12
Part 79	2,83	0,08
Part 80	3,57	0,14
Part 81	2,55	0,11
Part 82	2,50	0,12
Part 83	2,51	0,08
Part 84	2,37	0,10
Part 85	2,84	0,12
Part 86	2,47	0,07
Part 87	2,77	0,08
Part 88	2,90	0,11
Part 89	2,65	0,10
Part 90	3,51	0,15
Part 91	2,77	0,07
Part 92	2,48	0,09
Part 93	2,49	0,09
Part 94	2,20	0,08
Part 95	2,66	0,08
Part 96	2,23	0,07
Part 97	2,78	0,08
Part 98	2,71	0,06
Part 99	2,08	0,07
Part 100	2,60	0,11
Part 101	2,37	0,09
Part 102	2,27	0,10
Part 103	2,39	0,07
Part 104	2,18	0,06
Part 105	2,55	0,08
Part 106	2,35	0,07
Part 107	2,54	0,05
Part 108	2,75	0,08
Part 109	1,85	0,08
Part 110	3,13	0,10
Part 111	2,55	0,11
Part 112	2,03	0,10
Part 113	2,43	0,12
Part 114	2,18	0,10
Part 115	2,54	0,10
Part 116	2,29	0,10
Part 117	2,42	0,07
Part 118	2,72	0,08
Part 119	1,97	0,06
Part 120	2,36	0,07
Part 121	2,23	0,06
Part 122	2,13	0,08
Part 123	2,31	0,09
Part 124	2,07	0,06
Part 125	2,89	0,05
Part 126	2,41	0,09
Part 127	2,48	0,12
Part 128	2,18	0,14
Part 129	2,76	0,08
Part 130	3,00	0,14
Part 131	2,86	0,10
Part 132	2,43	0,12
Part 133	2,74	0,14
Part 134	2,78	0,11
Part 135	3,26	0,12
Part 136		
Part 137	3,12	0,11
Part 138	3,44	0,15
Part 139	2,98	0,14
Part 140		

Appendix 7 - Measurements and Analysis

	Weight average	Height average	Weight MIN	Weight MAX	Height MIN	Height MAX
Part 1-70	2,52	0,087	1,81	3,42	0,03	0,15
Part 71-140	2,62	0,098	1,85	3,57	0,05	0,18

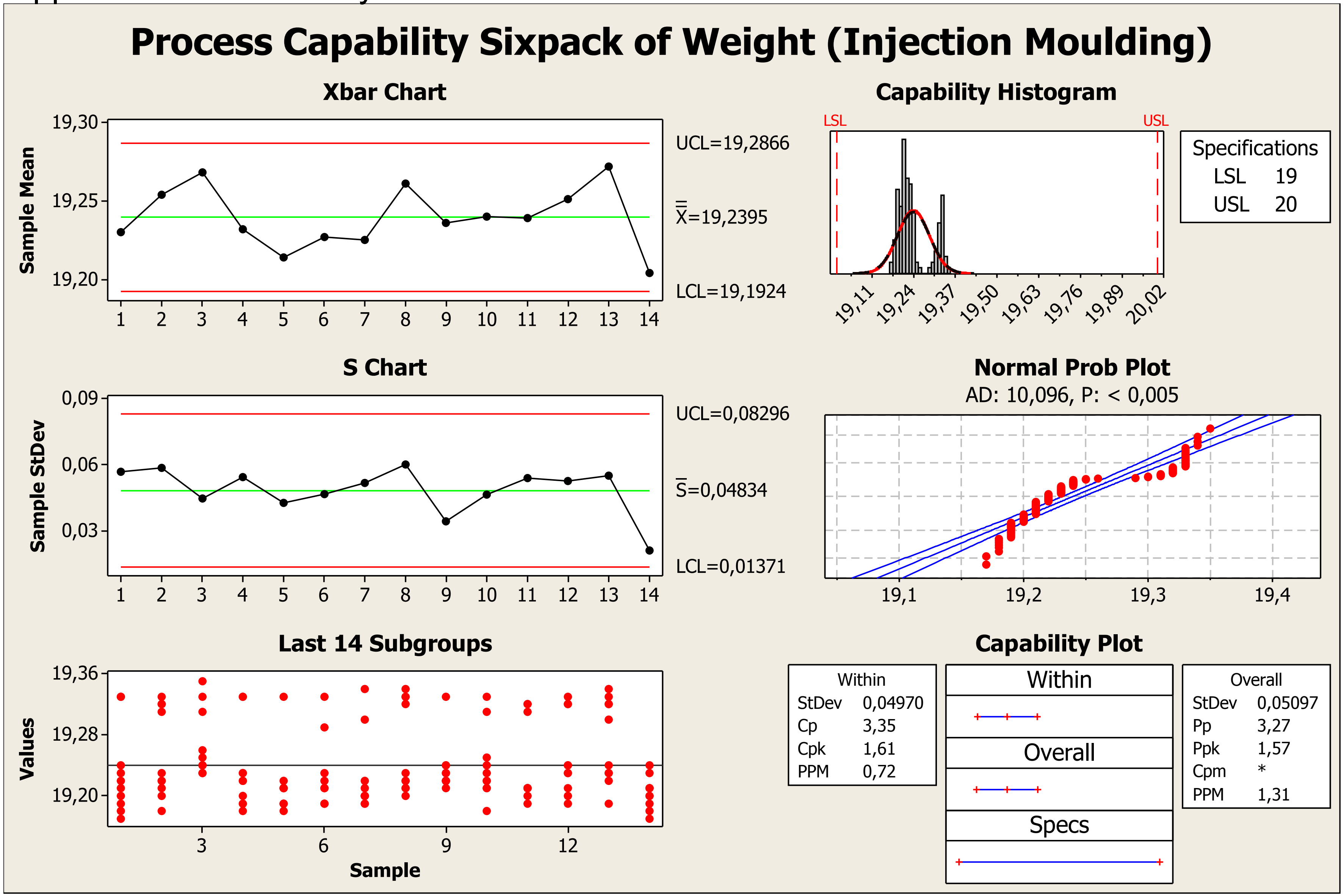
Appendix 7 - Measurements and Analysis

1 SCRAP
2 OVER 3 grams weight change
3 UNDER 2,30 grams weight change
4 4 =/OVER 0,14mm height change
5 5 =/UNDER 0,05mm height change*
Parts picked for laser test-run
0,06 for second bar

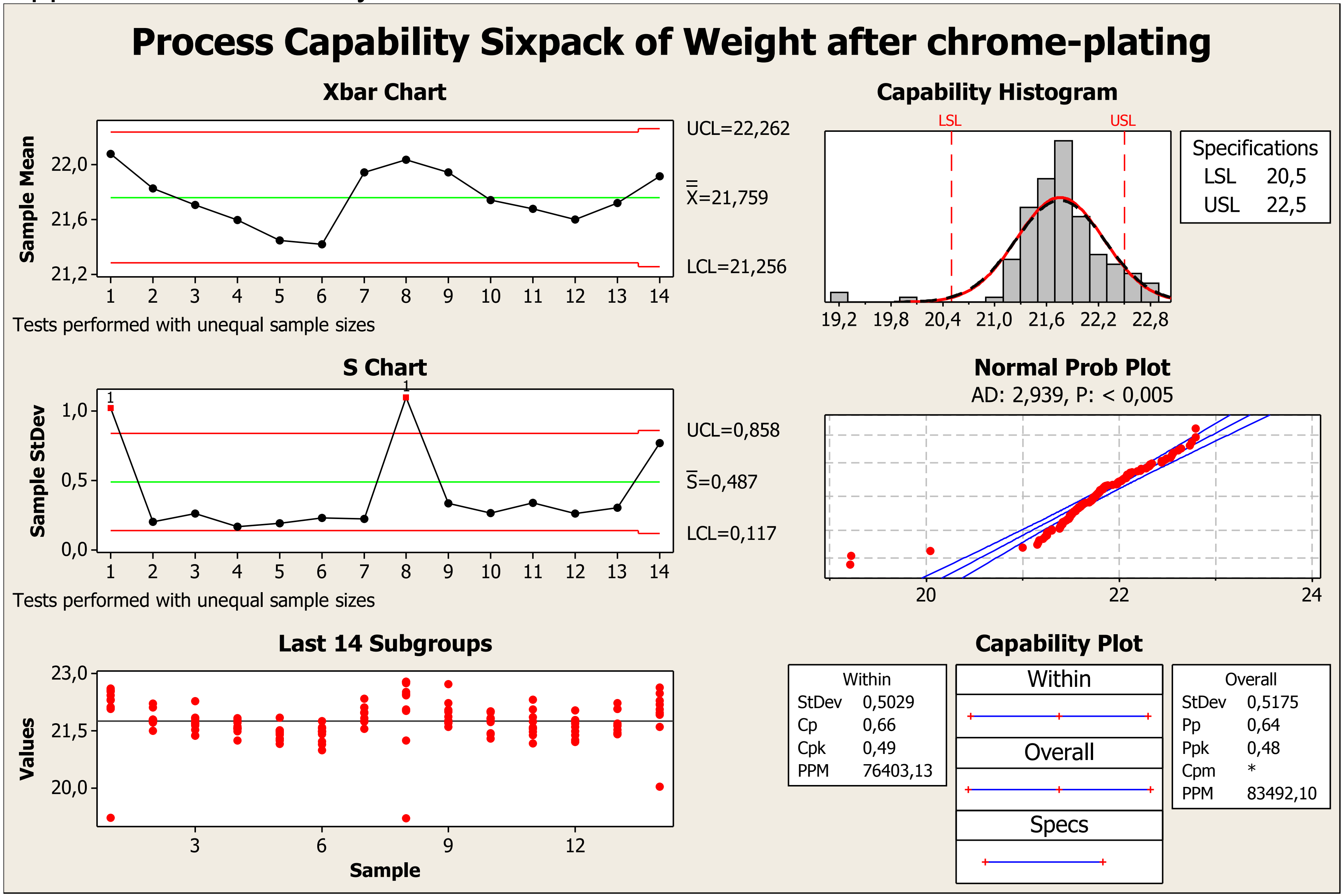
1		2		3		4		5		6		7		8		9		10	
	11		12		13		14		15		16		17		18		19		20
21		22		23		24		25		26		27		28		29		30	
	31		32		33		34		35		36		37		38		39		40
41		42		43		44		45		46		47		48		49		50	
	51		52		53		54		55		56		57		58		59		60
61		62		63		64		65		66		67		68		69		70	

	71		72		73		74		**75**		76		77		78		79		80
81		82		83		84		85		86		87		88		89		90	
	91		92		93		94		95		96		97		98		99		100
101		102		103		104		105		106		107		108		109		110	
	111		112		113		114		115		116		117		118		119		120
121		122		123		124		125		126		127		128		129		130	
	131		132		133		134		135		**136**		137		138		139		140

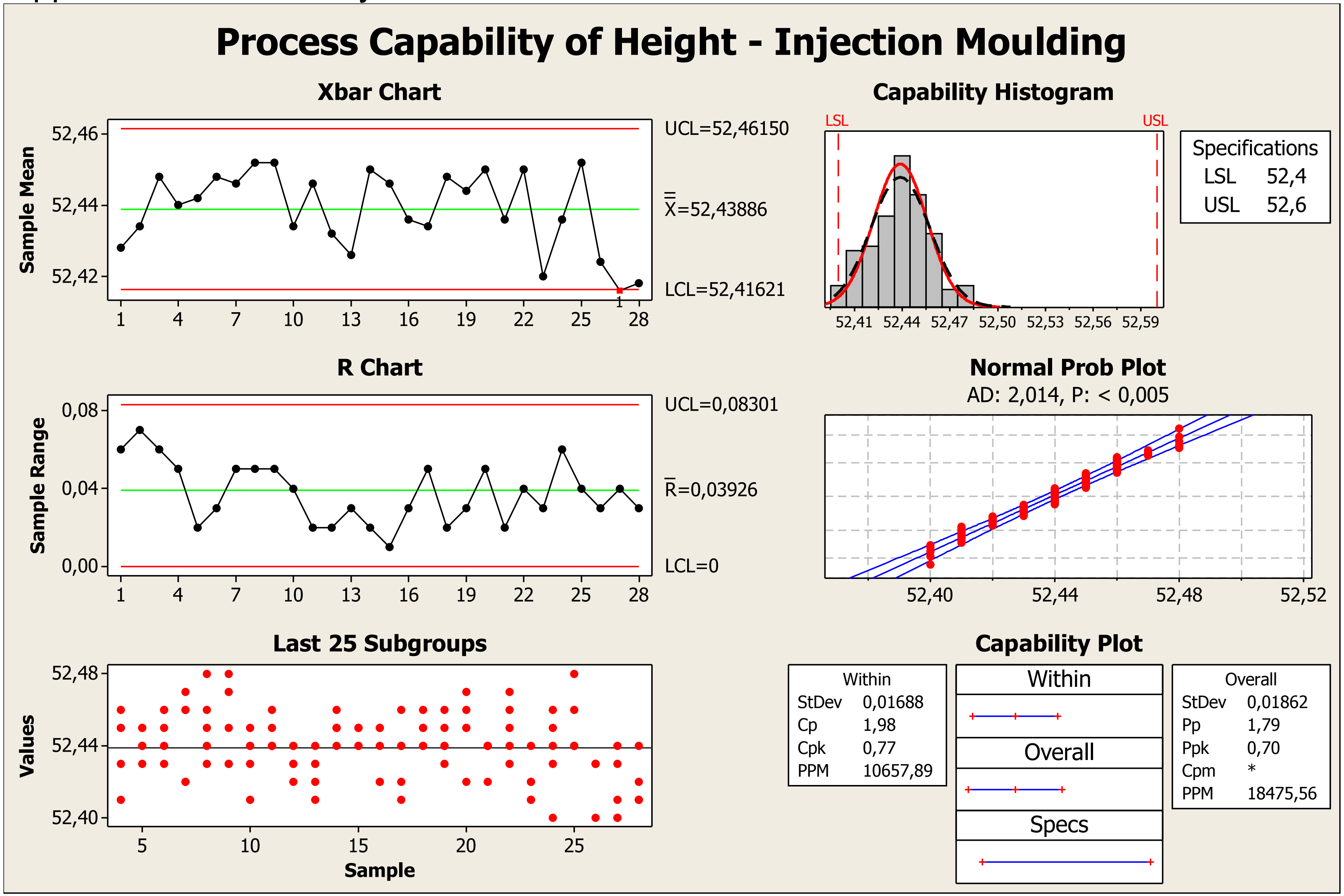
Appendix 8 - CPK Analysis



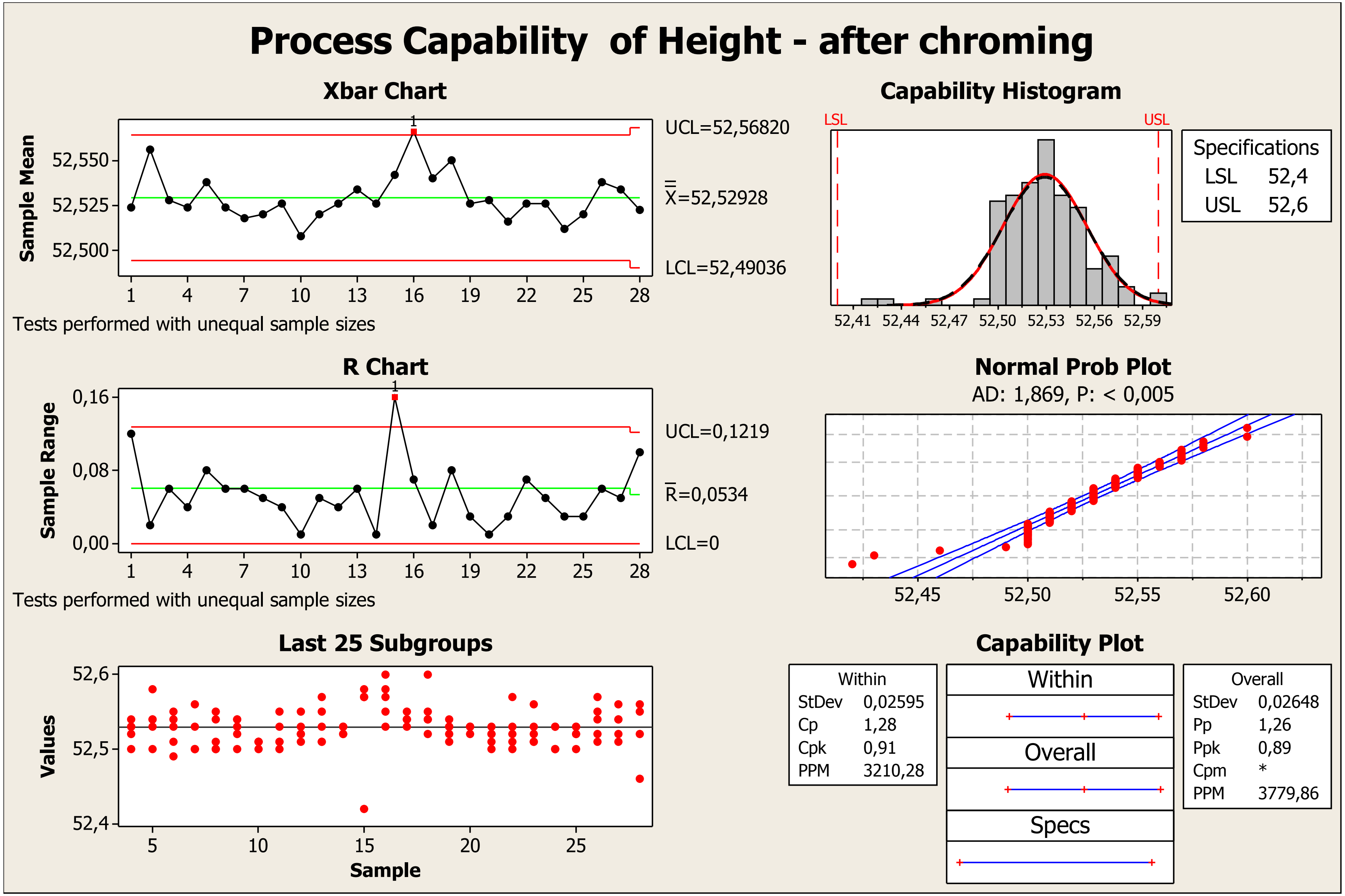
Appendix 8 - CPK Analysis



Appendix 8 - CPK Analysis



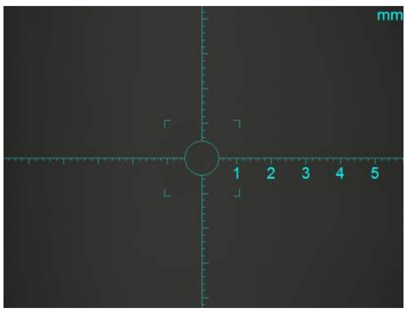
Appendix 8 - CPK Analysis



Appendix 9 – Coating Thickness Results

HELMUT FISCHER GmbH
Industriestrasse 21
71069 Sindelfingen

Fischerscope®   XRAY XDL 220
Product: 2403120 / Cr/Ni/Cu/ABS(B)   Dir.: Fischer   Block: 1 Part 36
Application: 2 / Cr/Ni/Cu/ABS(B)



n= 1 Cr 1 = 0.286 µm Ni 2 = 11.1 µm Cu 3 = 17.3 µm

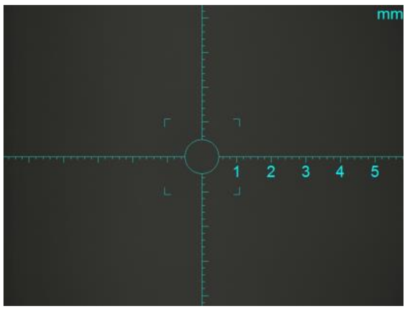
Mean	0.286	µm	11.05	µm	17.28	µm
Standard deviation	---------	µm	---------	µm	---------	µm
C.O.V. (%)	0.00		0.00		0.00	
Range	0.000	µm	0.000	µm	0.000	µm
Number of readings	1		1		1	
Min. reading	0.286	µm	11.1	µm	17.3	µm
Max. reading	0.286	µm	11.1	µm	17.3	µm
Measuring time	30	sec				

Operator:
Date: 4/24/2017 Time: 12:42:21 PM

Appendix 9 – Coating Thickness Results

HELMUT FISCHER GmbH
Industriestrasse 21
71069 Sindelfingen
Fischer®

Fischerscope® XRAY XDL 220
Product: 2403120 / Cr/Ni/Cu/ABS(B) **Dir.: Fischer** **Block: 2 Part 45**
Application: 2 / Cr/Ni/Cu/ABS(B)



n= 1 Cr 1 = 0.098 µm Ni 2 = 13.1 µm Cu 3 = 13.7 µm

Mean	**0.098**	µm	**13.11**	µm	**13.72**	µm
Standard deviation	**--------**	µm	**--------**	µm	**--------**	µm
C.O.V. (%)	**0.00**		**0.00**		**0.00**	
Range	**0.000**	µm	**0.000**	µm	**0.000**	µm
Number of readings	**1**		**1**		**1**	
Min. reading	**0.098**	µm	**13.1**	µm	**13.7**	µm
Max. reading	**0.098**	µm	**13.1**	µm	**13.7**	µm
Measuring time	**30**	sec				

Operator:
Date: 4/24/2017 Time: 12:43:15 PM

Appendix 9 – Coating Thickness Results

HELMUT FISCHER GmbH
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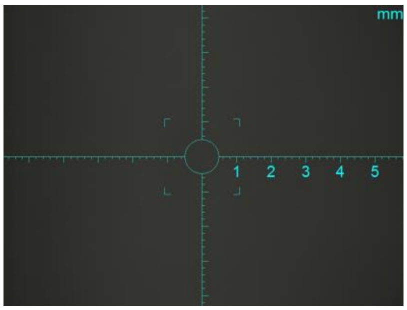
Fischerscope® **XRAY XDL 220**
Product: 2403120 / Cr/Ni/Cu/ABS(B) **Dir.: Fischer** **Block:** **3 Part 61**
Application: 2 / Cr/Ni/Cu/ABS(B)



n= 1 Cr 1 = 0.110 µm Ni 2 = 16.3 µm Cu 3 = 15.0 µm

Mean	0.110 µm	16.29 µm	15.02 µm
Standard deviation	-------- µm	-------- µm	-------- µm
C.O.V. (%)	0.00	0.00	0.00
Range	0.000 µm	0.000 µm	0.000 µm
Number of readings	1	1	1
Min. reading	0.110 µm	16.3 µm	15.0 µm
Max. reading	0.110 µm	16.3 µm	15.0 µm
Measuring time	30 sec		

Operator:
Date: 4/24/2017 Time: 12:43:21 PM

Appendix 9 – Coating Thickness Results

HELMUT FISCHER GmbH

Industriestrasse 21
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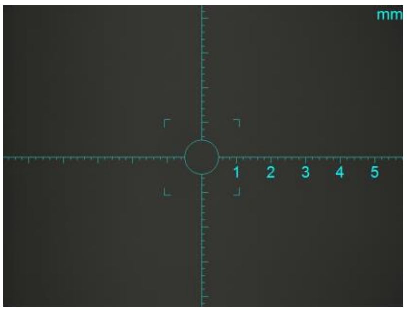
Fischerscope®   XRAY XDL 220

Product: **2403120 / Cr/Ni/Cu/ABS(B)**   **Dir.: Fischer**   **Block:**   **4 Part 21**

Application: 2 / Cr/Ni/Cu/ABS(B)



n= 1 Cr 1 = 0.245 µm Ni 2 = 16.0 µm Cu 3 = 14.8 µm

	Cr 1		Ni 2		Cu 3	
Mean	0.245	µm	16.03	µm	14.78	µm
Standard deviation	--------	µm	--------	µm	--------	µm
C.O.V. (%)	0.00		0.00		0.00	
Range	0.000	µm	0.000	µm	0.000	µm
Number of readings	1		1		1	
Min. reading	0.245	µm	16.0	µm	14.8	µm
Max. reading	0.245	µm	16.0	µm	14.8	µm
Measuring time	30	sec				

Operator:

Date: 4/24/2017 Time: 12:43:28 PM

Appendix 9 – Coating Thickness Results

HELMUT FISCHER GmbH
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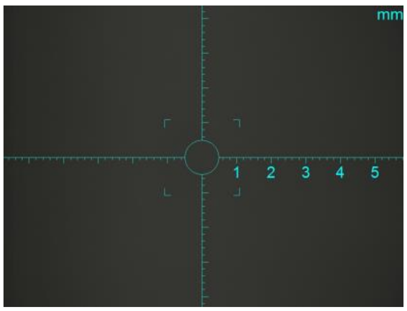
Fischerscope® XRAY XDL 220

Product: 2403120 / Cr/Ni/Cu/ABS(B) **Dir.: Fischer** **Block: 5 Part 4**
Application: 2 / Cr/Ni/Cu/ABS(B)



n= 1 Cr 1 = 0.252 µm Ni 2 = 17.3 µm Cu 3 = 18.6 µm

Mean	0.252 µm	17.30 µm	18.62 µm
Standard deviation	-------- µm	-------- µm	-------- µm
C.O.V. (%)	0.00	0.00	0.00
Range	0.000 µm	0.000 µm	0.000 µm
Number of readings	1	1	1
Min. reading	0.252 µm	17.3 µm	18.6 µm
Max. reading	0.252 µm	17.3 µm	18.6 µm
Measuring time	30 sec		

Operator:
Date: 4/24/2017 Time: 12:43:35 PM

Appendix 9 – Coating Thickness Results

HELMUT FISCHER GmbH
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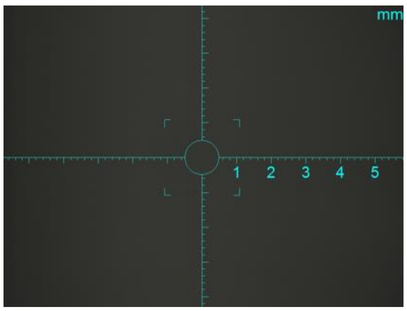
71069 Sindelfingen

Fischerscope® **XRAY XDL 220**
Product: **2403120 / Cr/Ni/Cu/ABS(B)** **Dir.: Fischer** **Block:** **6 Part 138**
Application: 2 / Cr/Ni/Cu/ABS(B)



n= 1 Cr 1 = 0.064 µm Ni 2 = 6.37 µm Cu 3 = 9.93 µm

Mean	**0.064** µm	**6.373** µm	**9.934** µm
Standard deviation	-------- µm	-------- µm	-------- µm
C.O.V. (%)	0.00	0.00	0.00
Range	0.000 µm	0.000 µm	0.000 µm
Number of readings	1	1	1
Min. reading	0.064 µm	6.37 µm	9.93 µm
Max. reading	0.064 µm	6.37 µm	9.93 µm
Measuring time	30 sec		

Operator:
Date: 4/24/2017 Time: 12:57:08 PM

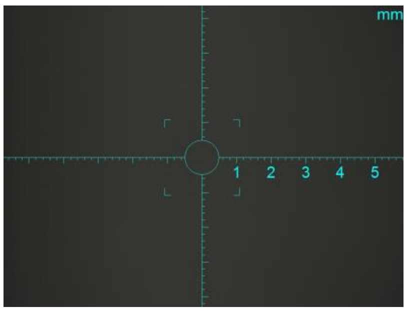
Appendix 9 – Coating Thickness Results

HELMUT FISCHER GmbH
Industriestrasse 21
71069 Sindelfingen

Fischerscope® XRAY XDL 220

Product: 2403120 / Cr/Ni/Cu/ABS(B) **Dir.: Fischer** **Block: 7 Part 124**

Application: 2 / Cr/Ni/Cu/ABS(B)



n= 1 Cr 1 = 0.001 µm Ni 2 = 3.31 µm Cu 3 = -0.459 µm

Mean	0.001	µm	3.312	µm	-0.459	µm
Standard deviation	--------	µm	--------	µm	--------	µm
C.O.V. (%)	0.00		0.00		0.00	
Range	0.000	µm	0.000	µm	0.000	µm
Number of readings	1		1		1	
Min. reading	0.001	µm	3.31	µm	-0.459	µm
Max. reading	0.001	µm	3.31	µm	-0.459	µm
Measuring time	30	sec				

Operator:

Date: 4/24/2017 Time: 12:57:59 PM

Appendix 9 – Coating Thickness Results

HELMUT FISCHER GmbH
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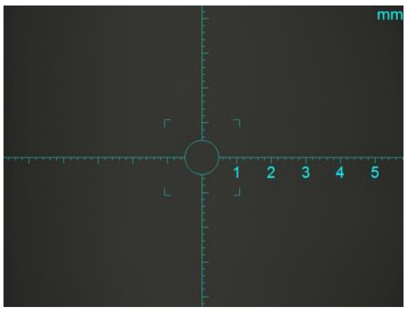
71069 Sindelfingen
fischer®

Fischerscope® XRAY XDL 220
Product: 2403120 / Cr/Ni/Cu/ABS(B) **Dir.: Fischer** **Block:** **8 Part 119**
Application: 2 / Cr/Ni/Cu/ABS(B)



n= 1 Cr 1 = -0.002 µm Ni 2 = 2.70 µm Cu 3 = -0.641 µm

Mean	-0.002	µm	2.700	µm	-0.641	µm
Standard deviation	--------	µm	--------	µm	--------	µm
C.O.V. (%)	0.00		0.00		0.00	
Range	0.000	µm	0.000	µm	0.000	µm
Number of readings	1		1		1	
Min. reading	-0.002	µm	2.70	µm	-0.641	µm
Max. reading	-0.002	µm	2.70	µm	-0.641	µm
Measuring time	30	sec				

Operator:
Date: 4/24/2017 Time: 12:58:09 PM

Appendix 9 – Coating Thickness Results

HELMUT FISCHER GmbH
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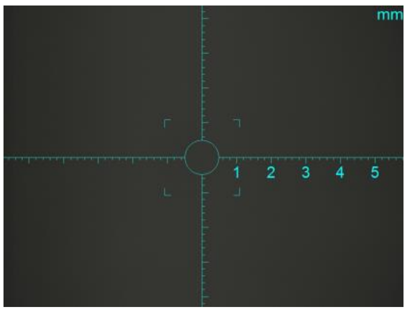
71069 Sindelfingen

Fischerscope® **XRAY XDL 220**

Product: **2403120 / Cr/Ni/Cu/ABS(B)** **Dir.: Fischer** **Block:** **9 Part 80**

Application: 2 / Cr/Ni/Cu/ABS(B)



n= 1 Cr 1 = 0.035 µm Ni 2 = 9.54 µm Cu 3 = 6.50 µm

Mean	0.035	µm	9.540	µm	6.496	µm
Standard deviation	--------	µm	--------	µm	--------	µm
C.O.V. (%)	0.00		0.00		0.00	
Range	0.000	µm	0.000	µm	0.000	µm
Number of readings	1		1		1	
Min. reading	0.035	µm	9.54	µm	6.50	µm
Max. reading	0.035	µm	9.54	µm	6.50	µm
Measuring time	30	sec				

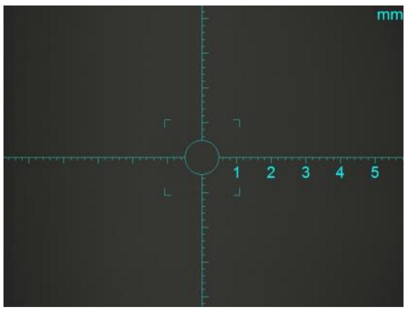
Operator:

Date: 4/24/2017 Time: 12:58:22 PM

Appendix 9 – Coating Thickness Results

HELMUT FISCHER GmbH
Industriestrasse 21
71069 Sindelfingen

Fischerscope® **XRAY XDL 220**
Product: 2403120 / Cr/Ni/Cu/ABS(B) **Dir.: Fischer** **Block:** **10 Part 90**
Application: 2 / Cr/Ni/Cu/ABS(B)



n= 1 Cr 1 = 0.060 µm Ni 2 = 9.32 µm Cu 3 = 7.02 µm

Mean	**0.060**	µm	**9.316**	µm	**7.017**	µm
Standard deviation	--------	µm	--------	µm	--------	µm
C.O.V. (%)	0.00		0.00		0.00	
Range	0.000	µm	0.000	µm	0.000	µm
Number of readings	1		1		1	
Min. reading	0.060	µm	9.32	µm	7.02	µm
Max. reading	0.060	µm	9.32	µm	7.02	µm
Measuring time	30	sec				

Operator:
Date: 4/24/2017 Time: 12:58:32 PM

Appendix 10 – LASER RESULTS

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